EVALUATING THE EFFECTIVENESS OF WETLAND ASSESSMENT METHODS FOR DETERMINING THE CONDITION OF DEPRESSIONAL AND LACUSTRINE FRINGE WETLANDS IN OKLAHOMA

By

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Abstract: The U.S. Environmental Protection Agency has developed a three-tiered framework to categorize wetland assessments. Level 1 assessments are conducted remotely and condition is evaluated based on surrounding land-use. Level 2 assessments rely on rapid assessment methods (RAMs) to evaluate condition. Level 3 assessments use the most intensive sampling techniques to produce quantitative data. RAMs have become the preferred method for many programs, because they are conducted on-site, and require less time and expertise than Level 3 methods. Because RAMs are based on best professional judgment and inferred relationships between indicators of stress and wetland condition, validation with intensive data is necessary to confirm that condition scores are reflected in quantifiable components of the ecosystem. Chapter 1 presents our validation analysis of the Oklahoma Rapid Assessment Method (OKRAM) in 28 depressional wetlands across the state. We found strong, consistent relationships between OKRAM scores and Level 1 (e.g., Landscape Development Intensity Index) and Level 3 (e.g., plant and soil) data to suggest that OKRAM is tracking condition within the wetland as well as with anthropogenic disturbance factors in the surrounding landscape. Chapter 2 presents the initial application of OKRAM in 30 lacustrine fringe wetlands within central Oklahoma, alongside abiotic (e.g., soil and water quality) and biotic (e.g., vegetation and macroinvertebrate) data collection. Our analysis did not reveal consistent relationships between OKRAM and intensive data, indicating the method requires further modification. In addition to RAMs, Floristic Quality Assessment (FQA) is also used to evaluate wetland condition and guide conservation and management efforts. FQA results are assumed to be valid across large regions, despite areas of high environmental variability. Given the diverse ecoregions and environmental gradients across the state, Oklahoma provides an opportunity to examine spatial variation on FQA results. Chapter 3 presents our evaluation of 68 depressional wetlands to examine the influence of environmental variation on FQI scores. We found substantial variation between reference wetlands based on location, with higher scores occurring in the east (high precipitation) and lower scores occurring in the west (low precipitation). Our results highlight the importance of considering regional environmental differences when developing thresholds for wetland assessments.

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CHAPTER I

VALIDATION OF THE OKLAHOMA RAPID ASSESSMENT METHOD (OKRAM) IN DEPRESSIONAL WETLANDS USING EPA'S THREE-TIERED FRAMEWORK

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Abstract: The U.S. Environmental Protection Agency has developed a three-tiered framework to categorize wetland assessment methods. Level 1 assessments are conducted remotely and wetland condition is evaluated based on surrounding land-use practices. Level 2 assessments rely on rapid assessment methods (RAMs) to evaluate wetlands by using systematic, repeatable indices that represent wetland condition. Level 3 assessments rely on the most intensive sampling techniques to produce quantitative data. Because RAMs are conducted on-site, but require less time and expertise than Level 3 assessments, they have become an integral part of many state and federal wetland programs by providing a consistent method for ambient monitoring and prioritizing wetland management activities such as protection, restoration, and compensatory mitigation. RAMs evaluate condition along an anthropogenic disturbance gradient based on qualitative and quantitative measures of wetland indicators. Because RAMs are based on best professional judgment and inferred relationships between visible indicators of stress and wetland condition, validation with intensive data (i.e., Level 3 data) is necessary to confirm that condition scores are reflected in quantifiable components of the ecosystem. We conducted a validation analysis of the Oklahoma Rapid Assessment Method (OKRAM) in 28 depressional wetlands across the state using Level 1 and Level 3 data. Specifically, we evaluated OKRAM's ability to detect condition along a disturbance gradient and assessed the repeatability of OKRAM between practitioners and consistency of results across seasons. We found strong, consistent relationships between OKRAM scores and plant data (e.g., Floristic Quality Index, species richness, and diversity) and with the Landscape Development Intensity Index, a landscape assessment of surrounding anthropogenic disturbance. Our results indicate that OKRAM is tracking wetland condition within the wetland as well as with anthropogenic disturbance factors in the surrounding landscape. The difference in scores between practitioners was below the acceptable threshold of 10%, indicating the method is repeatable. OKRAM scores between spring and summer assessments had an average difference of only 2.4%, indicating the method is consistently detecting condition regardless of when OKRAM was applied. Based on our results we are confident that OKRAM has utility as a tool for differentiating between high quality depressional wetlands for protection and low quality depressional wetlands for restoration. Currently, we recommend the State apply OKRAM in future evaluations of depressional wetlands throughout Oklahoma. However, further calibration and validation is needed to expand OKRAM use to other Oklahoma wetlands.

Key Words: Depressional Wetlands, Oklahoma Rapid Assessment Method, Rapid Assessment Method, Wetland Assessments
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INTRODUCTION

Although wetlands are now widely recognized as valuable ecosystems that provide a variety of important functions and services, they continue to undergo degradation through draining, dredging, and filling, hydrological alterations, highway construction, mining and mineral extraction, and water pollution (Mitsch and Gosselink 2007). To improve our understanding of how these anthropogenic disturbances alter wetland condition, the development of unified and consistent assessment methods capable of detecting direct and indirect stressors is key for wetland monitoring programs. Rapid assessment methods (RAMs) have been recognized for their utility in state and federal wetland programs by providing a consistent, affordable approach for ambient monitoring and prioritizing wetland management activities such as protection, restoration, and compensatory mitigation (USEPA 2006). Moreover, because they are less time-consuming compared to other methods, they are becoming an important element of wetland monitoring programs.

RAMs fit within the three-tiered framework established by the United States Environmental Protection Agency (USEPA), which evaluates wetland condition based on qualitative and quantitative measures of wetland indicators (USEPA 2006). Level 1 assessments use readily available geographic information and remote sensing techniques to determine wetland extent across a landscape as well as wetland condition according to surrounding land-use practices. Level 2 assessments rely on RAMs to evaluate wetlands by using systematic, repeatable indices that represent wetland condition (Sutula et al. 2006). Level 3 assessments rely on the most intensive sampling techniques to produce quantitative data, often by implementing wetland bioassessments (i.e., indices of biological integrity [IBIs]) or hydrogeomorphic functional assessment methods (USEPA 2006). All three levels of assessments provide unique, valuable information about the condition of wetlands, but each provides information at different scales and requires different resources (e.g., personnel, equipment, training, etc.) and costs to implement.

In recent years, much research has focused on the development of Level 1 GIS-based assessment methods that utilize remote sensing techniques to determine wetland condition. These assessments typically require less time than field-based assessments, use fewer resources, and are especially beneficial when fieldwork is limited or not possible. An example of a Level 1 assessment is the Landscape Development Intensity Index (LDI). The LDI index is based on the types of land-use practices surrounding the wetland, with each land-use type assigned a coefficient based on its potential as an anthropogenic disturbance (Brown and Vivas 2005). As land-use types such as agricultural, residential, and recreational can impact wetland condition at multiple scales, the surrounding land-use is typically assessed at multiple scales or within multiple buffers (Rooney et al. 2012). Considering several ecologically-relevant scales can reduce errors associated with applying a scale that is too broad or too narrow. Level 1 assessments are based on the assumption that the composition and configuration of landscapes are predictive of wetland condition.

Level 2 assessments, also known as RAMs, use metrics to record observable field indicators such as vegetation, topography, and alterations to the wetland's hydrology (e.g., sedimentation, dikes, ditches, etc.) to define wetland condition. Specifically, these metrics provide qualitative measurements of a biological or physical attribute that reflect ecological condition (Sutula et al. 2006). Individual metric scores are aggregated into an overall condition score, which represents the relative degree of deviation in condition from least-disturbed wetlands (e.g., reference condition). In comparison to Level 1 assessments, these on-site Level 2 evaluations provide consideration for local factors that are often disregarded when applying Level 1 assessments alone. RAMs offer a compromise between coarse, remote Level 1 methods and often costly, intensive Level 3 methods (Reiss and Brown 2007).

In an evaluation of several existing RAMs, Fennessy et al. (2007) recommended that each RAM should be calibrated and validated through a comparison of RAM scores with independent measures of wetland condition (e.g., Level 3 assessment data). Because Level 2 assessment data are often based on inferred relationships and best professional judgment, it is necessary to confirm that condition scores are actually reflected in quantifiable components of the ecosystem. Therefore, validation and calibration are important components in the development of RAMs. Validation determines the accuracy of the RAM to compute condition scores that correspond with known measures of condition (i.e., responsiveness) obtained from more intensive assessments such as IBIs or the Floristic Quality Index (FQI) (Stein et al. 2009). Calibration is the process of adjusting the assessment method by rescaling or rescoring metrics to improve the RAM's ability to discern differences in wetland condition (Stein et al. 2009). Several states have completed RAM validations using various abiotic measurements (e.g., soil and water chemistry) and biotic assemblages such as bird, amphibian, macroinvertebrate, and vegetation communities. In the calibration and validation of the Ohio Rapid Assessment Method (ORAM), Mack et al. (2000) found strong, linear trends when comparing a vegetation IBI with overall ORAM scores. Stein et al. (2009) also reported significant correlations in the validation of the California Rapid Assessment Method (CRAM) between overall CRAM scores and IBIs (bird, macroinvertebrate, and vegetation). Additional validations include the use of bird and amphibian communities for ORAM (Micacchion 2004; Stapanian et al. 2004; Peterson and Niemi 2007) and macroinvertebrates for the Kentucky Wetland Rapid Assessment Method (Garrison 2013). In each case, RAM comparisons with Level 3 assessment data either confirmed the validity of the RAM for determining wetland condition or provided insight for further calibration to assure the method is capable of capturing wetland condition.

Wetland assessments have become an important focus for Oklahoma's Conservation Commission (OCC) Wetlands Program with the primary objective of developing a monitoring and assessment strategy to track local and statewide trends in wetland health and extent, which will allow the state to prioritize wetlands for protection and restoration and provide guidance for compensatory mitigation projects (OCC 2013). Currently, Oklahoma is in the early stages of developing an effective assessment method for the evaluation of wetlands across the state. During the RAM development process, RAMs shown to be effective in other states (e.g., CRAM and the Functional Assessment of Colorado Wetlands [FACWet]) were applied in Oklahoma wetlands; however, these methods were not able to consistently evaluate wetland condition (Dvorett et al. 2014; Gallaway et al. 2016). These results emphasize the fact that RAM applicability outside of the calibration and validation region may be difficult or inappropriate due to differences in wetland types, natural variability, and types of stressors. Therefore, it is necessary to develop a state- or region-specific RAM to provide an effective method with the most consistent and reliable results.

A recently completed wetland program development project (Dvorett et al. 2014) developed the Oklahoma Rapid Assessment Method (OKRAM) for assessing the condition of depressional wetlands. OKRAM was initially applied to depressional wetlands in the Cimarron River Pleistocene Sand Dunes Ecoregion of central Oklahoma. The application of OKRAM to this ecoregion confirmed that all RAM requirements were met (i.e., the method can determine condition, is truly rapid, requires a site visit, and can be verified; USEPA [2006]), and OKRAM is capable of capturing condition along an anthropogenic disturbance gradient. Although this initial method has been shown be an effective tool for assessing wetland condition, further refinement and validation across Oklahoma is required for OKRAM to be an effective tool for the state. Therefore, our primary objective was to evaluate the effectiveness of OKRAM at assessing the condition of depressional wetlands through a statewide validation and calibration analysis following U.S. EPA's three-tiered framework. A secondary objective was to evaluate the repeatability of OKRAM results among practitioners and consistency of OKRAM results across seasons by conducting assessments at two different times of the year (i.e., early growing season and late growing season).

METHODS

Study Area

The study area encompasses the majority of Oklahoma, including five ecoregions (Central Great Plains, Cross Timbers, Central Irregular Plains, Arkansas Valley, and South Central Plains; Figure 1). The Central Great Plains Ecoregion is a dry-subhumid area mostly underlain with red, Permian-age sedimentary rock. The vegetation is predominantly mixed-grass prairie and riparian forests. Common agricultural crops in the ecoregion include wheat, rye, alfalfa, and sorghum. The Cross Timbers Ecoregion is the transition zone between eastern forests and western prairies and is comprised of a mix of savannas, woodlands, native prairies, and rangelands (Omernik 1987; Woods et al. 2005). Oak-woodlands occur on coarse-textured soils and are dominated by post oak (*Quercus stellata)* and blackjack oak (*Quercus marilandica)*, while finer-textured soils are dominated by tall-grass prairies. This region is typically not suitable for crops; therefore, rangeland and pastureland are the predominant land uses. The Central Irregular Plains Ecoregion has a variable topography as compared to the Central Great Plains Ecoregion, resulting in a mix of land cover, including rangeland, grassland, woodland, floodplain, farmland, and cropland. The Arkansas Valley Ecoregion occurs between the Ozark Plateau and the Ouachita Mountains, consisting of oak savanna, prairie, and oak-hickory-pine forests. Land use within the ecoregion includes pastureland, cropland, timber harvest, poultry production, coal mining, and natural gas production (Omernik 1987; Woods et al. 2005). Lastly, the South Central Plains Ecoregion consists of uplands with oak-hickory-pine forests and bottomlands in floodplains. With approximately two-thirds of the ecoregion being forested, lumber and pulpwood production are major economic activities in this area. Annual precipitation varies greatly across the study area, with precipitation ranging from 61 cm in western counties to 142 cm in the southeastern portion of the state (Oklahoma Climatology Survey 2015).

We identified depressional wetlands following HGM guidance (Brinson 1993; Smith et al. 1995) and a dichotomous key developed by Dvorett et al. (2012). Depressional wetlands occur in topographic depressions that accumulate water from precipitation, surface flows, and groundwater discharge (Smith et al. 1995). Depressional wetlands may function as an open wetland with numerous inlets or outlets or as a closed wetland (Brinson 1993). Hydrodynamics are dominated by vertical fluctuations in water levels with water loss via outlets, evapotranspiration, or groundwater recharge (Smith et al. 1995). Depressional wetlands provide many functions and services, including groundwater recharge, nutrient cycling, water quality improvement, and wildlife habitat. These wetlands are also highly dynamic systems with variable hydroperiods based on climate and geographic location.

We used National Wetlands Inventory maps and 2008-2013 National Agricultural Imagery Program (NAIP) aerial imagery to locate 28 depressional wetlands. Wetlands were selected based on the level of anthropogenic disturbance (e.g., agricultural and urban land-use, point and non-point source runoff, etc.) and alterations to hydrology (e.g., dikes, ditches, culverts, etc.) to represent the disturbance gradient (Table 1). Surrounding land-use was determined using 2011 National Landcover Dataset (NLCD), which classifies land cover into categories based on 30-meter Landsat TM imagery. Wetlands initially selected to represent the least-disturbed category based on surrounding land-use were further validated using field reconnaissance to confirm the lack of hydrological and biological disturbance. Wetlands confirmed to have minimal anthropogenic impacts were included as reference wetlands (i.e., best attainable condition). Additionally, we further segregated wetlands using I-35 as the geographic boundary between high (east of I-35; 14 wetlands) and low precipitation (west of I-35; 14 wetlands). Wetlands were located on both public and private land. Prior to conducting the assessment, we selected an assessment area (AA) within each wetland as a representative sample of the entire wetland. The AA for depressional wetlands was based on the 1.0-hectare threshold recommended in CRAM (Collins et al. 2013). For wetlands comprising smaller than 1.0-hectare, the entire wetland was considered the AA. For wetlands larger than 1.0-hectare, the AA was defined by a 1.0-hectare circle randomly placed within the wetland.

Data Collection

For Level 1 data, we initially calculated the LDI Index for each depressional wetland using ArcGIS 10.2 within a 100 m, 500 m, and 1,000 m buffer surrounding the wetland. The percentage of each land-use type surrounding the wetland (e.g., agricultural, residential, industrial, commercial, transportation, natural areas, and open water) was recorded within each of the three buffers. Each land-use type was weighted by land-use coefficients representing the level of disturbance (Brown and Vivas 2005; Mack 2006; Table 2). LDI Index scores were calculated using the equation (Brown and Vivas 2005):

$$\mathrm{LDI_{total}} = \%\mathrm{LU_i} \times \mathrm{LDI_i}$$

where LDI_{total} = LDI ranking for landscape unit (i.e., buffer zone or watershed) and $\%LU_i$ = percent of the total area in land-use i. Higher LDI Index scores represent greater deviations from least-disturbed systems.

Between June and mid-August 2015, two practitioners applied OKRAM in each of the 28 depressional wetlands. Additionally, we re-visited 10 of the depressional wetlands in the early-growing season of the following year (i.e., April-May 2016) to assess any potential seasonal effects on overall OKRAM scores and individual metric scores.

OKRAM uses nine metrics, which are divided into three attributes (hydrologic condition, water quality, and biotic condition) to identify the presence and severity of stressors impacting wetlands (Appendix A). Hydrologic condition identifies alterations to the hydroperiod, water source, and hydrologic connectivity. The water quality attribute examines the input of excessive nutrients, sediment, and chemical contaminants and the ability of the surrounding buffer to reduce input of contaminants. Lastly, the biotic condition attribute evaluates any anthropogenic disturbance to the vegetation community and the percentage of contiguous habitat surrounding the wetland. Each metric is scored as a value between 0 and 1. Several metrics are scored as a percentage of intact function, such as percent functioning buffer or percent of connected habitat. The remaining metrics are scored based on a weighted severity of stress using minor, moderate, and major categories (i.e., 0.25, 0.50, and 0.75, respectively). The area impacted by a stressor (e.g., sedimentation, algal blooms, chemical spills, etc.) is multiplied by the severity of the disturbance. OKRAM aggregates the metrics into an overall score ranging from 0 to 1, with 0 being complete degradation and 1 being least-disturbed condition.

We collected Level 3 vegetation and soil data within each AA concurrently with OKRAM application. We collected vegetation community data using a step-point method in which transects were randomly placed throughout the wetland, and all plant species occurring at each meter were recorded (Smith and Haukos 2002). All transects were placed along an elevational gradient in each wetland and terminated at the edge of the AA or upland transition zone. Within each AA, we walked a minimum of three transects, totaling at least 150 sampling points. The length of transects were variable as AAs were not the same shape or size. To avoid sampling bias, all transects were traversed through the entirety of the AA, which led to more than 150 m of vegetation sampling in several wetlands. In these cases, we randomly selected 150 points from the total number of points sampled for inclusion in analyses (Smith and Haukos 2002). All unknown plant species were collected, pressed, and identified to the lowest taxonomic group possible using dichotomous keys (Mohlenbrock 2005, 2006, 2008, 2010; Tyrl et al. 2009). For each wetland, we calculated native species richness, species richness, Shannon-Weiner diversity, and FQI. FQI is a widely used vegetation method that infers condition based on plant species richness and species' tolerance to anthropogenic disturbance. Experts assign each species a coefficient of conservatism (*C*-value) ranging from 0 to 10 based on the likelihood of the species to occur at a disturbed site within a specific region. Generally, a rank of zero is given to non-native and opportunistic invasive species and a rank of 10 is assigned to plant species with a high degree of fidelity to a narrow range of synecological parameters (Andreas and Lichvar 1995). We calculated FQI using the following equation (Andreas and Lichvar 1995):

$$FQI = \left(\frac{\sum CC_i}{S}\right)\sqrt{S}$$

where *CC* is the coefficient of conservatism for species *i* and *S* is total species richness.

We collected one composite soil sample at each wetland, comprised of five subsamples taken to a depth of 10 cm. Subsamples were taken at locations in proportion to the dominant habitat cover types. Soil samples were immediately labeled, placed on ice, and stored at 4°C until processing. Samples were thoroughly mixed prior to being analyzed by the Oklahoma State Soil Water and Forage Analytical Laboratory for nitrate (NO_3), ammonium (NH_4), sodium (Na), phosphorus (P), pH, organic matter, total soluble salts (TSS), and sodium adsorption ratio (SAR). Phosphorous was extracted using the Mehlich III method, while sodium was extracted using a 1:1 soil to water extraction. Both phosphorous and sodium values were determined using inductively coupled plasma mass spectrometry. Nitrate and ammonium were extracted using a 1M KCL extraction and calculated using a flow injection analyzer. Sodium, nitrate, ammonium, phosphorous, and TSS are presented as parts per million (ppm) dry weight. Organic matter was calculated using a combustion analyzer and is presented as a percentage of dry weight.

OKRAM Validation Analysis

We evaluated the effectiveness of OKRAM to identify the condition in depressional wetlands by comparing overall OKRAM, individual attribute, and individual metric scores with Level 3 vegetation and soil data based on Spearman's non-parametric correlations using R version 3.2.2. (Crawley 2013; R Core Development Team 2015).

Consistent patterns of correlations in expected directions were interpreted as evidence of OKRAM responsiveness (i.e., ability to discern differences in wetland condition; Stein et al. 2009). A second assessment of OKRAM's ability to determine wetland condition was based on the relationships between overall OKRAM scores and the LDI Index. Spearman's correlations were used as an additional measure of the OKRAM's ability to capture disturbance within the surrounding landscape. The repeatability of OKRAM was evaluated to estimate potential observer-to-observer variability. We assessed repeatability by determining the difference in overall OKRAM, individual attribute, and individual metric scores between assessments completed by two practitioners. Metrics were deemed to be repeatable if they varied by an average of less than ten percent between OKRAM users (Stein et al. 2009). Seasonal influences were also addressed by revisiting approximately one-third of the wetlands during the early-growing season. Additionally, wetlands were placed into condition classes of good, fair, and poor based on overall OKRAM scores. The 25th percentile of overall OKRAM scores for *a priori* reference or least-disturbed wetlands was utilized as the threshold for the good condition class and the 75th percentile of *a priori* high disturbance wetlands as the threshold for the poor condition class (Sifneos et al. 2010).

RESULTS

Responsiveness of OKRAM to Level 1 and 3 Data

Level 1 data (LDI scores) indicated that our wetlands occurred along an anthropogenic disturbance gradient, with scores ranging from 1.04 to 9.01 within the 100 m buffer, 1.24 to 9.00 within the 500 m buffer, and 1.30 to 8.61 within the 1,000 m buffer. OKRAM overall scores were significantly negatively correlated with LDI scores across all spatial scales (Table 3). Additionally, all OKRAM attributes were significantly negatively correlated with LDI scores at each of the spatial scales.

We found consistent, significant relationships between overall OKRAM scores and Level 3 data. Overall OKRAM scores exhibited moderate to strong correlations with plant data (species richness: $\rho = 0.647$, $P = 0.001$, native species richness: $\rho = 0.72$, $P < 0.001$, Shannon-Weiner diversity: $\rho = 0.487$, $P = 0.009$, and FQI: $\rho = 0.701$, $P < 0.0001$; Figure 2). Additionally, overall OKRAM scores were moderately correlated with soil chemistry data (P: $\rho = -0.495$, $P = 0.007$ and SAR: $\rho = 0.436$, $P = 0.02$; Figure 3). Furthermore, we found significant relationships between OKRAM attributes (hydrologic condition, water quality, and biotic condition) and Level 3 data (Table 4). Hydrologic condition and water quality attributes had the strongest correlations with native species richness. Biotic condition scores were significantly correlated with plant data (e.g., native and total species richness, Shannon-Weiner diversity, and FQI) and soil chemistry data (e.g., P and SAR).

Repeatability and Consistency across Seasons

The average difference in overall OKRAM scores for two practitioners was 1.9% and the maximum difference for one site was 7.5% (Table 5). Eight of the nine metrics had an average difference below 5%. The water source metric, within the hydrologic condition attribute, had the greatest difference in scores between practitioners, with an average difference of 8.4%. Although we found substantial differences between water source metric scores (e.g., 50.7 % for one site), these differences were not common. Overall OKRAM and attribute scores from assessments in summer 2015 and spring 2016 were comparable (Table 5). Eight of the nine metrics had an average difference in scores below 5%, except the vegetation metric, which had an average difference of 12.8%. The average difference between overall scores was only 2.4% and the greatest difference observed at one site was 11.3%.

DISCUSSION

Responsiveness of OKRAM to Level 1 and 3 Data

The use of RAMs to define wetland condition relies on the assumption that a set of qualitative field metrics can capture biological and physical attributes of wetlands and represent overall condition (Stein et al. 2009). Based on this assumption and the reliance on best professional judgment of the practitioners, RAMs are inherently subjective and must be validated to confirm that the individual metric, attribute, and overall scores represent wetland condition (Sutula et al. 2006). Without proper validation, RAMs may produce misleading results that overestimate or underestimate actual wetland condition. Validation of OKRAM with Level 1 and Level 3 data confirms the method can define wetland condition and establishes the scientific defensibility necessary to apply OKRAM for wetland regulatory and management efforts.

Level 1 assessments have been used in other studies to provide support for RAM validations (Mack 2006; Reiss and Brown 2007; Margriter et al. 2014). The strong relationships between overall OKRAM and attribute scores with a Level 1 assessment (i.e., LDI index) demonstrates the ability of the method to detect anthropogenic disturbance within the surrounding landscape up to 1,000 m. Specifically, the strong relationships between LDI and water quality and biotic condition attributes indicate that OKRAM is effectively capturing evidence of landscape stressors on-site within the wetland and surrounding buffer (e.g., excessive nutrients and sedimentation due to non-point source runoff). Significant correlations between OKRAM and LDI across all spatial scales (e.g., 100 m, 500 m, and 1,000 m) suggest that a 100 m buffer may be sufficient to detect landscape disturbances to depressional wetlands. Brown and Vivas (2005) found similar results, concluding that a 100 m buffer is the most appropriate width for small depressional wetlands. Although a 100 m buffer may be sufficient to detect landscape stressors, as the buffer width increases, correlation strength also increases, indicating that a greater inference can be made when using a larger scale.

In addition to using a Level 1 assessment, an important component of RAM validation is to confirm that the RAM metric, attribute, and overall scores are representative of wetland biological condition (e.g., vegetation, invertebrate, bird, and amphibian communities). In ephemeral depressional wetlands where wetlands are often dry during sampling, vegetation is the most commonly used assemblage to represent biological condition. Plant communities are known to shift in response to the severity and type of anthropogenic disturbance with highly disturbed sites having lower species richness and diversity and an increase in invasive species (Chipps et al. 2006; DeKeyser et al. 2009; Tsai et al. 2012). In addition to observing lower species richness and diversity in disturbed wetlands, we also found strong, significant relationships between overall OKRAM scores and FQI. FQI has been established as an indicator of condition for depressional wetlands (Fennessy et al. 1998; Lopez and Fennessy 2002; Andreas et al. 2004) and has been used to validate RAMs in other states (Miller and Wardrop 2006; Wardrop et al. 2007).

Because each RAM attribute represents a different component of wetland condition (e.g., hydrological, water quality, biotic condition), it is important to evaluate the relationships between individual attributes and Level 3 data. For example, the strong relationships between plant data and the biotic condition attribute were anticipated, given that they both evaluate vegetation; however, the significant relationships between plant and soil chemistry data with OKRAM hydrologic condition and water quality attributes are also an indication that the method is detecting hydrological alterations (e.g., changes in hydroperiod and water source impacts) and water quality stressors (e.g., nutrient and sedimentation). For instance, sites with lower water quality attribute scores typically had lower species richness and diversity and increased phosphorus levels. Furthermore, sites with intact buffers typically had decreased phosphorus levels, which suggests that the OKRAM buffer metric is effectively tracking the influence of buffer on reducing nutrient impacts.

OKRAM Calibration

RAM calibration assures that the method can detect condition changes along the entire disturbance gradient and typically involves the modification of metrics, such as rescaling or rescoring, to improve RAM performance (Stein et al. 2009). Our results confirm that the OKRAM metric and attribute scores reflect the disturbance gradient from least to most-disturbed. However, our results suggest that one of the nine OKRAM metrics, habitat connectivity, which is currently assessed as the percent of contiguous habitat within a 2,500 m buffer around the wetland, could be improved by using a different scale. Relationships between habitat connectivity metric scores and Level 3 data were consistently stronger at 500 m and 1,000 m compared to 2,500 m. This is likely due to Oklahoma's highly fragmented landscape in which large areas of contiguous habitat are uncommon and typically only occur in the southeastern part of the state. For instance, habitat connectivity metric scores reflect this fragmentation, with only 4 of the 28 study wetlands receiving scores of 0.9 or greater. Our results suggest that assessing this metric at a smaller scale may be more appropriate for Oklahoma, however, it is also important to consider the scale at which wildlife species utilize wetlands and surrounding habitat. Many reptiles and amphibian species depend on terrestrial habitats surrounding wetlands during at least a portion of their life cycle (e.g., nesting, hibernating, aestivating, foraging, and dispersal; Gibbons 2003). For example, Semlitsch (1998) compiled traveled distances for six species of salamanders and found the average distance to be 164 m, with some individuals traveling 450-625 m. Wetland-dependent birds also use wetlands at multiple scales. In the Southern Great Plains, habitat density of suitable habitat within 1,500 m was shown to be an important predictor of shorebird density and richness within wetland stopover sites (Albanese and Davis 2015). When assessing habitat connectivity, it is critical to consider at what scales wildlife species, especially wetland-dependent species, use wetlands and surrounding landscape. We recommend adjusting the habitat connectivity metric to be calculated using a 1,000 m buffer, which may improve the range and representativeness of the metric while accounting for the biologically relevant scales at which organisms utilize wetlands.

In general, providing additional guidance for calculating individual metrics can improve interpretation and OKRAM results. For instance, determining the severity (i.e., minor, moderate, major) of hydrologic and water quality stressors (e.g., alterations to the hydroperiod, nutrients, and sedimentation) can be improved by including photo examples and detailed descriptions of each stressor at different severities. Now that the method has been validated in depressional wetlands statewide, developing a comprehensive user guidebook with photos and detailed descriptions will be a top priority for OKRAM development.

Repeatability and Seasonal Effects

Assessing a method's repeatability is an important component of the RAM development process. Repeatability evaluates the consistency among users for metric interpretation and calculation to assure the method can produce consistent, reliable results. We recognize that our repeatability analysis only used the results of two practitioners; therefore, our results should be interpreted as a preliminary repeatability analysis. We recommend further assessment of the repeatability of OKRAM across multiple practitioners and teams. Nonetheless, all OKRAM metrics had an average difference in scores below the 10% threshold applied by Stein et al. (2009), indicating the metrics are repeatable. The differences observed in the water source metric are likely due to the metric requiring an observer to delineate the wetlands' watershed and record potential impacts to the water source. When two practitioners delineate the watershed differently, certain stressors may be included or excluded from calculations, resulting in a difference in scores. Providing additional clarification and guidance for delineation would likely improve the metric's repeatability.

Because wetland regulatory and management actions (e.g., protection, restoration, mitigation, etc.) are not confined to the growing season, condition assessments that are not influenced by seasonal changes and can be applied year-round are desirable. A comparison of RAM results from applications at different times of the year can be used to evaluate seasonal influence on the method. Our comparison of spring (i.e., early growing season) and summer (i.e., late growing season) assessments confirms that the majority of

OKRAM metrics are not influenced by timing of application. The metrics most susceptible to seasonal influence are the metrics within the water quality attribute (i.e., nutrients, sediments, and chemical contaminants) and the vegetation metric. The greatest change observed in the nutrient metric for one site was an increase of 7.5% in the spring assessment due to algae only occurring in the summer assessment. The greatest difference in the chemical contaminants metric for one site (12.5%) was due to the presence of an oil sheen in the summer assessment that was not observed in the spring assessment. For the sediment metric, the greatest observed difference at one site was a 5.0% decrease in the spring based on the presence of water turbidity that was not observed in the summer. The differences we observed between seasons were minor (e.g., maximum deviation for the water quality attribute was only 4.7%) and represent natural fluctuations in the condition based on climatic and intrinsic factors. We did not observe seasonal differences for any of the water quality metrics in 7 of the 10 revisited wetlands. Additionally, because metrics are aggregated into attribute and overall scores, the deviation of one metric is moderated by the others.

RAMs, such as CRAM and ORAM that are designed to assess vegetation structure and composition to determine overall wetland condition are likely to have variable scores across seasons (Mack 2001; Collins et al. 2013). Because these RAMs use metrics to evaluate plant community complexity (e.g., number of plant layers; horizontal interspersion), they are not recommended for use outside of the growing season (Mack 2001; Collins et al. 2013). Alternatively, the OKRAM vegetation metric does not focus on the complexity of plant communities, but rather detects indicators of stress (e.g., vegetation removal, invasive and exotic species, monocultures, herbicide application, excessive grazing, and mechanical disturbance). Because OKRAM uses a stressor-based approach, rather than the assessment of vegetation complexity to define condition, the method is not susceptible to natural variation within plant communities.

Our comparison of spring and summer assessments resulted in vegetation metric scores differing for 6 of the 10 revisited wetlands. However, these differences in scores were due to changes in stressors rather than changes in plant community complexity. Thus, differences in vegetation metric scores reflect actual changes in wetland condition. For example, a wetland with a high percentage of invasive species during the summer assessment received a low vegetation score. The wetland underwent vegetation removal to promote the growth of native species in the spring, which improved the vegetation metric score and overall OKRAM score. Additionally, a wetland with hydrophytic vegetation present in the summer was then disked and planted with wheat before the spring assessment, resulting in a lower vegetation and overall score. In these instances, OKRAM is not being impacted by seasonal effects, but rather reflecting actual changes in wetland condition. However, it is important to recognize that RAMs are assessing the condition of a wetland at one specific time and are subject to inconsistencies resulting from the difficulty in identifying invasive and exotic species outside of the flowering and fruiting stage. With an average seasonal difference of only 2.4% for overall scores, our seasonality analysis confirms OKRAM is not significantly influenced by seasonal effects and can be applied at different times throughout the year.

Condition Classes

Development of an assessment method with the ability to differentiate between high quality and low quality wetlands is an important objective of Oklahoma's wetland monitoring and assessment program. Following the protocol outlined by Sifneos et al. (2010), the threshold for reference condition was 0.84. Thus, all wetlands scoring 0.84 and greater were considered to be in reference condition. The poor condition class threshold was 0.50 and included all wetlands scoring 0.50 and lower. Wetlands scoring between 0.84 and 0.50 were considered to be in fair condition. These thresholds are very similar to those determined in the previous OKRAM application (0.81 and 0.50 from Dvorett et al. [2014]). When applying these thresholds, 10 wetlands were categorized as good condition, all of which were in the *a priori* good class, and 8 wetlands were categorized as poor condition, all of which were in the *a priori* poor condition class. The remaining 10 wetlands were considered to be in fair condition, of which two were in the *a priori* good class and three were in the *a priori* poor class. There was an 82% agreement between assigned condition classes and *a priori* classifications, which provides support for the appropriateness of these thresholds (Table 6).

CONCLUSION

The overall goal of OKRAM is to provide state and federal agencies with a consistent, rapid, and affordable wetland assessment method with statewide applicability. OKRAM incorporates a multi-scale approach by assessing local stressors within the wetland and evaluating impacts within the watershed at a larger scale. Applying different spatial scales within an assessment method promotes the detection of stressors that may be otherwise excluded when focusing on a single scale, such as a 100 m buffer. RAMs are efficient and effective tools for determining wetland condition and when properly validated, they can be applied year-round regardless of the presence of water within the wetland. With the natural dynamic wet and dry cycles of wetlands, a method that can be applied in the absence of surface water and wetland vegetation is important. Additionally, this study has highlighted the importance of using a multi-metric approach to evaluate wetland condition, as opposed to focusing on vegetation or surrounding land-use alone. When evaluating condition, all components should be considered, including the hydrological, biological, physical, and chemical processes occurring within wetlands.

This study provides an example of conducting a Level 1 assessment for additional support in RAM validations. Our results also demonstrate the utility of FQI as a validation tool for Level 1 and Level 2 assessments in Oklahoma. FQI has been applied in ecoregions to assess the condition of Oklahoma wetlands (Bried et al. 2014), but it has not previously been used to define the condition of depressional wetlands across the entire state. While FQI proved to be an excellent tool for validation, it is important to recognize that FQI can vary between different plant communities (i.e., wetland vs. upland; Rooney and Rogers 2002), based on seasonal influences (i.e., time of year of sampling; Matthews 2003; Euliss and Mushet 2011), and the ability of evaluators to identify plants correctly (Chamberlain and Brooks 2016). Additionally, we observed substantial variation in FQI scores based on geographic location (e.g., the average FQI score for high quality wetlands was 19.9 in eastern sites and 14.1 in western sites). Stratification by ecoregions can improve assessments by reducing spatial variability in soils, climate, vegetation, and land cover (Stoddard 2005; Bried et al. 2016). FQI has been shown to be a good indicator of wetland condition, and with these considerations taken into account, it can be applied to gather intensive data about plant communities and wetland health.

Our validation analysis of OKRAM with Level 1 and Level 3 data demonstrates its ability to define condition in depressional wetlands across a large study area. Our analysis confirms that with adequate training and guidance, OKRAM is repeatable and can assess wetland condition regardless of geographic location or time of year. Based on our results, we are confident that OKRAM has utility as a tool for differentiating between high quality wetlands for protection and low quality wetlands for restoration. Currently, we recommend the State apply OKRAM in future evaluations of depressional wetlands throughout Oklahoma. However, further calibration and validation is needed to expand OKRAM use to other Oklahoma wetlands.

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FIGURES AND TABLES

Figure 1: Map of the study area and location of the 28 depressional wetlands sampled in 2015 across Oklahoma. Wetlands were segregated based on high (east of I-35; 14 sites) and low precipitation (west of I-35; 14 sites).

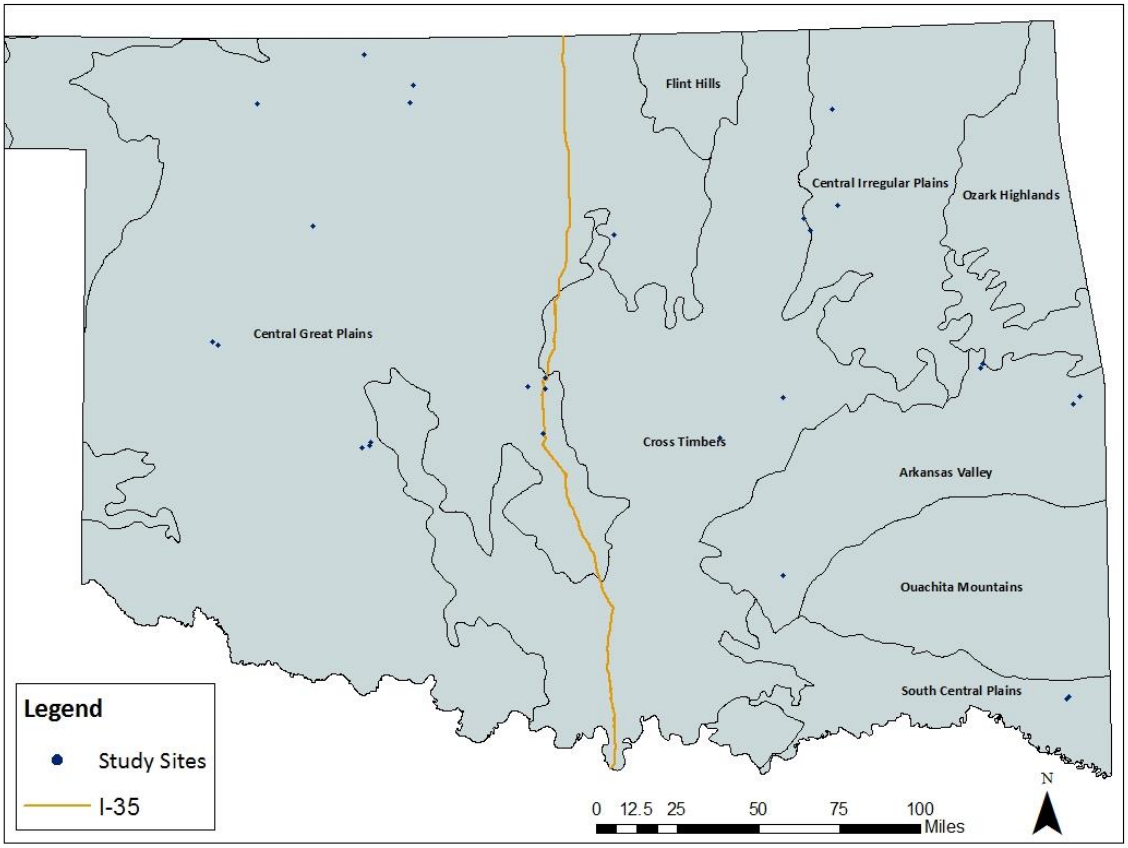

Figure 2: Relationships between Oklahoma Rapid Assessment Method (OKRAM) overall scores and biotic condition attribute scores with a) plant species richness, b) native species richness, and c) floristic quality index. Correlations are presented in terms of Spearman's r (ρ).

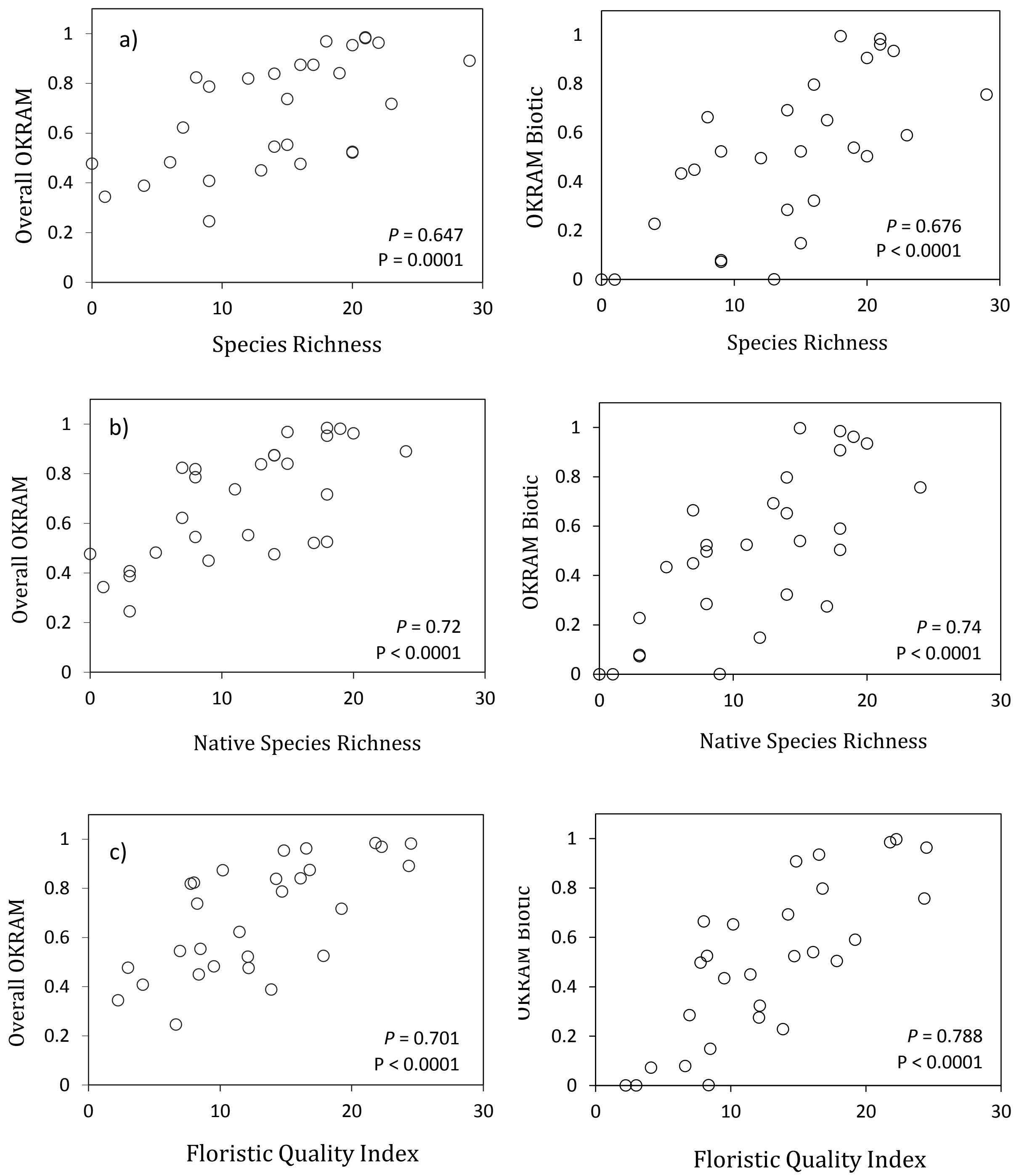

Figure 3: Relationships between Oklahoma Rapid Assessment Method (OKRAM) overall scores and water quality attribute scores indicated by soil phosphorus. Correlations are presented in terms of Spearman's r (ρ).

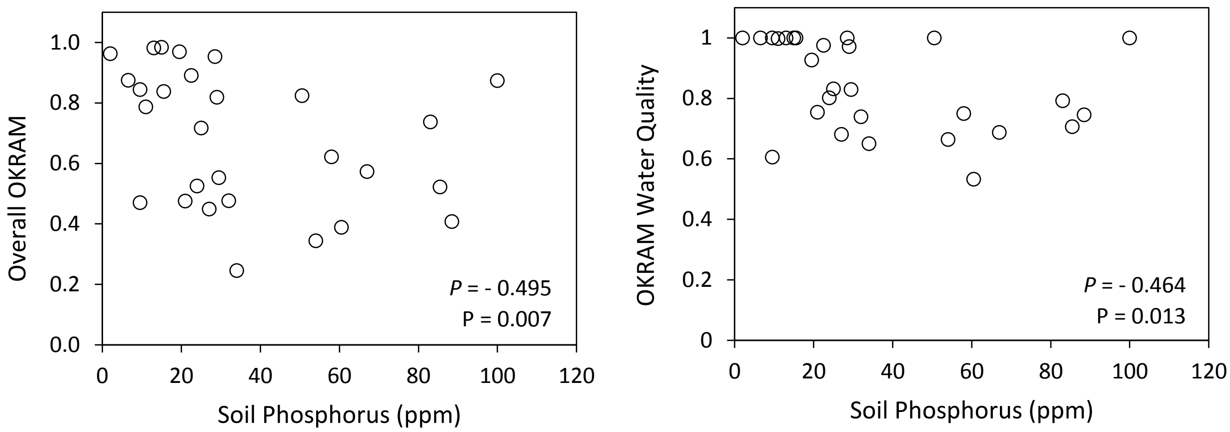

Figure 4: The distribution of Oklahoma Rapid Assessment Method (OKRAM) scores across 28 depressional wetland sites in Oklahoma during 2015.

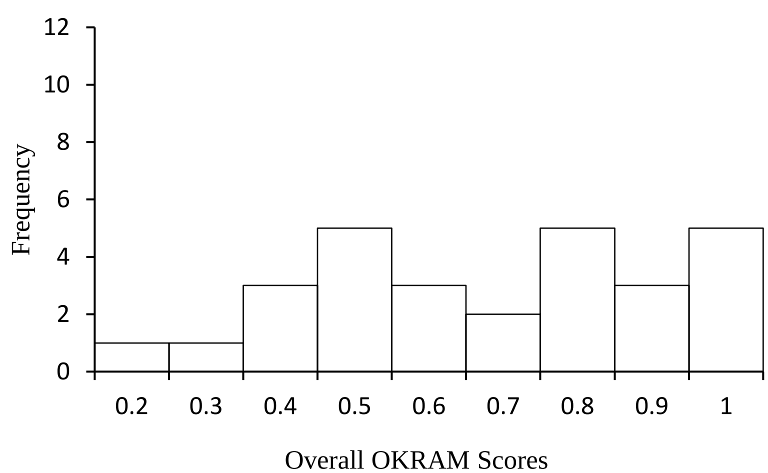

Table 1: Descriptions of depressional wetlands sampled in 2015 across Oklahoma. Wetlands are categorized by *a priori* classification, which is based on a GIS desktop analysis of the land-use types surrounding wetlands. Reference represents best attainable condition with minimal anthropogenic disturbance and no hydrological alterations, fair condition wetlands were moderately disturbed, and poor condition wetlands were significantly altered (e.g., agricultural or urban landscapes).

***A priori* Classification**	**Number of Wetlands**	**Size Range (ha)**	**Mean Size (ha)**
Reference	12	0.05 - 2.27	0.52
Fair	5	0.45 - 2.30	1.01
Poor	11	0.06 - 2.10	0.57

Table 2: Oklahoma land-use classes defined by National Land Cover Database (NLCD) and corresponding coefficients used to calculate Landscape Development Intensity Index (LDI) scores (Brown and Vivas 2005; Mack 2006)

Land Use Classification	**LDI Coefficient**
Natural System	1.0
Open Water	1.0
Pasture	3.41
Developed, Open Space	6.92
Cropland	7.0
Developed, Low Intensity	7.55
Barren Land	8.32
Developed, Medium Intensity	9.42
Developed, High Intensity	10.0

Table 3: The relationships between the Landscape Development Intensity Index (LDI) at three spatial scales (e.g., 100 m, 500 m, and 1,000 m) and the Oklahoma Rapid Assessment Method (OKRAM) attributes (i.e., hydrologic, water quality, and biotic condition) and overall OKRAM scores. Additionally, the relationships between LDI and Level 3 data are shown, including plant species richness (SPR), native species richness (NSPR), Floristic Quality Index (FQI), and soil phosphorus (P). Correlations are presented in terms of Spearman's r (ρ) and all relationships that are significant at $\alpha = 0.05$ level are shown.

LDI	**Level 2 and 3 Metrics**	ρ	**P-value**
LDI 100 m	A1: Hydrologic Condition	-0.754	<0.0001
	A2: Water Quality	-0.802	<0.0001
	A3: Biotic Condition	-0.839	<0.0001
	Overall OKRAM	-0.832	<0.0001
	SPR	-0.522	0.004
	NSPR	-0.589	0.001
	FQI	-0.596	0.001
	P (ppm)	0.433	0.020
LDI 500 m	A1: Hydrologic Condition	-0.814	<0.0001
	A2: Water Quality	-0.761	<0.0001
	A3: Biotic Condition	-0.824	<0.0001
	Overall OKRAM	-0.853	<0.0001
	SPR	-0.497	0.001
	NSPR	-0.547	0.003
	FQI	-0.553	0.003
	P (ppm)	0.488	0.020
LDI 1000 m	A1: Hydrologic Condition	-0.795	<0.0001
	A2: Water Quality	-0.744	<0.0001
	A3: Biotic Condition	-0.843	<0.0001
	Overall OKRAM	-0.861	<0.0001
	SPR	-0.580	0.001
	NSPR	-0.605	0.001
	FQI	-0.570	0.002
	P (ppm)	0.421	0.030

Table 4: Relationships between Oklahoma Rapid Assessment Method (OKRAM) attributes and overall scores with Level 3 data based on Spearman's rank correlation (ρ). Level 3 data includes species richness (SPR), native species richness (NSPR), Floristic Quality Index (FQI), Shannon-Weiner diversity (SWD), soil phosphorus (P), soil nitrate (NO_3), soil ammonium (NH_4), and sodium absorption ratio (SAR). All relationships that are significant at $\alpha = 0.05$ level are shown.

OKRAM	**Level 3 Metric**	$\boldsymbol{\rho}$	**P-value**
A1: Hydrologic Condition	SPR	0.459	0.014
	NSPR	0.503	0.006
	FQI	0.463	0.013
	SAR	0.385	0.043
A2: Water Quality	SPR	0.564	0.001
	NSPR	0.632	0.0003
	FQI	0.569	0.002
	SWD	0.475	0.010
	P (ppm)	-0.464	0.013
A3: Biotic Condition	SPR	0.676	<0.0001
	NSPR	0.740	<0.0001
	FQI	0.788	<0.0001
	SWD	0.464	0.013
	P (ppm)	-0.524	0.004
	NO_3 (ppm)	-0.479	0.010
	NH_4 (ppm)	0.398	0.036
	SAR	0.506	0.006
Overall OKRAM	SPR	0.647	0.0001
	NSPR	0.720	<0.0001
	FQI	0.701	<0.0001
	SWD	0.487	0.009
	P (ppm)	-0.495	0.007
	SAR	0.436	0.020

Table 5: Repeatability of the Oklahoma Rapid Assessment Method (OKRAM) was assessed as the average difference and the maximum difference between the scores of two practitioners. Seasonal differences were assessed as the average and maximum difference in scores between spring and summer assessments.

OKRAM Metrics and Attributes	Avg. Practitioner Difference (%)	Max. Practitioner Difference (%)	Avg. Seasonal Difference (%)	Max. Seasonal Difference (%)
Hydroperiod	1.2	15.0	0.5	3.8
Water Source	8.4	50.7	3.6	12.9
Hydrologic Connectivity	3.0	50.0	0.0	0.0
Attribute 1: Hydrology	4.0	17.5	1.5	4.3
Nutrients	1.6	25.0	1.5	7.5
Sediment	2.3	15.0	1.8	5.0
Chemical Contaminants	1.2	25.0	2.0	12.5
Buffer Filter	2.0	16.0	0.9	6.5
Attribute 2: Water Quality	1.4	9.4	1.4	4.7
Vegetation	3.1	14.8	12.8	50.0
Habitat Connectivity	4.2	26.9	1.5	8.1
Attribute 3: Biotic Condition	3.9	17.3	7.9	27.5
Overall OKRAM Score	1.9	7.5	2.4	11.3

Table 6: Comparison of *a priori* classifications and condition classes assigned based on overall Oklahoma Rapid Assessment Method (OKRAM) scores. Condition classes were determined by using the 25th percentile of OKRAM scores for *a priori* reference wetlands and the 75th percentile of OKRAM scores for *a priori* poor wetlands. Resulting thresholds were 0.84 and greater for reference condition, 0.50 and lower for poor condition, and sites falling in between were considered to be in fair condition.

Site	***A priori* Classification**	**Overall OKRAM Score**	**OKRAM Condition Classification**
1	Reference	0.96	Reference
2	Reference	0.95	Reference
3	Reference	0.87	Reference
4	Poor	0.48	Poor
5	Fair	0.82	Fair
6	Poor	0.48	Poor
7	Reference	0.82	Fair
8	Poor	0.40	Poor
9	Fair	0.53	Fair
10	Poor	0.62	Fair
11	Reference	0.79	Fair
12	Poor	0.55	Fair
13	Poor	0.25	Poor
14	Poor	0.47	Poor
15	Poor	0.45	Poor
16	Reference	0.84	Reference
17	Fair	0.74	Fair
18	Fair	0.54	Fair
19	Reference	0.87	Reference
20	Poor	0.52	Fair
21	Reference	0.84	Reference
22	Poor	0.34	Poor
23	Poor	0.41	Poor
24	Reference	0.89	Reference
25	Reference	0.97	Reference
26	Fair	0.72	Fair
27	Reference	0.98	Reference
28	Reference	0.98	Reference

CHAPTER II

DEVELOPMENT OF A RAPID ASSESSMENT METHOD FOR DETERMINING THE CONDITION OF LACUSTRINE FRINGE WETLANDS IN CENTRAL OKLAHOMA

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Abstract: Wetland assessments have become a fundamental component of many state and federal wetland programs, as they provide consistent methods for the evaluation of wetland ecological condition. Wetland assessments have been categorized into a three-tiered framework by the U.S. Environmental Protection Agency based on the type of assessment (i.e., remote or field-based) and the type of data collected (i.e., qualitative or quantitative). Level 1 assessments evaluate wetland condition based on the composition of the surrounding landscape. Level 2 assessments, known as rapid assessment methods (RAMs), use repeatable metrics on-site to collect qualitative measurements of biological and physical attributes that reflect ecological condition. Level 3 assessments utilize the most intensive sampling techniques to produce quantitative data, which is often used to develop wetland bioassessments. Oklahoma agencies have developed a RAM, the Oklahoma Rapid Assessment Method (OKRAM), which has been applied and validated in depressional wetlands. In order to be an effective tool applicable to all wetlands, OKRAM application and validation with Level 3 data is needed in other wetland types across the state. Our study presents the initial application of OKRAM in 30 lacustrine fringe wetlands within central Oklahoma, alongside intensive abiotic (e.g., soil and water quality) and biotic (e.g., vegetation and macroinvertebrate) data collection. We also evaluated the effectiveness of two other methods (California Rapid Assessment Method

[CRAM] and Functional Assessment of Colorado Wetlands [FACWet]) at assessing wetland condition in lacustrine fringe wetlands. Spearman's non-parametric analysis did not reveal consistent relationships between OKRAM and intensive data, which indicates that the method requires further modification. There was no evidence to support that CRAM and FACWet were able to detect wetland condition. Based on our results, we determined several key stressors of lacustrine fringe wetlands that OKRAM is not currently detecting, (e.g., reservoir water level fluctuations and stability). We also recommend further investigation into the existing disturbance gradient (i.e., highly degraded and pristine sites) to develop a list of potential sample sites. Lastly, given the unique attributes of these wetlands, OKRAM refinement would be aided by additional information on the relationship between biotic communities and water quality degradation from surrounding land-use practices.

Key Words: Condition Assessments, Lacustrine Fringe Wetlands, Rapid Assessment Methods, Validation
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INTRODUCTION

Wetland assessments have become a fundamental component of many state and federal wetland programs, as they provide consistent methods for the evaluation of wetland ecological condition. Assessments can be applied to meet ambient monitoring goals and wetland regulatory actions including mitigation, restoration, and protection (USEPA 2006; Fennessy et al. 2007). Wetland assessment methods have been categorized into a three-tiered framework by the U.S. Environmental Protection Agency (USEPA) based on the type of assessment (i.e., remote or field-based) and the type of data collected (i.e., qualitative or quantitative; USEPA 2006). Level 1 assessments rely on GIS and remote sensing techniques to evaluate wetland condition based on the composition of the surrounding landscape. Level 2 assessments, known as rapid assessment methods (RAMs), use repeatable metrics on-site to collect qualitative measurements of biological and physical attributes that reflect ecological condition

(Sutula et al. 2006). RAM metrics detect the presence and severity of stressors within and around the wetland (e.g., alterations to wetland hydrology, disturbance to vegetation, impacts to water quality, etc.). Level 3 assessments utilize the most intensive sampling techniques to produce quantitative data, which is often used to develop wetland bioassessments (i.e., indices of biological integrity [IBIs]) or hydrogeomorphic functional assessment methods (USEPA 2006). Specifically, these assessments involve on-site collections of abiotic (e.g., soil and water chemistry) and biotic (e.g., diatom, macroinvertebrate, vegetation) data to estimate wetland condition.

Level 2 assessments (RAMs) typically require less time in the field than intensive Level 3 assessments, while providing consideration for on-site factors that may be overlooked by coarse, Level 1 assessments (Fennessy et al. 2007; Reiss and Brown 2007). As such, RAMs have become a preferred method, with many states (e.g., California [Collins et al. 2013], Colorado [Johnson et al. 2013], Delaware [Jacobs 2010], Montana [Apfelbeck and Farris 2005], New Mexico [Muldavin et al. 2011], Ohio [Mack 2001], Oregon [Adamus et al. 2016], and Rhode Island [Kutcher 2011]) developing their own RAMs.

A central component in RAM development is to determine the method's accuracy in computing scores that are representative of actual wetland condition (Fennessy et al. 2007). Because RAMs are based on inferred relationships between wetland indicators and condition and rely on the best professional judgment of evaluators, validation with independent measures of wetland condition (e.g., Level 3 assessments) is necessary (Fennessy et al. 2007; Stein et al. 2009). In addition to a validation with Level 3 data, RAMs should also be calibrated along a disturbance gradient prior to implementation for wetland monitoring and management. Calibration involves the rescaling or rescoring of metrics to improve the method's ability to discern differences in condition along an anthropogenic disturbance gradient (Stein et al. 2009). Following these steps in RAM development will increase reliability and scientific defensibility of the method (Fennessy et al. 2007). Despite the importance of undergoing these developmental steps, Fennessy et al. (2007) found that most RAMs had not been validated or calibrated across the regions in which they were applied. Nonetheless, there are examples provided in the literature, including the calibration and validation of the Ohio Rapid Assessment Method (ORAM) with vegetation (Mack et al. 2000), amphibians (Micacchion et al. 2004), and birds (Stapanian et al. 2004; Peterson and Niemi 2007) and the validation of the California Rapid Assessment Method (CRAM) with multiple assemblages using IBIs (e.g., bird, macroinvertebrate, and vegetation communities; Stein et al. 2009). These studies can act as guidelines for other states in conducting RAM calibration and validation analyses to ensure that RAM scores represent true wetland condition.

Another critical component in RAM development is the recognition of different wetland types because wetlands vary in their susceptibility to different types and severities of stressors (Fennessy et al. 2007). For example, stressors from surrounding land-use practices are critical when assessing depressional wetlands where surface runoff is a dominant water source, but may be less significant in some riverine wetlands where overbank flow is the dominant water source (Brinson 1993). If this variation is not recognized or accounted for, applying RAMs within different wetland types may produce misleading results. One way to reduce this variability in wetland assessments is to use the hydrogeomorphic approach (HGM), which classifies wetlands based on geomorphic setting, water source, and hydrodynamics (Brinson 1993). Variation can be further reduced by classifying wetlands into subclasses (Dvorett et al. 2013). The development and validation of RAMs for each wetland type will likely increase the precision of RAMs and their applicability in wetland monitoring and management programs.

The Oklahoma Conservation Commission (OCC) has recognized the importance of wetland assessment methods and has made the development of a RAM capable of defining the condition of all wetlands across the state a priority of its Wetlands Program (OCC 2013). This study builds on results from recent efforts including the initial development and application of the Oklahoma Rapid Assessment Method (OKRAM) in interdunal depressional wetlands in the Cimarron River Pleistocene Sand Dunes Ecoregion (Dvorett et al. 2014) and the validation of OKRAM in depressional wetlands statewide (Chapter 1). With the initial development and validation of OKRAM complete, further application across Oklahoma's wetland classes is imperative.

Lacustrine fringe wetlands are a dominant wetland class in Oklahoma, making them an important target for the next OKRAM validation. According to HGM classification, lacustrine fringe wetlands occur adjacent to lakes where the water table is maintained by the elevated water levels of lakes (Brinson 1993). These wetland systems are located along the numerous reservoirs created by the Army Corps of Engineers, U.S. Bureau of Reclamation, and Grand River Dam Authority that occur across the state (Johnson 1993). Lacustrine fringe wetlands typically maintain long hydroperiods with additional water sources of precipitation and groundwater discharge and water loss occurring via evapotranspiration and receding floodwaters (Smith et al. 1995). They provide a variety of functions and services, including breeding and foraging habitat for various wildlife species, reducing the direct input of sediment into lakes, and filtering nutrients within the lake water.

While there have been many wetland assessment studies (e.g., IBIs and RAMs) conducted within natural lake systems, such as the Great Lakes region (Wilcox et al. 2002; Uzarski et al. 2004; Bourdaghs et al. 2006; Peterson and Niemi 2007; Rothrock et al. 2008), condition assessments of wetlands associated with man-made reservoirs are deficient. Reservoirs or impoundments provide a suite of stressors such as the age of the reservoir, manipulation of lake water levels for recreation, water supply, and storage, and disconnection with the nearby upland that are not typically considered when assessing natural systems. Wardrop et al. (2007) applied a RAM within wetlands associated with reservoirs; however, there were not enough sample sites for a proper validation. To the best of our knowledge, our study presents the first application of RAMs targeting unnatural lacustrine fringe systems for the purpose of validation and calibration.

The primary objective of our study was to conduct the first application of OKRAM in lacustrine fringe wetlands and evaluate the ability of the method to define wetland condition through validation using a Level 1 assessment and Level 3 assessment data (e.g., vegetation, macroinvertebrate, soil, and water quality data). Our second objective was to conduct two additional assessment methods (CRAM and Functional Assessment of Colorado Wetlands [FACWet]) to determine if any additional metrics could improve OKRAM results. Our final objective was to evaluate the repeatability of OKRAM to minimize observer error and address any potential seasonal effects by conducting assessments at two different times of the year (i.e., early growing season and late growing season).

METHODS

Study Area

The study area occurs within the Central Great Plains and Cross Timbers ecoregions of Oklahoma (Figure 1). The Central Great Plains Ecoregion is a dry-subhumid area mostly underlain with red, Permian-age sedimentary rock. The vegetation is predominantly mixed-grass prairie and riparian forests. Common agricultural crops in the ecoregion include wheat, rye, alfalfa, and sorghum. The Cross Timbers Ecoregion is the transition zone between eastern forests and western prairies, and is comprised of a mix of savannas, woodlands, native prairies, and rangelands (Omernik 1987; Woods et al. 2005). Oak-woodlands occur on coarse-textured soils and are dominated by post oak (*Quercus stellata)* and blackjack oak (*Quercus marilandica)*, while finer-textured soils are dominated by tall-grass prairies. As this region is typically unsuitable for crops, rangeland and pastureland are the dominant land-uses. Mean annual precipitation within the study area increases eastward and varies from approximately 56 to 97 cm (Oklahoma Climatology Survey 2015).

We selected 30 lacustrine fringe wetlands along an anthropogenic disturbance gradient in central Oklahoma using ArcGIS 10.2 desktop application (Table 1). Surrounding land-use was based on the 2011 National Land Cover Dataset (NLCD), which classifies land-use types into 16 categories at a 30-meter scale (Homer et al. 2015). Lacustrine fringe wetlands were selected alongside reservoirs comprising at least five hectares of open water to reduce variability and assure that wetlands were adjacent to deepwater habitat (i.e., wetland hydrology maintained by lake levels). Wetlands were selected on both public and private land. A majority of the reservoirs on public land serve as recreational lakes and sources of drinking water, with some also serving to provide hydropower generation. To account for the size variability between individual wetlands, two wetlands were sampled within each reservoir. One wetland was positioned within a cove or concave area of reservoir's shoreline, resulting in a larger circular wetland, while the second wetland was characterized as a narrow strip on a convex curve, creating a much smaller, linear wetland. Lacustrine fringe wetlands were selected to represent a disturbance gradient from least-disturbed to most-disturbed condition. Placement into an *a priori* disturbance category (i.e., low, intermediate, and high disturbance) was based on a GIS desktop analysis to determine the degree of anthropogenic disturbance (e.g., impervious surface, nearby roads, point and non-point source runoff, etc.) impacting the wetland. Within each wetland, we selected an assessment area (AA) as a representative sample of the entire wetland. For wetlands comprising smaller than 0.5-hectare, the entire wetland was considered the AA. For wetlands larger than 0.5-hectare, the AA was defined by a 0.5-hectare circle randomly placed within the wetland (Sifneos et al. 2010).

Level 1 Assessment

We applied a well-established Level 1 assessment method, the Landscape Development Intensity Index (LDI), to define the condition of the 30 study wetlands for our validation analysis. LDI evaluates condition based on the types of land-use surrounding a wetland and each land-use type is assigned a predetermined coefficient based on the severity of anthropogenic disturbance (Brown and Vivas 2005). The LDI index has been calculated using multiple scales, including 100 m (Brown and Vivas 2005; Chen and Lin 2011), 200 m (Reiss et al. 2010), 1,000 m (Mack 2006; Margriter et al. 2014), and at the watershed scale (Nestlerode et al. 2014). Evaluating assessment methods across several scales may reduce errors associated with applying scales that are too broad or too narrow.

An LDI was calculated for each wetland within a 100 m, 500 m, and 1,000 m buffer using GIS desktop application. Within each buffer, the percentage of each land-use type was recorded (e.g., agricultural, residential, industrial, commercial, transportation, natural areas, and open water). Coefficients were assigned following Brown and Vivas (2005) and Mack (2006) (Table 2). Open water was excluded from the analysis to reduce the bias from the wetland's position within the reservoir. LDI scores range from 1 to 10, with 1 representing natural systems and 10 representing the highest anthropogenic disturbance. LDI scores were calculated as an area weighted average using the equation (Brown and Vivas 2005):

$$\mathrm{LDI}_{\mathrm{total}} = \%\mathrm{LU}_{\mathrm{i}} \times \mathrm{LDI}_{\mathrm{i}}$$

where LDI_{total} = LDI ranking for landscape unit (i.e. buffer zone or watershed), $\%LU_i$ = percent of the total area in land-use I, and LDI_i = LDI coefficient for land-use category i.

Level 2 Assessment

Between June and mid-August 2014, we conducted three RAMs (OKRAM, CRAM, and FACWet) at each of the 30 lacustrine fringe wetlands. A comparison table of RAM metrics is presented in Appendix D. At least two technicians consistently completed all three RAMs at each wetland, and repeatability was assessed by determining the difference between each individual's overall OKRAM score, attribute scores, and metric scores. Additionally, 10 wetlands were re-visited in the early-growing season of the following year (i.e., April-May 2015) to evaluate potential seasonal effects on OKRAM results.

OKRAM consists of nine metrics divided into three attributes (hydrologic condition, water quality, and biotic condition) and emphasizes the presence and severity of stressors within and adjacent to the AA. The hydrologic condition attribute focuses on alterations to the hydroperiod, water source impacts, and hydrologic connectivity. The water quality attribute assesses the input of excessive nutrients, sediments, and chemical contaminants and the ability of the surrounding buffer to reduce impacts. Lastly, biotic condition evaluates stressors to the vegetation community within the AA and the amount of contiguous habitat surrounding the wetland. Each individual metric is scored as a value between 0 and 1, and all metric scores are aggregated into an overall condition score ranging from 0 to 1, with 0 being complete degradation and 1 being ideal or a least-disturbed condition.

There is not a CRAM manual for lacustrine fringe wetlands, therefore we applied CRAM for depressional wetlands in each wetland. CRAM is comprised of ten metrics divided into four attributes: landscape, hydrology, physical structure, and biological structure. Each individual metric is given a letter grade of A, B, C, or D based on the narrative or numerical description that best fits the conditions observed at the time of assessment. Individual metric scores are aggregated into an attribute score, and attribute scores are then averaged to represent overall wetland condition. CRAM condition scores are calculated such that wetlands in the best condition (i.e., those providing multiple ecosystem functions) receive the highest overall scores. For a more detailed description of CRAM methods, refer to the CRAM depressional guidebook (Collins et al. 2013).

FACWet uses a stressor-based approach to evaluate a wetland's deviation from reference condition. As in OKRAM, when stressors are not identified, the wetland is assumed to represent the best possible ecological condition. Metrics are divided into eight attributes that target stressors to the habitat connectivity and surrounding area, hydrology, geomorphology, soil and water chemistry, and vegetation. Each metric is scored by selecting one of the five categories ranging from reference standard to non-functional. Reference standard refers to wetlands in a least-disturbed or pristine condition. Non-functional does not imply that the wetland has ceased all functionality, but rather it indicates that the wetland is in a state of extreme alteration from natural condition (Johnson et al. 2013). Metric scores are used to calculate seven functional capacity indices, which are then averaged into an overall condition score. For a more detailed description of FACWet metrics, refer to Johnson et al. (2013).

Level 3 Assessment

Level 3 assessments were conducted alongside RAM application and involved the collection of vegetation and soil data in each AA and macroinvertebrate and water quality data in each AA comprising at least 30% water. Vegetation community data were collected using a step-point method, in which transects were randomly placed throughout the wetland, and all plant species occurring at each meter were recorded (Smith and Haukos 2002). Within each wetland, a minimum of three transects were walked, totaling at least 150 sampling points. All transects were placed along the elevational gradient and terminated at the edge of the AA, deepwater habitat, or upland transition zone. Because AAs were not always the same shape or size, transect length was variable. All transects were traversed through the entirety of the AA to avoid sampling bias associated with discontinuing sampling midway through the wetland. This led to sampling more than 150 m of vegetation at several wetlands. When total transect length exceeded 150 m, we randomly selected 150 points from the total number of points sampled for inclusion in statistical analyses (Smith and Haukos 2002). All unknown plant species were collected, pressed, and identified to the lowest taxonomic group possible using dichotomous keys (Mohlenbrock 2005, 2006, 2008, 2010; Tyrl et al. 2009). For each wetland, we calculated species richness (SPR), native species richness (NSPR), Shannon-Weiner diversity (SWD), and the percent of wetland plants (i.e., facultative, facultative wetland, and obligate wetland species [%WET]).

We also calculated the Floristic Quality Index (FQI), a commonly applied vegetation method for evaluating wetland condition that is based on a species' tolerance to anthropogenic disturbance. The overall concept of FQI is that plant species differ in their fidelity to natural areas and in their ability to tolerate disturbance (Andreas and Lichvar 1995). Experts assign coefficients of conservatism (*C*-values) ranging from 0 to 10 to individual species based on the likelihood of the species to occur at a disturbed site within a particular region. Non-native and opportunistic species receive a value of zero, whereas species with a high degree of fidelity to sites in remnant condition are assigned a value of 10 (Andreas and Lichvar 1995). FQI was also calculated for each wetland using the following formula:

$$FQI = \left(\frac{\sum CC_i}{S}\right)\sqrt{S}$$

where *CC* is the coefficient of conservatism for species *i* and *S* is total species richness.

In each wetland, up to five dominant habitat cover types (i.e., comprising 10% or more of the entire AA) were identified as collection areas for macroinvertebrate, soil chemistry, and water quality data. Habitat cover types included areas dominated by a plant species (e.g., cattail [*Typha* spp.], black willow [*Salix nigra*], etc.), a specific functional group or structure (e.g., short emergent, short woody species, etc.), or open water. Macroinvertebrates were collected from dominant wet habitat cover types by sweeping a 500 µm mesh D-net within a 0.5 m^2 quadrat for 1 minute (USEPA 2002). At least two samples were collected from random locations within each habitat type, with a minimum of four samples collected per AA. The D-net was swept back and forth along the substrate, ensuring that all depths of the water column were sampled (Meyer et al. 2013). Obtaining samples within vegetated areas consisted of sweeping the D-net up and down vertically against the vegetation to assist with dislodging invertebrates. Samples were stored in 1-L polyethylene jars with 70% ethanol to preserve specimens. All macroinvertebrate samples were sorted, identified to appropriate taxonomic level, and counted (Stehr 1987; Smith 2001; Merritt et al. 2008; Thorp and Covich 2010). Twelve parameters were calculated for each wetland (percent of functional feeding groups [e.g., filterers, gatherers, shredders, and predators], percent of taxonomic groups [e.g., Diptera, Chironomidae, Oligochaeta, Ephemeroptera, Coleoptera, and Odonata], species richness (MSPR), and Shannon-Weiner diversity (MSWD).

One composite soil sample, which was comprised of five subsamples taken to a depth of 10 cm, was collected per wetland. Subsamples were taken from locations in proportion to the dominant habitat cover types. Soil samples were labeled, immediately placed on ice, and later stored at 4°C until processing. Samples were thoroughly mixed prior to being analyzed by the Oklahoma State Soil Water and Forage Analytical Laboratory for nitrate (NO_3), ammonium (NH_4), sodium (Na), phosphorus (P), pH, organic matter (OM), total soluble salts (TSS), and sodium adsorption ratio (SAR). P was extracted using the Mehlich III method, while Na was extracted using a 1:1 soil to water extraction. Both P and Na values were determined using inductively coupled plasma mass spectrometry. NO_3 and NH_4 were extracted using a 1M KCL extraction and calculated using a flow injection analyzer. Na, NO_3, NH_4, P, and TSS are presented as parts per million (ppm) dry weight. OM was calculated using a combustion analyzer and is presented as a percentage of dry weight.

One 1,000 ml composite water sample, comprised of five 200 ml samples, was collected per wetland. Subsamples were extracted from the middle of the water column using a polyethylene jar at locations proportional to the dominant habitat cover types. Water samples were immediately placed on ice and stored at 4°C until processing. A HACH CEL/850 environmental water quality kit was used to determine soluble reactive phosphorous (SRP), nitrate (NO_3), and ammonia (NH_3) in a laboratory at Oklahoma State University using methods in Standard Methods for the Examination of Water and Wastewater 20th Edition (APHA 1998). Additionally, physiochemical data including pH, dissolved oxygen, temperature, and conductivity were recorded using a YSI 556 multi-probe system (YSI Inc., Yellow Springs, Ohio, USA) at water collection sites. Turbidity was determined at these locations using a HACH 2100Q portable turbidimeter.

Validation Analysis

We evaluated the ability of OKRAM to accurately define wetland condition by comparing overall OKRAM, attribute, and metric scores with Level 3 intensive data using Spearman's non-parametric correlations in R version 3.2.2. (Crawley 2013; R Core Development Team 2015). Significant correlations in expected directions were interpreted as evidence of the method's ability to discern difference in wetland condition (Stein et al. 2009). Additionally, we examined the relationships between CRAM and FACWet scores and Level 3 data to determine if any additional metrics could improve OKRAM relationships. We evaluated the relationships between OKRAM and LDI scores to provide additional support for validation. Consistent relationships with LDI can demonstrate the ability of OKRAM to capture disturbance within the surrounding landscape. Additionally, wetlands were placed into reference (good), fair, and poor condition classes based on overall OKRAM scores. The 25th percentile of overall OKRAM scores for reference or least-disturbed wetlands was utilized as the threshold for the reference condition class and the 75th percentile of high disturbance wetlands as the threshold for the poor condition class (Sifneos et al. 2010).

RESULTS

Relationships between RAMs and Level 3 data

The relationships between RAMs and Level 3 data (e.g., vegetation, soil, macroinvertebrate, and water quality data) were evaluated to provide support for RAM validation. However, sufficient water for macroinvertebrate and water quality sampling was only present in 15 of the 30 lacustrine fringe wetlands. Nonetheless, we did not find consistent, relationships between OKRAM and Level 3 data to indicate the method is tracking wetland condition. For instance, there were no significant correlations between overall OKRAM scores and vegetation or macroinvertebrate data (Figure 2) and only a few significant relationships between soil data and OKRAM scores were noted (Na [ρ = - 0.614, P < 0.001], TSS [ρ = - 0.453, P = 0.01], and SAR [ρ = - 0.621, P < 0.001]). Additionally, there were few significant correlations between OKRAM attributes (hydrologic, water quality, and biotic condition) and Level 3 data (Table 3). For example, hydrologic condition scores were weak to moderately correlated with plant data (FQI [ρ = 0.387, P = 0.034], SPR [ρ = 0.423, P = 0.02], and NSPR [ρ = 0.445, P = 0.014]) and soil data (TSS [ρ = - 0.37, P = 0.044], Na [ρ = - 0.432, P = 0.02], and SAR [ρ = - 0.429, P = 0.018]). Water quality attribute scores were significantly correlated with two macroinvertebrate community metrics (% Chironomids [ρ = 0.604, P = 0.017] and % Diptera [ρ = 0.531, P = 0.042]) and water temperature (ρ = - 0.543, P = 0.036). Lastly, biotic condition displayed weak to moderate relationships with soil data (NO_3 [ρ = - 0.513, P = 0.004], Na [ρ = - 0.404, P = 0.027], and SAR [ρ = - 0.392, P = 0.032]).

We observed only a few weak to moderate significant relationships between overall CRAM scores and Level 3 data (macroinvertebrate SPR [ρ = 0.508, P = 0.05], water temperature [ρ = - 0.529, P = 0.045], and Na [ρ = - 0.363, P = 0.05]). Additionally, we observed only one significant relationship between overall FACWet scores and Level 3 data (water temperature [ρ = - 0.611, P = 0.018]).

Relationships between RAMs and LDI

We found significant, negative correlations between overall OKRAM scores and LDI at all three spatial scales (100 m [ρ = - 0.642, P = 0.0001], 500 m [ρ = - 0.664, P < 0.0001], and 1000 m [ρ = - 0.664, P < 0.0001; Figure 3). OKRAM attributes also displayed significant relationships with LDI at certain scales. For instance, we observed a weak relationship between hydrologic condition scores and LDI at 1,000 m (ρ = - 0.375, P = 0.04). In contrast, water quality and biotic condition scores were significantly correlated with LDI at all three spatial scales (Table 4). However, we did not find any relationships between LDI and several OKRAM metrics including hydroperiod, hydrologic connectivity, nutrients, sediments, chemical contaminants, and vegetation. We found similar correlations between overall CRAM scores and LDI (100m [ρ = - 0.544, P = 0.002], 500 m [ρ = - 0.561, P = 0.001], and 1,000 m [ρ = - 0.50, P = 0.005]). We observed weaker relationships between overall FACWet scores and LDI (100m [ρ = - 0.378, P = 0.039], 500 m [ρ = - 0.368, P = 0.045], and 1,000 m [ρ = - 0.247, P = 0.188]).

OKRAM Repeatability and Seasonality Analyses

OKRAM repeatability and seasonal influences were examined for both overall OKRAM scores and individual metric scores (Table 5). The average difference in the overall OKRAM scores of two evaluators was 1.7%, with the maximum difference for one site being 10.9%. All individual metrics had an average difference below 5%. We revisited 10 wetlands the following spring (i.e., early growing season) and compared overall OKRAM and metric scores to evaluate any seasonal influences on the method. The average difference between overall scores was 2.4% and the greatest difference observed at one site was 5.7%. Metrics with the greatest average changes between seasons were nutrients (4.7%), sediments (6.2%), and vegetation (10.5%).

DISCUSSION

OKRAM Validation

To validate a RAM within a wetland type, statistical analysis should reveal strong, consistent relationships between overall RAM scores, attribute scores, and metric scores with Level 3 data. RAM validations have implemented the weight-of-evidence approach in which multiple lines of evidence (i.e., several assemblages, such as vegetation, birds, and amphibians as well as a landscape assessment) are used to provide support for the ability of the RAM to effectively determine wetland condition (Stein et al. 2009).

The validation analysis of OKRAM in lacustrine fringe wetlands did not reveal consistent relationships with Level 3 data indicating the method is likely not able to provide accurate estimates of condition. The few significant OKRAM correlations may indicate that some metrics are appropriate for use in lacustrine systems, while others need to be modified. For instance, from the correlations of hydrologic condition with plant data (e.g., SPR, NSPR, and FQI) and soil data (e.g., TSS, Na, and SAR), we can infer that the attribute is detecting meaningful changes in condition. Through further investigation, we found that while the water source metric has a relationship with Level 3 data, the hydroperiod and hydrologic connectivity metrics did not exhibit a relationship with Level 3 data. From these results, we can conclude that the attribute is likely not detecting all of the hydrologic stressors having an impact on the wetland. Additionally, we found significant correlations between the water quality attribute and certain macroinvertebrate data (i.e., % Chironomids and % Diptera) and water temperature. However, based on the lack of relationships between the water quality attribute and any other macroinvertebrate or water quality data, OKRAM metrics within this attribute (i.e., nutrients, sedimentation, chemical contaminants, and buffer filter) are likely not capturing the full extent of disturbance within the wetland. Furthermore, a lack of correlation with plant and soil data suggests that we may be missing key stressors within these systems and/or metric severities (i.e. minor, moderate, or major) may need to be modified. Lastly, the biotic condition attribute only had weak to moderate relationships with soil data (e.g., NO_3, Na, and SAR). The lack of a relationship between biotic condition scores and plant or macroinvertebrate data can be explained in two scenarios: (1) the attribute is not detecting disturbance to the wetland biotic communities and needs to be modified or (2) plant and macroinvertebrate data collected for this study do not adequately represent the biotic condition within the wetland.

The limited or lack of relationships between Level 3 biological data and OKRAM can be attributed to several factors. First, it is important to recognize that reservoirs in Oklahoma are man-made, often highly regulated, and are not characterized by natural lacustrine fringe wetland systems. In fact, water level fluctuations in natural lakes are considered natural patterns necessary for the survival of many plant species and have been found to increase both productivity and biodiversity (Gafny et al. 1992; Gafny and Gasith 1999; Wantzen et al. 2002). For example, high lake levels may eliminate canopy-dominating emergent and woody species, but as water recedes, extremely low water depths expose areas of open mudflat and provide the opportunity for expansion of annual species and invasion of upland and woody species (Wilcox et al. 2002). In contrast, plant communities in regulated lakes tend to be less diverse, contain more exotic species, and are usually devoid of rare species, when compared to unregulated waterbodies (Hill et al. 1998). While natural water level fluctuations are known to have a positive impact on lacustrine fringe wetlands, some reservoirs undergo rapid and extreme water level fluctuations on several occasions throughout the season, which can also result in a stressed plant community (e.g., tree die off).

Stable water levels in manmade reservoirs can also alter the plant communities of lacustrine fringe wetlands. For example, reservoirs with highly stable water levels year-round commonly develop monocultures of competitive species, such as cattails (*Typha* spp.) and giant cutgrass (*Zizaniopsis miliacea*) (Wilcox et al. 1984; Shay et al. 1999; Albert and Minc 2004). We observed similarities in the species richness and diversity of lacustrine fringe plant communities regardless of local stressors (i.e., sedimentation, surface runoff, etc.), which may be the result of stable conditions provided by the reservoir. For instance, ten wetlands in highly disturbed areas (i.e., urban or agricultural landscape, excessive sedimentation, golf course runoff, etc.) had an average SPR of 24, and twelve wetlands in least-disturbed areas (i.e., minimal use recreation areas and private reservoirs) had an average SPR of 28. When assessing the health of wetlands, it is critical to assess the impacts of the hydroperiod and the reservoir's water levels on plant communities.

Wetland habitat for fauna, including invertebrates and fish, also undergoes substantial changes due to these water level fluctuations and changes in plant communities (McDonald 1955; Farney and Bookhout 1982; Keddy and Reznicek 1986). Wilcox et al. (2002) recognized that due to significant variations in lake levels and corresponding variations in wetland plant communities and fauna habitat, plant, invertebrate, and fish indices may not be reproducible throughout the year and between years. Furthermore, studies evaluating local and landscape stressors on wetland invertebrate communities have reached equivocal results. A recent study in depressional wetlands in western Oklahoma found local variables and sampling date to be more important than landscape variables when evaluating invertebrate communities (Meyer et al. 2015). Additionally, in lacustrine fringe systems, the influence of fish predation can play a significant role in the distribution and abundance of invertebrate communities. Between-site differences in invertebrate communities may result from variability in fish communities as well as the environmental determinants of fish predation rates, such as substrate and turbidity (Pierce and Hinrichs 1997). Our study highlights the need to further investigate the biological and physiochemical components of lacustrine fringe wetlands to determine which components would be appropriate to collect for future RAM validation in these systems.

Metric Calibration

We observed significant relationships between overall OKRAM and attribute scores and LDI at all three spatial scales. From these results, we can infer that OKRAM metrics (e.g., water source, nutrients, sedimentation, and habitat connectivity) are capturing disturbance within the surrounding landscape. Although we found relationships with LDI, a lack of evidence and support from the validation with Level 3 data indicates that OKRAM is not effectively discerning condition in lacustrine fringe wetlands.

While OKRAM metrics are capturing landscape stressors (e.g., nearby agricultural and urban land-use), it appears that the metrics developed and applied in depressional wetlands do not appropriately characterize the hydrological condition of lacustrine fringe wetlands. Hydrological differences between natural and manmade wetlands are an important consideration for wetland assessment methods and should be addressed in future versions of OKRAM, as well as for any RAMs developed for lacustrine fringe wetlands associated with manmade reservoirs. We aim to incorporate a hydrologic metric that evaluates lake water levels through direct observation and information obtained online from state monitoring programs in a future version of OKRAM for lacustrine fringe wetlands.

The location of lacustrine fringe wetlands within the reservoir relative to the dam may also be an important consideration for assessing wetland condition. Water chemistry differs depending on the location within the reservoir (Jones and Knowlton 1993). For example, water quality near the stream inflow differs from water quality within the down-lake zone near the dam, where in-reservoir processes (e.g., sedimentation, uptake, and dilution) have altered the chemistry of inflow from the catchment. It may be important to determine if the wetland's location (i.e., near the dam vs. near the stream inflow) is impacting sedimentation rates and nutrient loading. Additionally, Jones et al. (2004) found that flushing index, which is the inflow volume relative to reservoir volume, explained some of the variation in total phosphorus among sample sites in Missouri reservoirs. These results suggest that the ratio of the watershed to the lake surface area, along with wetland location within the reservoir, could be important factors to integrate into the water quality attribute (i.e., nutrient and sedimentation metrics) in lacustrine fringe wetland assessments.

In addition to modifying hydrology metrics, we found the buffer metric to be inappropriate for lacustrine fringe systems. The metric currently calculates the percentage of buffer based on land-use types occurring in the cardinal and ordinal directions around the AA. Lacustrine fringe wetlands by definition are adjacent to deep water; thus, if open water is considered a suitable buffer, there is a significant bias based on the amount of water surrounding each wetland. The metric should be modified to estimate buffer similar to CRAM, in which open water is considered neutral and is excluded from the assessment (Collins et al. 2013). Additionally, many reservoirs are surrounded by vegetated recreational areas that are frequently mowed and often comprised of invasive or exotic species. The current version of OKRAM does not consider these areas as suitable buffer, which results in similarly low buffer metric scores across the majority of lacustrine fringe wetlands. Further research is needed to determine the buffer potential of these vegetated areas to reduce the impact of urban and agricultural runoff on water quality and wetland condition.

Site Selection

In addition to modifying OKRAM metrics, wetland site selection along the entire disturbance gradient (i.e., reference, fair, and poor condition) is a critical component for RAM calibration. Wetlands were initially selected based on the extent of urban and agricultural impacts within the watershed via desktop analysis, but more consideration should be given to localized stressors within or adjacent to the wetland. For instance, several sites that were considered to be in reference condition based on an *a priori* desktop classification (i.e., minimal urban and agricultural use within the watershed) were later found to be in poor condition due to on-site stressors (e.g., presence of cattle, excessive sedimentation, etc.). With several of our *a priori* reference condition sites actually representing fair or poor condition, we were not able to sample the entire disturbance gradient. In future calibration analyses for lacustrine fringe wetlands, we recommend thorough site reconnaissance to confirm that high quality wetlands are being sampled. Further consideration in site selection should include wetlands along stable reservoirs and wetlands in areas with extreme water level fluctuations to assess the significance of this stressor on plant communities and wetland functions.

Repeatability and Seasonal Effects

Using the 10% repeatability threshold established in Stein et al. (2009), all OKRAM metrics were deemed repeatable. Metrics with the greatest differences in scores between evaluators were hydroperiod, hydrologic connectivity, vegetation, and habitat connectivity. The hydroperiod metric accounts for alterations to the wetland's hydrology. Evaluators were inconsistent in their determination of the severity at which services provided by the reservoir (e.g., drinking water, hydropower generation, etc.) may impact the hydroperiod. Additionally, hydrologic connectivity metric, which refers to the wetland's connectivity with the surrounding upland, exhibited differences between practitioners due to inconsistencies when scoring the metric based on the presence of nearby impervious surface, riprap, and steep banks. Providing more clarification of these stressors, including photos and descriptions, could greatly improve the repeatability of this metric. We also found inconsistencies with the vegetation metric that derived from differences in the evaluators' estimations of percent cover of invasive species. Providing lists of commonly found invasive species within particular ecoregions and comparative charts for estimating percent cover could increase user consistency. Lastly, habitat connectivity, which estimates the amount of contiguous habitat surrounding a wetland, could be improved by providing additional guidelines for other land-uses (e.g., hay meadows) that are not currently considered for this metric. In general, providing additional guidance for each metric through the development of an OKRAM guidebook will certainly increase the method's repeatability. Furthermore, providing training opportunities and workshops will also increase consistency among users and ensure OKRAM metrics are interpreted correctly (Sutula et al. 2006; Herlihy et al. 2009).

We did not observe a significant seasonal influence on the majority of OKRAM metrics. In some instances, the differences we observed between spring and summer assessments were reflecting actual changes in wetland condition (e.g., vegetation removal through mowing or haying, an increase in invasive species, etc.). These changes may be a response to different management practices at different times of the year. However, we did observe differences that can be attributed to seasonal influence. For example, three of the 10 revisited wetlands had an increase in sedimentation likely due to increased precipitation and runoff in the spring. We also found a significant seasonal influence on the nutrient metric (i.e., 30% score difference) for two wetlands due to extensive algal blooms in late summer that were no longer present in spring of the following year. We recognize that the absence of algae at one time does not imply absence of excess nutrients, but rather that the method is only detecting it when algae is present. As we continue to modify the method, we will continue examining additional indicators of stress and impairment. Because OKRAM metric scores are aggregated into a single condition score, the minor differences observed for some metrics had little impact on overall scores. Our results suggest that OKRAM is not significantly influenced by seasonal differences and can be applied at different times throughout the year.

OKRAM and other RAMs

We did not observe consistent relationships between CRAM and FACWET and Level 3 data. There was no evidence to support that either of these two methods are able to detect condition in these wetlands. When analyzing score distributions, overall OKRAM scores ranged from 0.61 to 0.92, CRAM scores ranged from 0.52 to 0.80, and FACWet scores ranged from 0.72 to 0.96 (Figure 4). These narrow score ranges are likely a result of the inability of the RAMs to detect condition in lacustrine fringe wetlands, and our site selection did not encompass the entire disturbance gradient. Despite our intensive reconnaissance efforts, we were unable to sample a sufficient number of least-disturbed or most-disturbed wetlands. It is possible that lacustrine fringe wetlands on both ends of the disturbance gradient may be rare due to water levels being highly regulated in many of the reservoirs, resulting in many of the these wetlands being moderately impacted. Further investigation is needed into the existing disturbance gradient for lacustrine fringe wetlands to determine potential sample wetlands for future calibration.

CRAM typically scores wetlands lower than both OKRAM and FACWet, which is likely due to the high significance that the method places on wetland complexity (e.g., topographic complexity, plant structural complexity, structural patch richness, etc.). Wetlands generally had low plant structural complexity and interspersion, which decreased overall scores. CRAM acknowledges that the method may not perform well in low-complexity seasonal wetlands (Collins et al. 2013). Plant communities of lacustrine fringe wetlands are closely tied to water table levels and the frequency of inundation, which often results in linear strips of plant species (Wilcox et al. 2002). Obligate wetland species (e.g., pondweeds [*Potamogeton* spp.], spikerushes [*Eleocharis* spp.]) occur near frequently inundated areas and species less dependent or tolerant of water grow outward towards the uplands (Cronk and Fennessy 2001). Even when these wetlands have high plant species richness and diversity, the communities are typically not interspersed and have low structural complexity.

FACWet scores were not shown to be effective in assessing lacustrine fringe wetlands in Oklahoma. The FACWet scoring procedure differs from OKRAM in that each variable in FACWet is scored by determining which category captures the wetland's condition (e.g., reference standard [0.9 to 1.0], highly functioning [0.8 to 0.9], functioning [0.7 to 0.8], functioning impaired [0.6 to 0.7], and non-functioning [< 0.6]; Johnson et al. 2013). FACWet variables are typically scored between 0.5 and 1.0, as scores less than 0.5 are rare, indicating a complete loss of wetland function. This differs significantly from OKRAM where the potential scoring range for each metric is 0 to 1.0. The FACWet narrow score range could partially explain why we found stronger correlations with OKRAM and CRAM and LDIs at all three spatial scales.

CONCLUSION

RAMs provide a consistent, affordable approach for the evaluation of wetland condition. However, without proper validation, methods can overstate or understate actual wetland condition (Fennessy et al. 2007). Because RAMs may be applied for wetland regulatory and management purposes, misleading assessment results can have serious implications for wetland protection, restoration, and mitigation. If RAMs have not been validated within the wetland class or location of concern, methods may underestimate the condition of high quality wetlands, resulting in fewer mitigation requirements. In this case, valuable wetlands could be removed from the landscape without appropriate mitigation and restoration to offset wetland loss.

Our calibration and validation analyses of OKRAM in lacustrine fringe wetlands did not provide support for the ability of the method to detect condition within these systems. The current version of OKRAM is not applicable in lacustrine fringe wetlands, but based on our initial assessment results, we were able to determine key stressors of these wetlands (e.g., impact of stable water levels of reservoirs and fluctuating hydroperiods due to significant withdrawal from reservoirs on wetland functions and plant communities) that OKRAM is not currently detecting. Further refinement of existing metrics (e.g., hydroperiod, hydrologic connectivity, buffer filter, etc.) and the incorporation of additional metrics (e.g., accounting for the location of the wetland within the reservoir, the ratio of the watershed to the lake surface area, etc.) may allow us to better assess the condition of lacustrine fringe wetlands. We also recommend further investigation into the occurrence of a wider range of disturbance gradients on the landscape as our efforts were initially hampered by the lack of extremes along the disturbance gradient for calibration. Specifically, wetlands at both ends of the disturbance gradient (i.e., highly degraded and pristine sites) need to be sampled. It is possible that lacustrine fringe wetlands only exist in moderately disturbed sites due to the nature of Oklahoma's man-made and often highly managed reservoirs. Lastly, further refinement of OKRAM and future validation analyses would be aided by additional information on the relationship between plant and invertebrate communities and water quality degradation from surrounding land-use practices.

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FIGURES AND TABLES

Figure 1: Map of the study area and locations of the 30 lacustrine fringe wetlands sampled in 2014 within the Central Great Plains and Cross Timbers ecoregions.

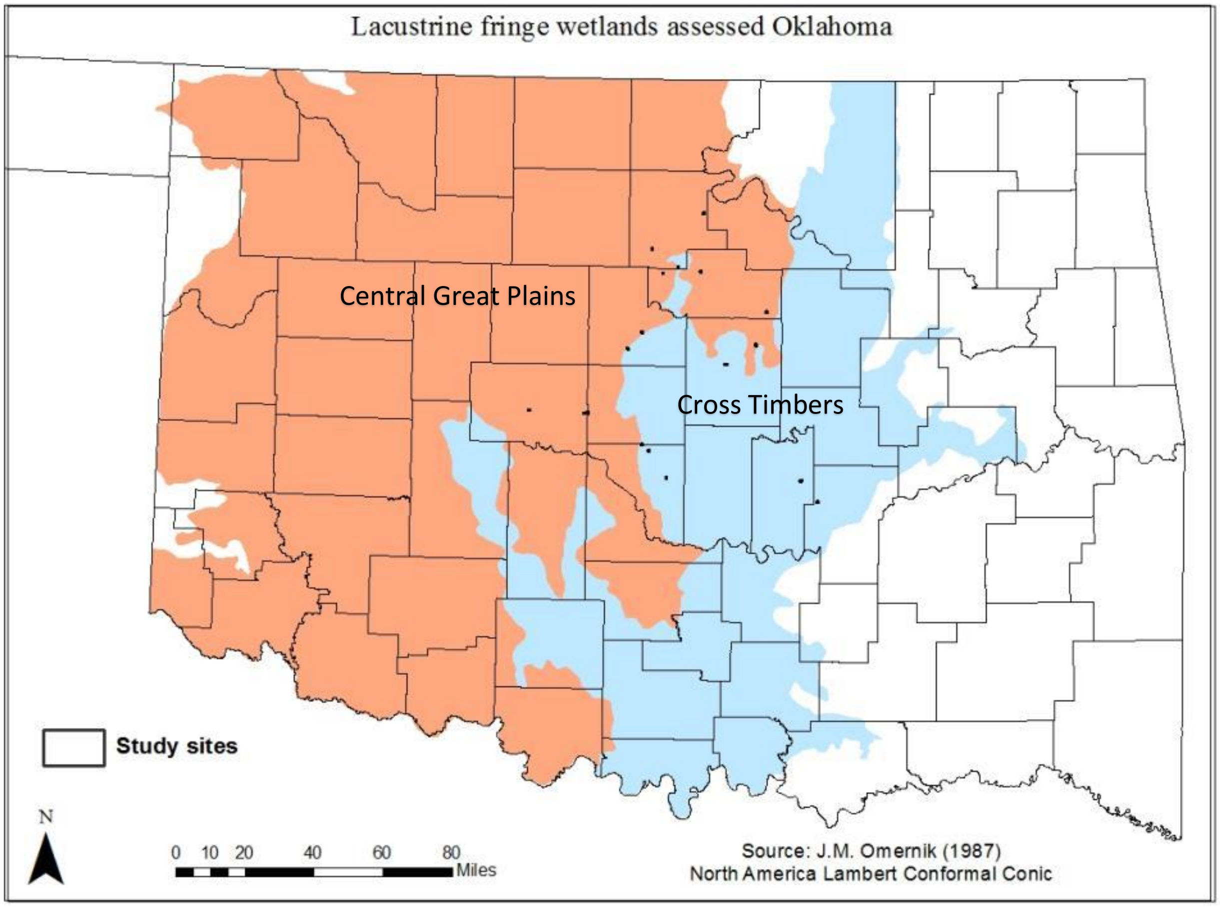

Figure 2: Relationships between Oklahoma Rapid Assessment Method (OKRAM) overall scores and biotic attribute scores with a) plant species richness, b) native species richness, and c) Floristic Quality Index for lacustrine fringe wetlands. Correlations are presented in terms of Spearman's r (*ρ*).

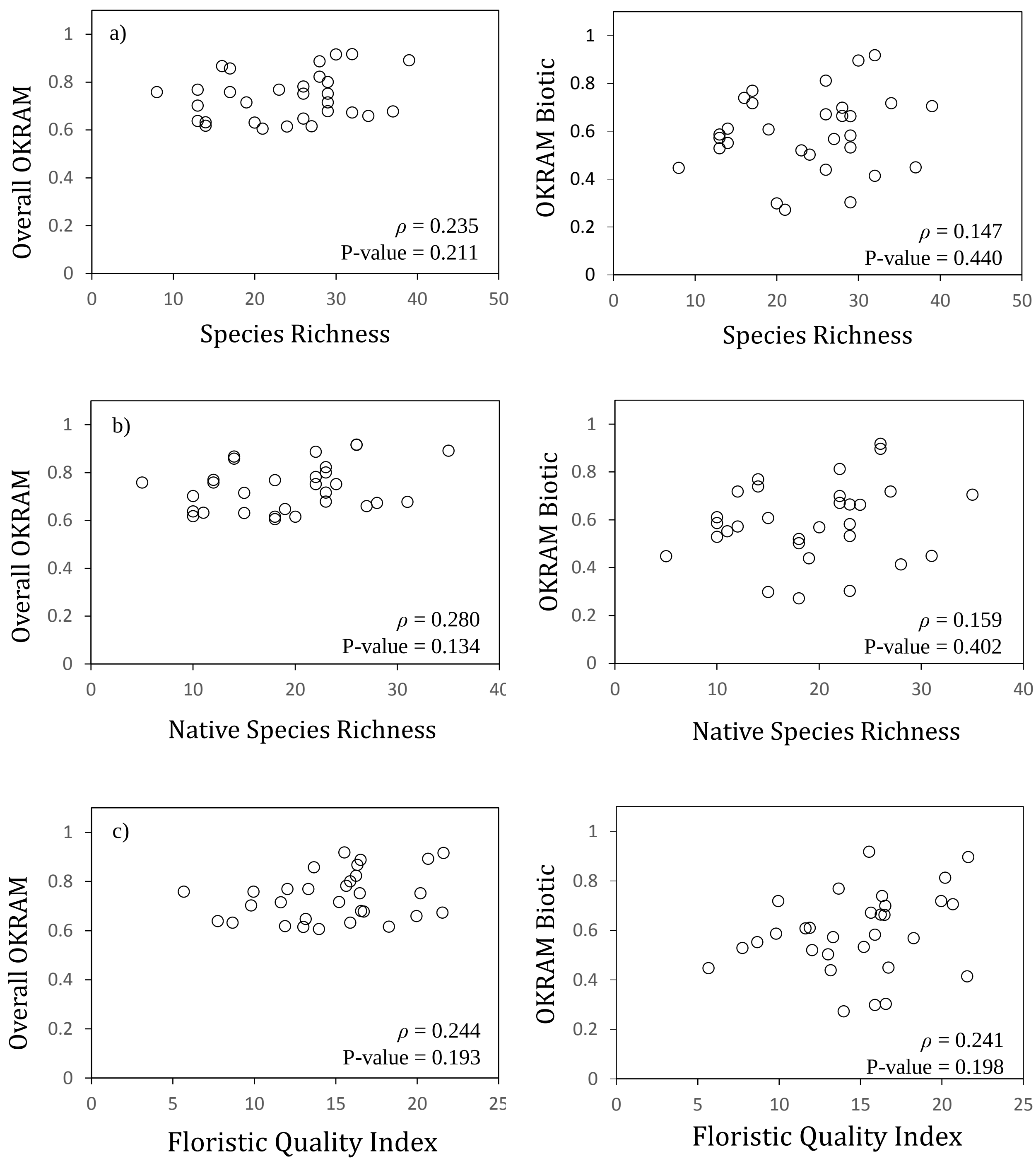

Figure 3: Relationships between Oklahoma Rapid Assessment Method (OKRAM) overall scores and Landscape Development Intensity Index scores at 100 m, 500 m, and 1,000m buffers around lacustrine fringe wetlands. Correlations are presented in terms of Spearman's r (ρ).

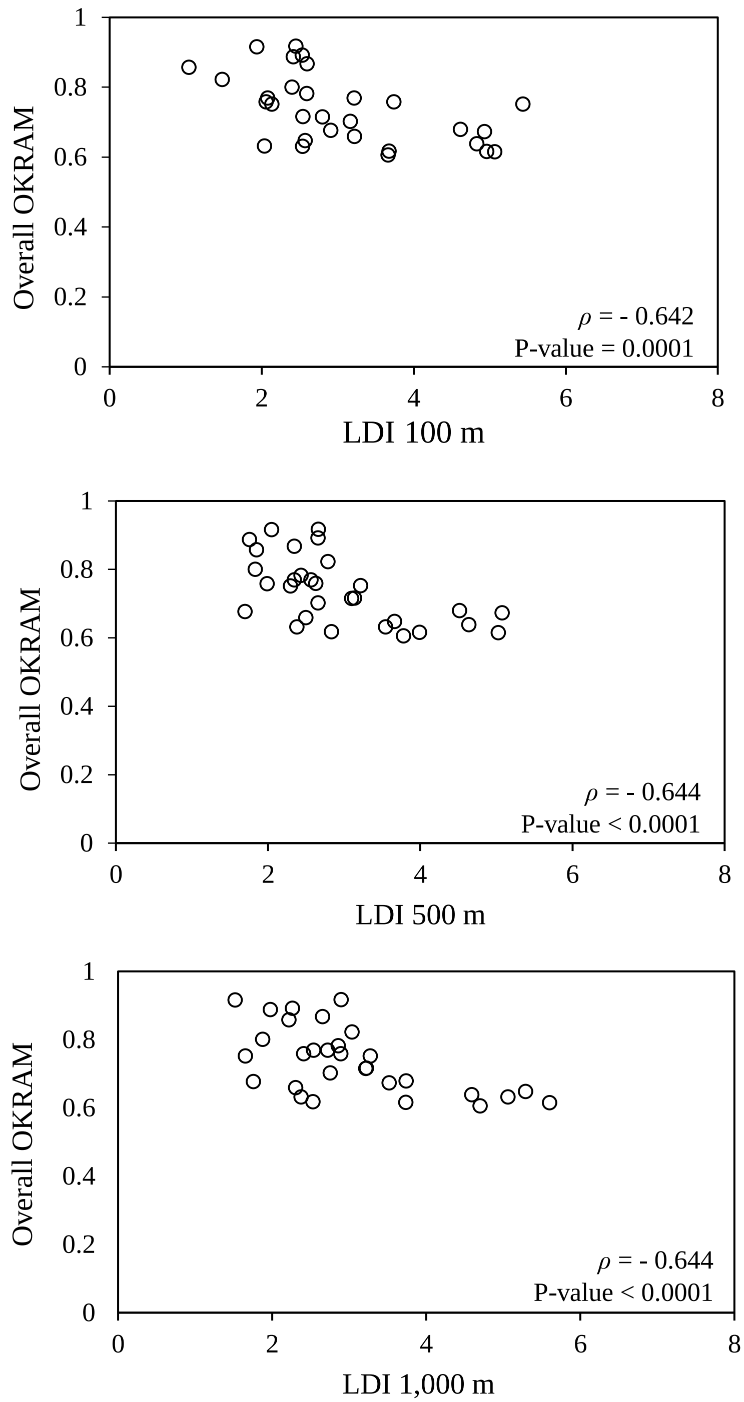

Figure 4: Distributions of rapid assessment method scores for 30 lacustrine fringe wetlands assessed in 2014, a) Oklahoma Rapid Assessment Method (OKRAM), b) California Rapid Assessment Method (CRAM), and c) Functional Assessment of Colorado Wetlands (FACWet).

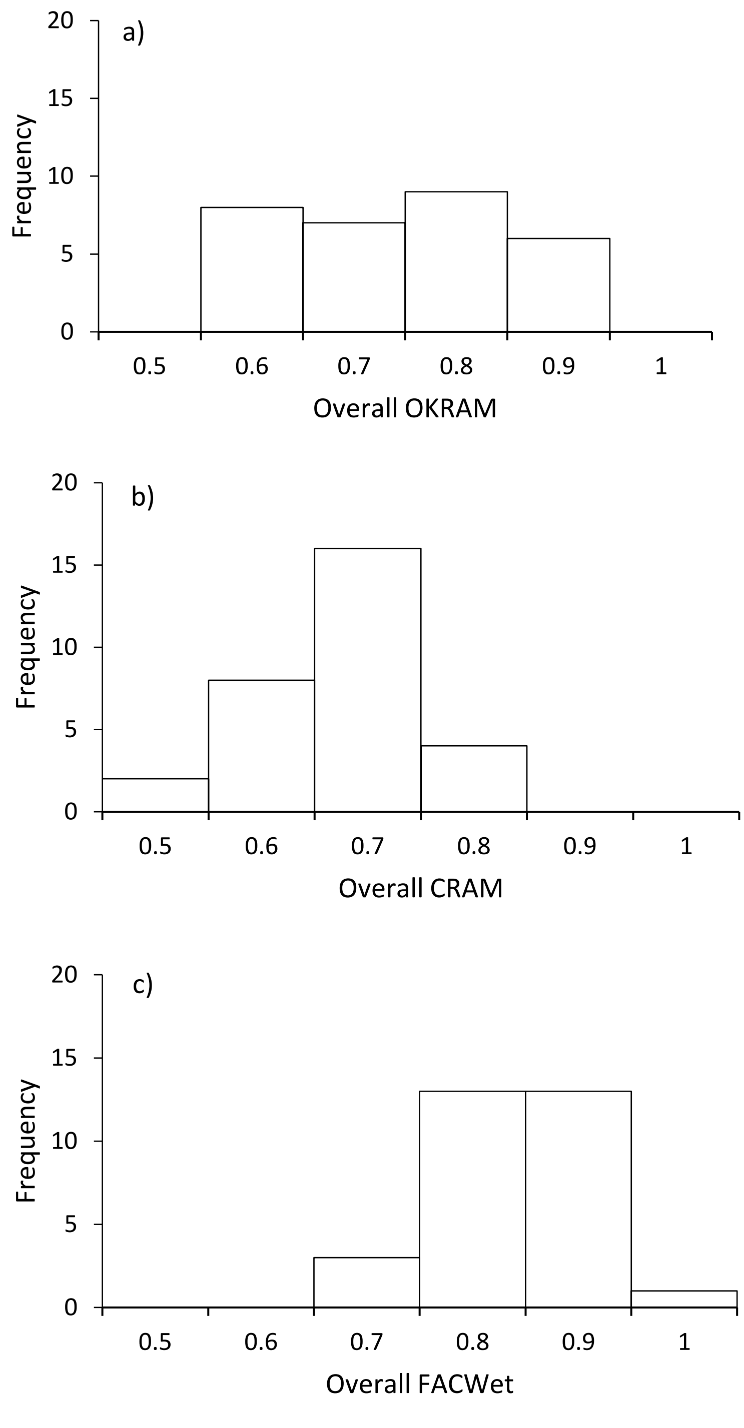

Table 1: Descriptions of lacustrine fringe wetlands sampled in 2014 in Oklahoma. Wetlands are categorized by *a priori* classification, which is based on land-use types within the surrounding landscape. Reference represents best attainable condition with minimal anthropogenic disturbance and no hydrological alterations, fair condition wetlands occur in moderately disturbed landscapes, and poor condition wetlands represent highly altered systems (e.g., agricultural or urban landscapes).

A priori **Classification**	**Number of Wetlands**	**Size Range (ha)**	**Mean Size (ha)**
Reference	12	0.09 - 0.50	0.23
Fair	10	0.07 - 0.68	0.32
Poor	8	0.03 - 1.10	0.31

Table 2: Oklahoma land-use classes defined by National Land Cover Database (NLCD) and corresponding coefficients used to calculate Landscape Development Intensity Index (LDI) scores in this study (Brown and Vivas 2005; Mack 2006)

Land-Use Classification	**LDI Coefficient**
Natural System	1.00
Open Water	1.00
Pasture	3.41
Developed, Open Space	6.92
Cropland	7.00
Developed, Low Intensity	7.55
Barren Land	8.32
Developed, Medium Intensity	9.42
Developed, High Intensity	10.00

Table 3: Relationships between Oklahoma Rapid Assessment Method (OKRAM) attributes and overall scores with Level 3 data based on Spearman's rank correlation (ρ) for lacustrine fringe wetlands. Level 3 data includes species richness (SPR), native species richness (NSPR), Floristic Quality Index (FQI), soil pH, soil sodium (Na), soil ammonium (NH4), soil nitrate (NO3), total suspended solids (TSS), sodium absorption ratio (SAR), and water temperature (WTemp). Level 3 data also includes macroinvertebrate metrics % shredders, % Chironomidae (%Chiron), and % Diptera. All relationships that are significant at $\alpha = 0.05$ level are shown.

OKRAM	**Level 3 Metric**	ρ	**P-value**
A1: Hydrologic Condition	SPR	0.423	0.020
	NSPR	0.445	0.010
	FQI	0.387	0.034
	Soil pH	-0.435	0.016
	Na (ppm)	-0.429	0.018
	TSS	-0.370	0.044
	SAR	-0.423	0.020
	% Shredders	0.600	0.018
	NH_3	0.615	0.015
A2: Water Quality	SAR	-0.372	0.043
	% Chiron	0.604	0.017
	% Diptera	0.531	0.042
	WTemp	-0.543	0.036
A3: Biotic Condition	Soil NO_3 (ppm)	-0.513	0.004
	Na (ppm)	-0.404	0.027
	SAR	-0.392	0.032
Overall OKRAM	Na (ppm)	-0.614	<0.001
	TSS	-0.453	0.010
	SAR	-0.621	<0.001

Table 4: Relationships between the Landscape Development Intensity Index (LDI) at three spatial scales (e.g., 100 m, 500 m, and 1,000 m) and the Oklahoma Rapid Assessment Method (OKRAM) attributes (i.e., hydrologic, water quality, and biotic condition), overall OKRAM, California Rapid Assessment Method (CRAM), and Functional Assessment of Colorado Wetlands (FACWet) scores for lacustrine fringe wetlands. Correlations are presented in terms of Spearman's r (*ρ*).

LDI	**Level 2: RAMs**	***ρ***	**p-value**
LDI 100m	A1: Hydrologic Condition	-0.351	0.057
	A2: Water Quality	-0.506	0.004
	A3: Biotic Condition	-0.451	0.012
	Overall OKRAM	-0.642	0.0001
	Overall CRAM	-0.544	0.002
	Overall FACWet	-0.378	0.039
LDI 500m	A1: Hydrologic Condition	-0.330	0.072
	A2: Water Quality	-0.573	0.001
	A3: Biotic Condition	-0.557	0.001
	Overall OKRAM	-0.664	< 0.0001
	Overall CRAM	-0.561	0.001
	Overall FACWet	-0.368	0.045
LDI 1,000m	A1: Hydrologic Condition	-0.375	0.040
	A2: Water Quality	-0.550	0.002
	A3: Biotic Condition	-0.554	0.002
	Overall OKRAM	-0.664	< 0.0001
	Overall CRAM	-0.500	0.005
	Overall FACWet	-0.247	0.188

Table 5: Two practitioners applied the Oklahoma Rapid Assessment Method (OKRAM) within 30 lacustrine fringe wetlands in central Oklahoma in 2014. Repeatability was evaluated as the average difference and the maximum difference between the scores of two practitioners. Ten of the 30 sites were revisited in the early growing season of 2015. Seasonal differences were assessed as the average and maximum difference in scores between spring and summer assessments.

OKRAM Metrics and Attributes	**Avg. Practitioner Difference (%)**	**Max. Practitioner Difference (%)**	**Avg. Seasonal Difference (%)**	**Max. Seasonal Difference (%)**
Hydroperiod	2.1	20.0	3.9	20.0
Water Source	2.5	9.8	0.9	2.0
Hydrologic Connectivity	2.9	43.0	1.8	7.0
Attribute 1: Hydrology	2.1	14.3	1.6	6.5
Nutrients	1.4	10.0	4.7	30.0
Sediments	1.7	15.0	6.2	22.5
Chemical Contaminants	0.1	3.8	0.0	0.0
Buffer Filter	0.8	12.5	0.3	2.5
Attribute 2: Water Quality	0.9	5.3	2.8	9.7
Vegetation	5.0	34.8	10.5	25.2
Habitat Connectivity	3.7	14.6	4.5	10.7
Attribute 3: Biotic Condition	4.1	18.5	6.6	15.6
Overall OKRAM Score	1.7	10.9	2.4	5.7

CHAPTER III

EVALUATING THE EFFECTIVENESS OF FLORISTIC QUALITY ASSESSMENT AS A TOOL FOR DETERMINING THE CONDITION OF DEPRESSIONAL WETLANDS IN OKLAHOMA

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Abstract: Floristic Quality Assessment (FQA) has been recognized as a useful tool for evaluating wetland condition and guiding conservation and management efforts. However, with no standard protocols established, methodologies, including the calculation of FQA metrics (Mean *C* and Floristic Quality Index [FQI]), are inconsistent across studies. In addition, FQA has not always undergone a validation analysis to confirm that results represent actual wetland condition. Furthermore, FQA results are assumed to be valid across large regions, despite areas of high environmental variability (e.g., temperature, precipitation, topography, etc.). Given the diverse ecoregions and environmental gradients across the state, Oklahoma provides an opportunity to examine spatial variation and environmental influence on FQA results. We sampled 68 depressional wetlands dispersed across the state to (1) evaluate the effectiveness of two methods of plant collection (e.g., transects and five-minute survey) and four metric calculations (e.g., with and without non-natives and species cover) for conducting FQAs, (2) validate FQA with two established methods (e.g., Landscape Development Intensity Index [LDI] and Oklahoma Rapid Assessment Method [OKRAM]), and (3) evaluate the influence of environmental variation (e.g., high and low precipitation) on FQI scores. When comparing FQIs from transect data with those from transects and the additional plant survey, we found that FQI scores increased significantly with increasing sampling effort. We also found that FQI scores were significantly lower when including non-native species compared to using only natives ($P < 0.0001$), but we found no significant differences when including species cover data for all species ($P = 0.883$) or for only natives ($P = 0.304$). In our validation analysis, we found strong positive relationships between FQIs and OKRAM to indicate the method can detect changes in depressional wetlands along a disturbance gradient. Additionally, strong negative relationships observed between FQI and LDI suggest that the method is effective at detecting stressors within the surrounding landscape. When evaluating environmental influence on FQI scores, we found substantial variation between reference wetlands based on location, with higher scores occurring in eastern sites (high precipitation) and lower scores occurring in western sites (low precipitation). We used Canonical Correspondence Analysis (CCA) to assess the relationship between plant communities and environmental variables, and found that precipitation was the single most important driver in the distribution of plant species. Our results demonstrate that wetland plant communities can differ based on environmental gradients regardless of wetland condition. This phenomenon highlights the importance of considering regional environmental differences when developing FQI thresholds for wetland assessments, especially across diverse states or regions. To reduce the influence of regional differences on FQIs, as well as other vegetation-based methods, condition class thresholds and reference criteria can be established based on ecoregions and use HGM guidance to minimize variation between wetland types.

Key Words: Depressional Wetlands, Environmental Gradients, Floristic Quality Assessment, Floristic Quality Index, Reference Condition
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INTRODUCTION

Assessment methods have become essential tools for state and federal agencies to evaluate the ecological integrity of wetlands and to make informed decisions to guide wetland conservation and management efforts. Specifically, assessment methods can be applied to track broad trends in wetland health, prioritize wetlands for protection and restoration, and determine mitigation needs if wetlands are degraded or removed from the landscape (Fennessy et al. 2007). Additionally, these methods provide agencies with the ability to comply with monitoring requirements for compensatory mitigation wetlands (National Research Council 2001; USACE 2002). Assessment methods often rely on ecological indicators to evaluate condition (Mack et al. 2004; Niemi and McDonald 2004), with vegetation being one of the most commonly used indicators (Cronk and

Fennessy 2001; USEPA 2002). Plant communities are known to respond to anthropogenic disturbance in predictable ways (Taft et al. 1997), making them a reliable indicator of wetland condition. For example, plant communities typically decrease in species richness and diversity as human disturbance (e.g., excessive sedimentation, nutrient enrichment, altered hydrology) within and surrounding a wetland increases (Jurik et al. 1994; Mahaney et al. 2003a, 2003b; Zedler and Kercher 2004). Furthermore, anthropogenic disturbance often results in a plant community shifting to favor those species (e.g., annuals, non-natives, and invasives) more tolerant of disturbance (van der Valk 1981; Thompson et al. 1987; Hobbs and Huenneke 1992).

Wetland condition has been evaluated using a wide range of assessment methods including Rapid Assessment Methods (RAMs) and Indices of Biotic Integrity (IBIs) for bird, invertebrate, and plant communities; however, one method based on floristic quality has become especially popular for combining measures of species richness and plant tolerances to disturbance (Bried et al. 2013). The Floristic Quality Assessment (FQA) was originally developed by Swink and Wilhelm (1979, 1994) to assess prairies and undeveloped land within the Chicago Region, but it has since become widely used to evaluate wetland condition in many states (Ladd 1993; Andreas and Lichvar 1995; Herman et al. 1997; Taft et al. 1997; Freeman and Morse 2002; Bernthal 2003; Rothrock 2004; Herman et al. 2006). The premise of FQA is that conservative species are less tolerant of anthropogenic disturbance and as such, the proportion of conservative species within a wetland can provide a metric for the severity of human disturbance (Wilhelm and Ladd 1988; Lopez and Fennessy 2002; DeKeyser et al. 2003). To calculate FQA metrics (e.g., Mean *C* and Floristic Quality Index [FQI]) experts assign a coefficient of conservatism (*C*-value) to each plant species based on its fidelity to high quality remnant habitats that represent unaltered conditions (Swink and Wilhelm 1994; Taft et al. 1997).

Although FQA has been established as a reliable method to evaluate wetland condition, there are limitations associated with plant-based indices, as well as inconsistencies in methodologies used across studies to determine FQI scores. For instance, a complete list of plant species representative of the entire wetland is required to compute FQA metrics (Herman et al. 1997; Taft et al. 1997), but obtaining such data typically requires rigorous and time-consuming sampling efforts as well as additional resources. Furthermore, *C*-values are assigned at the species level, and at times at the variety and subspecies level, which requires that each plant species must be identified to its lowest taxonomic level (USEPA 2002; Chamberlain and Brooks 2016). Unfortunately, such botanical expertise is typically not available, which is a confounding issue with using FQAs (Johnston et al. 2008). Plant-based indices are also limited by when sampling occurs because differences in phenology and growth of plants influence detection and identification of plant species (Andreas et al. 2004). In fact, FQI scores tend to increase with sampling date throughout the growing season (Matthews 2003), which emphasizes the importance of following standardized protocols (e.g., conduct plant surveys within the same time period or conduct multiple surveys throughout the growing season) to reduce inconsistencies in sampling methods and metric calculations that may limit comparisons of FQI scores (Lopez and Fennessy 2002).

FQA results are presumed to be independent of location across the regions in which they are applied, which typically occurs at the state level (Spyreas 2014). Because of this presumption, statewide implementation of FQA implies that natural variation is neutral, and differences in scores reflect meaningful changes in floristic quality and wetland condition (Spyreas 2014). However, plant community distributions are not restricted to state boundaries, and are known to vary considerably across ecological gradients (Pearman et al. 2006; Muratet et al. 2008), even in relatively undisturbed landscapes (Pickett and Parker 1994; Morgan and Short 2002). FQA has been effective in evaluating wetland condition across many states, but a number of studies have reported variable and inconsistent performance of FQA across large geographic regions (Nichols 1999; Reiss 2006; Johnston et al. 2010). For example, Reiss (2006) found that FQI scores for reference depressional wetlands in Florida varied among locations, with higher FQI values in the Panhandle and in the north and lower values in the south and central regions. Variations in scores between locations were attributed to both environmental conditions (e.g., climate) and human disturbances (e.g., increased development intensity, increased drainage, etc.) in the south and central regions. Score variations across regions due to environmental gradients emphasize the need to calibrate and apply methods using biological indicators on a regional level, with best reference condition sites observed within each region (Karr and Chu 1997). If assessment methods are not calibrated across the entire state, wetlands prone to lower scores could be unintentionally disfavored for protection and mitigation (Spyreas 2014). To be effective, wetland assessments should indicate the degree of anthropogenic disturbance and should not be confounded by temporal or spatial variation or by natural disturbance (e.g., flooding, drought, wildfires, and hurricanes).

Objectives

Despite FQA metrics being successfully applied in many states, there are no standard protocols established for plant data collection and metric calculation. Additionally, metric calculations for Mean *C* and FQI will vary based on the inclusion or exclusion of non-native species and the incorporation of species cover data. With different FQA calculations likely producing different results, our first objective was to evaluate the effectiveness of two methods of plant data collection (e.g., transects vs. transects plus a five-minute survey) for FQA and four FQI metrics. With Oklahoma currently in the process of developing assessment methods to evaluate the condition of all wetlands across the state, methods must be validated with independent measures of wetland condition statewide prior to integration within a monitoring and assessment program. Bried et al. (2014) conducted a validation of FQA in Oklahoma with a Level 1 assessment, the landscape development intensity index (LDI). Our second objective is to provide additional validation support for FQA application in depressional wetlands across Oklahoma using LDI and an established Level 2 method, the Oklahoma Rapid Assessment Method (OKRAM). Validation with OKRAM, a method conducted on-site, allows for consideration of local factors that may be overlooked by the landscape level assessment. Additionally, with other studies indicating varying FQA results across large geographic regions, our third objective was to evaluate the method's performance across Oklahoma. Given the diverse ecoregions and variable precipitation gradient across the state, this provides an excellent opportunity to examine spatial variation and the influence of environmental gradients on FQA results. Lastly, given the results from our three objectives, we provide recommendations for using FQA as a wetland assessment tool in Oklahoma.

METHODS

Study Area

The study area encompasses a large portion of Oklahoma that includes five Level III ecoregions (Central Great Plains, Cross Timbers, Central Irregular Plains, Arkansas Valley, and South Central Plains Ecoregions; Figure 1). Ecoregions range from a dry-subhumid area mostly underlain with red, Permian-age sedimentary rock and predominantly mixed-grass prairie and riparian forests in the Central Great Plains to uplands with oak-hickory-pine forests and bottomlands in floodplains in the South Central Plains (Woods et al. 2005). Land use varies across the state with agriculture dominating in western Oklahoma and areas of urbanization and pastureland more common in central and eastern Oklahoma (Omernik 1987; Woods et al. 2005). A large portion of the study sites occur in the Pleistocene Sand Dunes Ecoregion within the Central Great Plains. This area has a high density of depressional wetlands that formed in the valleys of dune fields on old alluvial terraces of the Cimarron River. Annual precipitation varies greatly across the study area, with precipitation ranging from 61 cm in western counties to 142 cm in the southeastern portion of the state (Oklahoma Climatology Survey 2015). The growing season also varies substantially, with 175 days in northwestern counties and 225-230 days in the southeastern counties (Oklahoma Climatological Survey 2012). The distribution of plant communities largely reflects the precipitation and temperature gradient that occurs across the state, with deciduous forests in the eastern third of the state shifting to tallgrass and mixed-grass prairies in central portion of the state and shortgrass prairies occurring in the western portion of the state (Hoagland 2000).

We identified depressional wetlands following Hydrogeomorphic (HGM) guidance (Brinson 1993; Smith et al. 1995) and a dichotomous key developed by Dvorett et al. (2012). Depressional wetlands occur in topographic depressions that accumulate water from precipitation, surface flows, and groundwater discharge (Smith et al. 1995). Hydrodynamics are dominated by vertical fluctuations in water levels with water loss through outlets, evapotranspiration, or groundwater recharge (Smith et al. 1995). Depressional wetlands provide many functions and services, including groundwater recharge, nutrient cycling, water quality improvement, and habitat provisioning for various wildlife species during breeding, migration, and wintering stages. They are typically found on private lands, with the majority occurring in the central and western portion of Oklahoma. Depressional wetlands are highly dynamic systems with hydroperiods that vary based on climate and geographic location.

We selected 28 depressional wetlands using National Wetlands Inventory (NWI) maps and 2008-2013 National Agricultural Imagery Program (NAIP) aerial imagery. Wetlands were dispersed along a precipitation gradient in which we used I-35 as the geographic boundary to separate high (east of I-35) and low (west of I-35) precipitation sites, with 14 sites selected from each. We also collected data in 2014 from 40 interdunal depressional wetlands within the Cimarron Pleistocene Sand Dunes Ecoregion in north central Oklahoma. Annual precipitation ranged from 69 cm to 94 cm for western wetlands (54 sites) and 94 cm to 135 cm for eastern wetlands (14 sites). Wetlands were selected on public and private land and placed into *a priori* classes (reference, fair, and poor) based on surrounding land-use practices (e.g., agricultural, urban, pastureland) and hydrologic alterations (e.g., culverts, dikes, ditches). Least-disturbed sites were selected to represent reference wetlands (i.e., best attainable condition). These sites were initially selected using GIS desktop surveys of surrounding land-use, and then field verified to confirm the lack of any hydrological alterations and biological disturbances. In total, our study includes 68 wetlands, with 27 wetlands in the *a priori* least-disturbed class, 13 wetlands in the *a priori* intermediate disturbance class, and 28 wetlands in the *a priori* high disturbance class (Table 1).

Condition Determination

We used two wetland condition assessments, LDI and OKRAM, to define the condition of the 68 study wetlands. These two assessments are applied at different scales (e.g., landscape scale and on-site) and overall condition scores were compared with FQA metric scores to evaluate the ability of the method to discern wetland condition along a disturbance gradient.

LDI is conducted remotely and defines wetland condition based on the land-use practices occurring within a specified buffer distance surrounding the wetland. Land-use types (e.g., agricultural, residential, pastureland, etc.) are assigned coefficients ranging from 1 to 10 based on the severity of human disturbance, with a value of 1 assigned to natural areas (forest, wetlands, and open water) and a value of 10 assigned to highly-developed urban areas. We used GIS desktop application to calculate an LDI Index within a 1,000 m buffer surrounding each wetland. In a previous depressional wetland study, land-use within 1,000 m of a wetland was shown to define wetland condition (Chapter 1), while accounting for a biological relevant scale at which wetland-dependent wildlife such as waterbirds, amphibians, and mammals may use wetlands (Semlitsch 1998; Gibbons 2003; Albanese and Davis 2015). We calculated the percentage of land-use types within the buffer based on 2011 National Land Cover Dataset (NLCD) (Homer et al. 2015) and each land-use type was assigned a weighted coefficient representing the level of disturbance (Brown and Vivas 2005; Mack 2006; Table 2). LDI Index scores were calculated using the equation (Brown and Vivas 2005):

$$\mathrm{LDI_{total}} = \ \%\mathrm{LU_i} \times \mathrm{LDI_i}$$

where $\mathrm{LDI_{total}}$ = LDI ranking for landscape unit (i.e., buffer zone or watershed) and $\%\mathrm{LU_i}$ = percent of the total area in land-use i. Higher LDI Index scores represent greater deviations from least-disturbed systems.

OKRAM, a rapid assessment method, has been validated and shown to be an effective method for the evaluation of the condition of depressional wetlands throughout the state (Chapter 1; Dvorett et al. 2014). OKRAM is conducted on-site and defines condition based on the presence and severity of stressors within and adjacent to a wetland. To minimize the effect of wetland size and area on results, a 1.0-hectare assessment area (AA) was selected within each wetland as a representative sample of the entire wetland. For wetlands smaller than 1.0-hectare, the entire wetland was considered the AA. For wetlands larger than 1.0-hectare, the AA was defined by a 1.0-hectare circle randomly placed within the wetland. The method computes an overall condition score based on nine metrics aggregated into three attributes (hydrologic condition, water quality, and biotic condition). Hydrologic condition detects alterations to the hydroperiod, water source inputs, and hydrologic connectivity to nearby uplands. Water quality metrics evaluate the input of excessive nutrients, sediment, and chemical contaminants into the wetland and the amount of surrounding buffer. Lastly, biotic condition measures disturbance to the wetland's plant community and the percentage of contiguous habitat surrounding the wetland. OKRAM was applied in each wetland concurrently with the collection of plant community data.

Wetland Vegetation

We collected plant community data within each wetland between June and August 2014 and 2015. We used a step-point method, in which transects were randomly placed throughout the AA, and all plant species occurring at each meter were recorded (Smith and Haukos 2002). Data collection was conducted within the AA, rather than the entire wetland, to make results comparable with OKRAM scores by using the same study area. However, the majority of wetlands (i.e., 60 of 68 sites) were 1.0 ha or smaller, thus the AA comprised the entire wetland. We walked a minimum of three transects totaling at least 150 sampling points within each wetland. All transects were placed along the elevational gradient, and terminated at the edge of the AA or upland transition zone. Because AAs were not always the same shape or size, transect length was variable. All transects were traversed through the entirety of the AA to avoid sampling bias associated with stopping mid-way through the wetland. This led to sampling more than 150 m of vegetation at several wetlands. When total transect length exceeded 150 m, we randomly selected 150 points from the total number of points sampled for inclusion in analyses (Smith and Haukos 2002). Additionally, we conducted a five-minute survey, in which we strategically walked through the wetland to collect species that were not encountered on transects. All unknown plant species were collected, pressed, and identified to the lowest taxonomic group possible using dichotomous keys (Mohlenbrock 2005, 2006, 2008, 2010; Tyrl et al. 2009).

To calculate FQA metrics, *C*-values developed for Oklahoma were assigned to all plant species (Ewing and Hoagland 2012), and those not listed were assigned values based on *C*-values developed for Kansas (Freeman and Morse 2002) and Missouri (Ladd 1993). Generally, low values (0-3) represent widespread taxa that are very tolerant of disturbance, intermediate values (4-6) are assigned to species that are associated with a specific plant community and tolerate moderate disturbance, and high values (7-10) represent species that are found in a narrow range of plant communities in advanced stages of succession with low disturbance tolerance (Andreas et al. 1995; Taft et al. 1997).

The primary components of FQA are Mean *C* and FQI, where Mean *C* is the average *C*-value of native vascular species observed at a site and FQI is the product of Mean *C* and the square root of native species richness (Swink and Wilhelm 1994). Modifications to FQI include the addition of non-native species (Lopez and Fennessy 2002; Andreas et al. 2004; Cohen et al. 2004; Rothrock 2004; Taft et al. 2006) and measures of abundance (Taft et al. 1997; Poling et al. 2003; Gara 2013). Higher Mean *C* and FQI scores typically indicate higher floristic integrity and a lower level of human disturbance for a given site. Because there is no standard methodology for FQI metric calculation, we calculated four FQIs to examine the influence of including non-natives and species cover data to determine which is the most effective. FQI incorporates species richness making it the more commonly used metric, therefore our study focuses on FQI.

Nonetheless, Mean C calculations are necessary to compute FQIs and the following formulas were used:

$$MeanC_{\text{native}} = \left(\frac{\sum CC_i}{N}\right) \qquad FQI_{\text{native}} = \left(\frac{\sum CC_i}{N}\right)\sqrt{N}$$

$$MeanC_{\text{all}} = \left(\frac{\sum CC_i}{S}\right) \qquad FQI_{\text{all}} = \left(\frac{\sum CC_i}{S}\right)\sqrt{S}$$

$$CoverMeanC_{\text{native}} = \left(\frac{\sum CC_i x_i}{\sum x_i}\right) \qquad CoverFQI_{\text{native}} = \left(\frac{\sum CC_i x_i}{\sum x_i}\right)\sqrt{N}$$

$$CoverMeanC_{\text{all}} = \left(\frac{\sum CC_i x_i}{\sum x_i}\right) \qquad CoverFQI_{\text{all}} = \left(\frac{\sum CC_i x_i}{\sum x_i}\right)\sqrt{S}$$

where CC is the coefficient of conservatism for species i, x is the cover of species i, N is native species richness, and S is total species richness.

Condition Classes

During our initial site selection, wetlands were placed into *a priori* condition classes (i.e., reference, fair, and poor) to assure that sites were sampled along the entire disturbance gradient. We then used these *a priori* determinations to establish condition classes based on FQI scores. For instance, we used the 25th percentile of FQI scores within the *a priori* reference class to represent reference condition, and the 75th percentile of high disturbance wetlands to represent poor condition (Sifneos et al. 2010). Sites falling between the thresholds for reference and poor condition were considered to be in fair condition. The same protocol was used in a previous study to establish condition classes based on OKRAM scores (e.g., $\geq$0.84 represents reference class and $\leq$0.50 represents poor condition; Chapter 1). We then evaluated the agreement between each classification protocol (i.e., *a priori*, classes based on FQI scores, and classes based on OKRAM scores).

Statistical Analyses

To meet our first objective and determine the most effective FQA method, we used paired t-test analyses to compare FQI scores (1) with and without additional species from the five-minute survey, (2) with and without non-native species, and (3) with and without species cover data. Because one or both of the assumptions of parametric statistics tests (normality and equality of variance) were violated in all of the data, paired comparisons were performed using a Wilcoxon Signed-Rank Test ($\alpha = 0.05$). To address our second objective and provide validation support for the use of FQI in Oklahoma depressional wetlands, we evaluated the relationships between FQI and other established methods (e.g., OKRAM and LDI) using Spearman's rank correlation ($\alpha = 0.05$) in R version 3.2.2. (Crawley 2013; R Core Development Team 2015). Lastly, we used Canonical Correspondence Analysis (CCA) to assess the relationship between plant communities and environmental variables, including site condition (i.e., reference vs disturbed), average annual precipitation, and inundation at the time of sampling (i.e., wet vs dry). All analyses were conducted using Canoco 5 (Šmilauer and Lepš 2014; ter Braak and Smilauer 2014). CCA is a direct gradient analysis that combines ordination and regression to define axes that are linear combinations of the environmental variables that best explain the variation in the vegetation data. We used constrained selection of environmental variables and Monte Carlo permutations tests with 5000 randomizations to test the significance of the constrained ordination (Šmilauer and Lepš 2014).

RESULTS

FQI Methodology

We identified 275 plant species along transects within the 68 study wetlands. We also identified an additional 152 plant species during the five minute survey following transect sampling. On average, we collected 3.2 additional species per site during the five minute survey, with a maximum of 11 additional species at one site. We compared Mean *C* and FQI scores from transects and transects combined with the five minute additional plant survey (Table 3). Three of the four Mean *C* calculations (i.e., $MeanC_{native}$, $CoverMeanC_{native}$, and $CoverMeanC_{all}$) were not significantly different when including additional survey species. Alternatively, all four of the FQI calculations were significantly different when including these additional species at the $\alpha = 0.5$ level. Our results demonstrate that increased sampling effort (e.g., five-minute survey) can significantly increase FQI scores; therefore, all species collected (e.g., transect data and additional survey data) were included in subsequent analyses.

In evaluating the influence of species abundance on FQI scores, abundance weighting did not improve relationships with OKRAM or LDI, and FQI scores did not change significantly between FQI_{native} and $CoverFQI_{native}$ ($P = 0.304$) or between FQI_{all} and $CoverFQI_{all}$ ($P = 0.883$). Alternatively, when comparing FQIs with and without non-natives, we found that scores changed significantly (FQI_{native} and FQI_{all} $P < 0.0001$; Table 4). When including non-native species, FQI scores decreased for 57 sites, increased for 1 site, and scores remained the same for 10 sites. Based on our results and the recognition of non-natives as indicators of anthropogenic disturbance for vegetation assessments (Lopez and Fennessy 2002; Rooney and Rogers 2002), we determined that FQI_{all} would be the most reliable indicator of wetland condition; therefore, it was used in all of the following analyses.

FQI Validation

Score ranges for OKRAM (i.e., 0.25 to 0.98) and LDI (i.e., 1.24 to 9.0) both reflect our site selection along the entire disturbance gradient. We found strong, consistent relationships between FQIs, OKRAM, and LDI (Table 5), with the strongest correlations being FQI_{all} and OKRAM ($\rho = 0.749$, $P < 0.0001$) and FQI_{all} and LDI ($\rho = -0.595$, $P < 0.0001$; Figure 2). We also found significant relationships between FQI_{all} and OKRAM attributes (hydrologic condition: $\rho = 0.496$, $P < 0.0001$, water quality: $\rho = 0.652$, $P < 0.0001$, and biotic condition: $\rho = 0.814$, $P < 0.0001$).

Condition Classes

Wetland condition classes were assigned based on FQI_{all} scores using the following criteria: reference condition was defined as $\geq$11 and poor condition as $\leq$8. Sites falling between this range were considered to be in fair condition. Of the 68 sites, 26 were considered reference condition, 12 fair condition, and 30 poor condition. Additionally, we used the same approach (i.e., 25^{th} percentile of *a priori* reference and 75^{th} percentile of *a priori* poor condition) to determine condition class thresholds for eastern (high precipitation) and western (low precipitation) sites. For the eastern sites, sites with FQI scores $\geq$18 were reference condition and sites with FQI scores $\leq$10 were poor condition. Alternatively, for the western sites FQI scores $\geq$10 represent reference condition and $\leq$7 represent poor condition. In defining condition classes for eastern and western sites, we found condition thresholds were quite different between the two regions. For instance, wetlands with FQI scores of 10 were considered reference condition in the western region, but wetlands with similar scores in the eastern region were considered in poor condition.

We evaluated the agreement between reference wetlands assigned using FQI_{all} scores and those assigned using OKRAM scores across all sites as well as within the eastern and western region. Of the 68 study sites, 18 sites (6 eastern and 12 western sites) were categorized as reference condition based on OKRAM scores. When comparing condition classes defined by FQI_{all} scores, there was an 89% agreement (i.e., 16 reference sites) with OKRAM. When applying condition classes defined by only western sites, there was a 94% agreement (i.e., 17 reference sites) with OKRAM. Finally, when applying classes based only on eastern sites, we found a 22% agreement with only four reference sites in agreement.

Relationship of Plant Communities to Environmental Variables

We included 326 plant taxa collected from 68 wetlands in the CCA. The sum of all canonical eigenvalues was 1.19, and the total variance was 13.0. The first and second CCA axes accounted for 7.4 % of the variance in species occurrences with 79.9% of the variation explained by environmental variables. The first CCA axis revealed a strong positive correlation to precipitation (0.81), indicating that average annual precipitation is the primary driver in plant species occurrence (Figure 3). The second CCA axis is positively correlated with reference site condition (0.77) and negatively correlated with disturbed site condition (-0.77).

DISCUSSION

As the development of wetland assessments continues in Oklahoma, it is imperative that performance of various wetland assessments be evaluated statewide and any existing limitations of these assessments be addressed prior to implementation for wetland management and conservation efforts. Without proper method validation, methods may produce misleading results for ambient monitoring programs and impede regulatory decision-making (e.g., mitigation, restoration). This study examines the inconsistencies in using FQA to determine wetland condition and provides a statewide validation of FQA based on two established wetland assessment methods (e.g., LDI and OKRAM). Additionally, we evaluated the potential use of FQA to discern differences in depressional wetland condition, particularly reference condition, given Oklahoma's diverse ecoregions and environmental gradients.

FQI Methodology

With no standard methodology established for the use of FQA metrics (i.e., Mean *C* and FQI), it is important to consider the influence of different vegetation collection techniques and metric calculations on scores. Our results demonstrate that FQI scores can increase significantly with increasing sampling effort (i.e., five-minute survey), which is likely the result of increasing species richness, as well as increasing the detection probability for rare or conservative species. Taft et al. (1997) also concluded that a few conservative species could have an impact on FQI scores, thus demonstrating the necessity for a comprehensive species list for each site. When evaluating the influence of species cover on scores, we found that the relationships between FQI and both OKRAM and LDI were not improved with the addition of abundance data. This suggests that while a complete list of species is necessary, sampling protocols to collect species cover are not necessary and a more rapid walk-through inventory could be sufficient, assuming all species are detected. Cohen et al. (2004) also noted that collecting abundance data is often too time consuming or too costly. Lastly, we found that the inclusion of non-native species resulted in significant changes to FQI scores.

These results are not surprising given that the establishment of non-natives has been shown to indicate ecosystem stress and anthropogenic disturbance (Simberloff et al. 1997; Cronk and Fennessy 2001). Thus, FQI methods using non-natives are likely to provide a more realistic evaluation of floristic quality (Fennessy et al. 1998; Bowles and Jones 2006; Cohen et al. 2004; Rocchio 2007).

FQI Validation

Validation is an important component of assessment method development to ensure that results are representative of actual wetland condition. FQI has been validated in other states using Level 1, 2, and 3 data. For example, Lopez and Fennessy (2002) found significant correlations between FQI and a Level 1 disturbance rank index for 20 depressional wetlands in Ohio. Additionally, Cohen et al. (2004) assessed 75 depressional wetlands in Florida and found significant relationships between FQI and LDI, as well as with soil and water chemistry metrics (e.g., turbidity, total phosphorus, total nitrogen, and organic matter).

The consistent relationships we observed between FQI and other established assessment methods (e.g., OKRAM and LDI) demonstrate the ability of FQI to detect changes in depressional wetland condition along a disturbance gradient. Not surprisingly, FQI had the strongest relationship with the OKRAM biotic condition attribute, which identifies disturbances to wetland plant composition and structure. Additionally, the strong relationships between FQI and the OKRAM water quality attribute indicate that the method is detecting the presence of water quality stressors (e.g., excessive nutrients, sedimentation, chemical contaminants, and the lack of buffer) and their influence on plant communities. Although FQI is an effective method, we found certain hydrological stressors that the method did not detect, such as culverts diverting water out of the wetland, nearby impervious surfaces, and levees obstructing the wetland's hydrologic connectivity with adjacent uplands. Collecting data to characterize hydrological alterations alongside FQI application may provide a more comprehensive outlook on wetland condition.

Variation in Reference Condition across Sites

The utility of FQI in wetland management programs (e.g., monitoring, mitigation, and restoration) can be improved with the establishment of reference condition criteria for the comparison of individual wetlands. FQI reference condition criteria have been used to estimate the integrity of wetlands being impacted, set mitigation ratios, and evaluate compensatory wetland mitigation projects (Herman et al. 1997; Streever 1999; Herman et al. 2001; Matthews et al. 2005; Matthews and Endress 2008; Matthews et al. 2009). FQI scores are often used as benchmarks to categorize wetlands into condition classes and used as targets for performance standards in mitigation and restoration projects. For example, performance standards in the Chicago District include an FQI score ≥20 and a Mean *C* ≥3.5 (Rocchio 2007). Bried et al. (2014) also recommended an FQI value of 20 to identify reference wetlands in Oklahoma.

We applied this benchmark (i.e., FQI score ≥20) to wetlands identified by OKRAM as reference condition, and found that no wetlands in the western portion of the study area and only four in the eastern portion of the study area met the criteria. We observed considerably lower FQI scores for western reference wetlands (e.g., range of 8.0 to 17.2), with a median of 13. The same held true when applying reference condition determined from eastern wetlands (i.e., FQI ≥18) statewide. These results indicate that a single threshold to designate reference condition cannot be applied statewide, as western wetlands are unlikely to meet the criteria. Other studies have documented floristic quality patterns across regions, with FQI scores typically increasing latitudinally (Reiss 2006; Johnston et al. 2010). For example, Johnston et al. (2010) found strong latitudinal variation in FQI scores from coastal emergent wetlands along the Great Lakes, with scores increasing to the north. Score variations were attributed to a combination of anthropogenic disturbance and natural variation based on latitudinal differences in mean annual temperature, length of growing season, and soil texture (Johnston et al. 2010). We found similar trends with FQI scores increasing from west to east along a precipitation gradient, as well as other environmental gradients (e.g., mean annual temperature and length of growing season).

Because FQI is calculated with species richness, several authors have criticized the method as being biased towards high richness sites and recommend using Mean *C* as an alternative when making site comparison (Taft et al. 1997; Francis et al. 2000; Matthews 2003; Cohen et al. 2004; Miller and Wardrop 2006; Bried et al. 2013). When using Mean C to identify reference wetlands across the state, we reached the same conclusions as with FQI, with higher values in the east (2.47 to 5.0) and lower values in the west (1.86 to 3.76). On average, plant communities within eastern reference wetlands were comprised of half as many low *C*-values species (i.e., 0-3) and almost five times as many high *C*-values species (i.e., 7-10), compared to western wetlands (Table 6).

Using plant communities to assess wetland condition relies on the assumption that species are stable in composition or in quality (Deimeke et al. 2013). However, plant community shifts in response to hydrology and climate are well documented, with species composition varying based on water depth, water chemistry, flow rates, and timing of inundation (Gosselink and Turner 1978; van der Valk 1981; Spence 1982; Wilcox 1995; Mitsch and Gosselink 2000; Euliss et al. 2004). Plant community shifts are especially common in ephemeral depressional wetlands that may undergo multiple wet and dry cycles in a single season. Because FQI is based on the conservatism of individual plant species, FQI scores will vary as a plant community changes in response to the wetland hydrology. For example, Euliss and Mushet (2011) found that FQI scores for seasonal wetlands varied dramatically over a four year study based on plant community shifts due to natural wet and dry cycles. Annual species, typically with lower *C*-values, dominated wetlands under dry conditions and when flooded, annuals were replaced by perennials, which are generally more conservative species (i.e., higher *C*-values). We found similar relationships between FQI and hydrology with FQI scores increasing as mean annual precipitation increases along a gradient from west to east.

FQI is intended to differentiate between high and low quality wetlands based on the presence of plant species (i.e., conservative vs. stress-tolerant), but our CCA results suggest that precipitation is the primary driver of plant species occurrence regardless of site condition (i.e., reference vs. disturbed). Annual precipitation in eastern Oklahoma typically promotes prolonged flooding in depressional wetlands to support a variety of wetland plants. In comparison, decreased rainfall in western Oklahoma often results in drought conditions that promote the establishment of more tolerant species (e.g., annuals, invasives, and non-natives), as well as the encroachment of upland species (Mulhouse et al. 2005; Euliss and Mushet 2011; Lovell and Menges 2013; Merlin et al. 2015). Based on the premise of FQI, this resulting preference for tolerant species in western plant communities is likely to impact the method's effectiveness at differentiating wetland condition.

Not all studies have concluded that FQI and Mean *C* were influenced by natural variation (Cohen et al. 2004; Bried et al. 2013). However, it is possible that wetlands in these studies did not undergo significant disturbance prior to or during the sampling season. For example, Bried et al. (2013) found that Mean *C* was not confounded by natural variation based on wetland size, surface water depth, or time of sampling within the growing season; however, all of the wetlands remained inundated throughout the study. The authors acknowledged that FQA metrics might be subjected to greater seasonal and inter-annual variation when applied in drought-prone regions. The influence of drought events on plant-based indices has been recognized by others, and their use is often not recommended following extreme weather events (Mack et al. 2008; Wilson et al. 2013). Hargiss et al. (2008) recommends including surrounding upland species in plant-based indices to account for the shift in species due to natural hydrological fluctuations. This method may improve FQI results in ephemeral depressional wetlands that are often dry during sampling.

In addition to drought susceptibility, western Oklahoma has endured more extreme land-use changes as compared to eastern Oklahoma. Although the state as a whole has undergone significant changes in land-use, the severity of disturbance and stressors associated with land-use types differ considerably across the state. For instance, anthropogenic land-use in eastern Oklahoma mainly consists of pastureland and hay meadows (i.e., 67% of total disturbed land), with smaller areas of urban development and agriculture. Whereas, land-use in western Oklahoma includes urban development and pastureland, but the predominant land-use is agriculture, which accounts for 83% of disturbed land-use (NLCD 2011). While urban development and pastureland have impacted wetlands statewide, wetlands in central and western Oklahoma have likely undergone greater stress as they are imbedded in an agriculturally intensive landscape. Although reference wetlands were surrounded by at least a 250 m buffer, it is possible these wetlands are being influenced by historic and current agricultural practices at a larger scale. For instance, wetlands may be susceptible to wind-blown sediment deposits, which may also carry pesticides during aerial application. Therefore, wetlands in relatively undisturbed watersheds, but within an agricultural landscape, may be impacted to a certain degree (Irwin et al. 1996; Thurman et al. 2000; Skagen et al. 2008).

Depressional wetlands in central and western Oklahoma have been characterized as being naturally low in vegetation complexity and diversity (Dvorett et al. 2014). With plant communities in stressful environments favoring stress-tolerant plant species (Grime 1979; Keddy and MacLellan 1990; Wisheu and Keddy 1992), we would expect to find a greater proportion of these species in these regions, where seasonal wetlands have historically undergone a greater severity of natural and anthropogenic disturbance. Despite being surrounded by native and relatively undisturbed grasslands, plant communities in western reference wetlands were comprised of more stress tolerant species compared to eastern reference wetlands. FQI is intended to characterize and compare floristic quality between wetlands, but FQI scores may reflect differences in plant communities rather than floristic quality (Andreas et al. 2004). As such, plant communities with naturally high proportions of habitat specialists will likely score higher than equally intact communities consisting primarily of generalist species.

CONCLUSION

A critical component in conducting wetland assessments is to define the overall objective and evaluate which method is the most appropriate to produce desirable results. For instance, if the objective is to designate natural areas with the highest floristic integrity across the state, then FQI application can identify wetlands that represent natural remnant condition. Alternatively, if the objective is to define current wetland condition for monitoring and regulatory purposes, then FQI may be prone to produce misleading results without prior development of performance criteria that considers regional variation in precipitation and other climatic variables. Because plant communities are known to vary along ecological gradients, an inherent bias exists when applying biological indicator methods statewide. While this notion may be irrelevant when identifying biological integrity based on comparisons with historic or pre-European settlement condition, it needs to be addressed when evaluating wetland condition for applied management (Nichols 1999; Reiss 2006; Matthews and Endress 2008).

To be an effective management tool for monitoring, restoration, and mitigation, wetland assessments should distinguish between high and low quality wetlands. Ideally, compensatory mitigation occurs within the same region in which wetlands were destroyed, in an effort to maintain "no net loss" policy (National Wetlands Policy Forum, 1988). If assessment methods are not calibrated within each region, the actual quality and value of impacted wetlands may be greatly underestimated. Likewise, if reference criteria are not appropriate across the region, mitigation performance standards may not be achievable, increasing costs throughout the mitigation process. In applying the reference standard previously established for Oklahoma and other states (i.e., FQI $\geq$ 20), our results suggest that there may be no reference wetlands found in the western half of the state, and the majority would occur within the southeastern region of the state. Although FQI is an invaluable tool for designating high floristic integrity, the method might overlook important wetlands for protection and mitigation. While, wetlands in western Oklahoma have undergone more natural and anthropogenic disturbance compared to wetlands located in eastern Oklahoma, they contribute valuable functions and services, including providing critical breeding, migration, and overwintering habitat for waterfowl and shorebirds, habitat for various other wildlife species, groundwater recharge, and water quality improvements through sediment and nutrient retention in an agriculturally dense landscape.

Our study demonstrates that wetland plant communities can differ based on environmental gradients regardless of wetland condition. This phenomenon highlights the importance of considering regional environmental differences when developing FQI thresholds for wetland assessments, especially across diverse states or regions. To reduce the influence of regional differences on FQIs, as well as other vegetation-based methods, condition class criteria can be established based on ecoregions and use HGM guidance to minimize variation between wetland types.

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FIGURES AND TABLES

Figure 1: Map of Oklahoma with the locations of depressional wetlands sampled in 2014 and 2015. Insert shows a cluster of wetlands sampled within the Cimarron River Pleistocene Sand Dunes Ecoregion. Wetlands were separated based on high (east of I-35; 14 sites) and low precipitation (west of I-35; 54 sites).

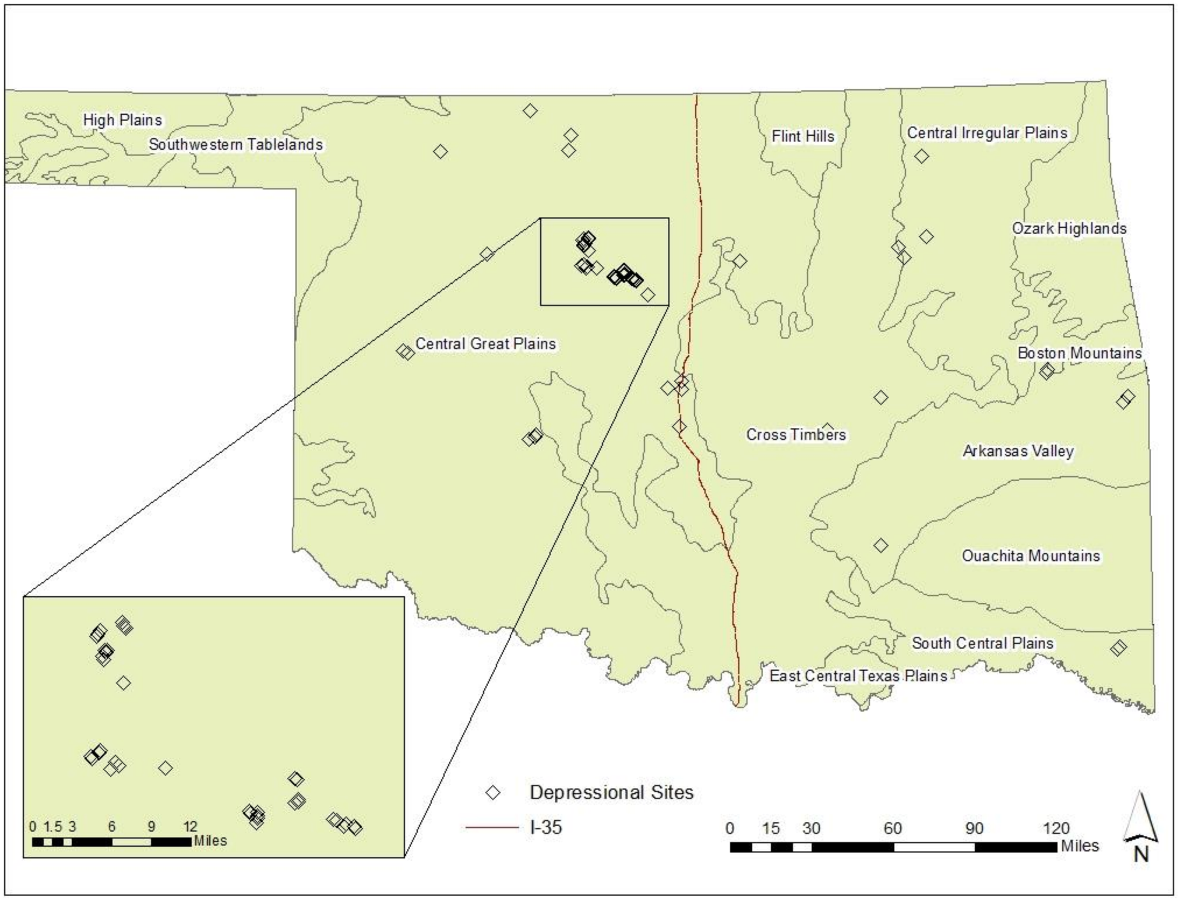
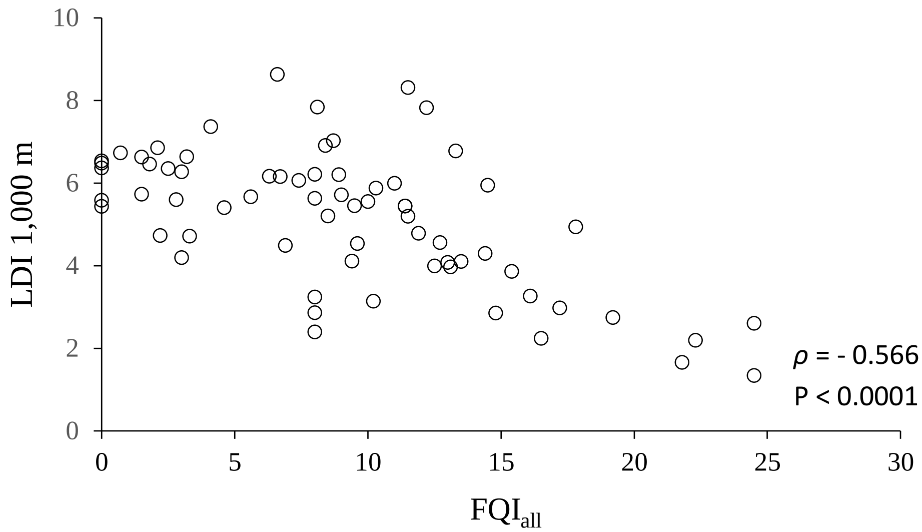


Figure 2: The relationships between Floristic Quality Index using total species richness (FQI_{all}) with the Landscape Development Intensity Index (LDI) at 1,000 m buffer and the Oklahoma Rapid Assessment Method (OKRAM) using Spearman's rank correlation *(ρ)*.



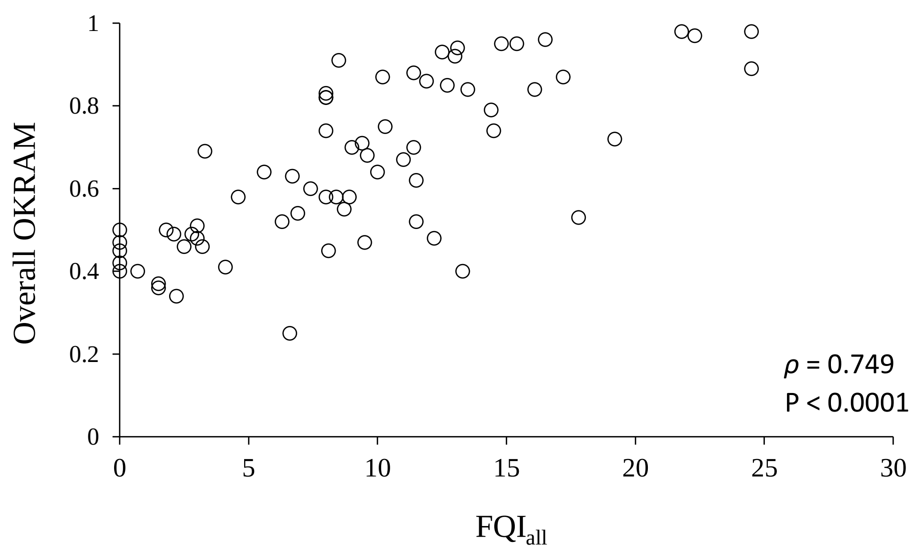


Figure 3: Biplot of the first and second CCA axes for plant taxa collected from depressional wetlands across Oklahoma in 2014 and 2015. Environmental variables are precipitation (PREC), reference condition (REF), disturbed condition (DIST), and hydrological condition of the wetland during sampling (DRY or WET). Plant species are categorized by *C*-values to represent tolerance to anthropogenic disturbance. Low values (0-3) represent widespread taxa very tolerant of disturbance (black triangle), intermediate values (4-6) represent species tolerant of moderate disturbance (purple diamond), and high values (7-10) represent species only found in a narrow range of plant communities with very low disturbance tolerance (blue triangle) (Andreas et al. 1995; Taft et al. 1997). Plant species shown are *Panicum capillare* (PACA), *Teucrium canadense* (TECA), *Ambrosia psilostachya* (AMPS), *Cephalanthus occidentalis* (CEOC), *Salix nigra* (SANI), *Polygonum hydropiperoides (*POHY), *Carex lupuliformis* (CALU), *Ludwigia palustris* (LUPA), *Diospyros virginiana* (DIVI), *Campsis radicans* (CARA), *Dichanthelium dichotomum* (DIDI), *Quercus nigra* (QUNI), *Juncus effusus* (JUEF), *Lycopus virginicus* (LYVI), *Trachelospermum difforme* (TRDI), *Impatiens capensis* (IMCA), *Liquidambar styraciflua* (LIST), *Mikania scandens* (MISC), *Panicum coloratum* (PACO), and *Sesbania herbacea* (SEHE).

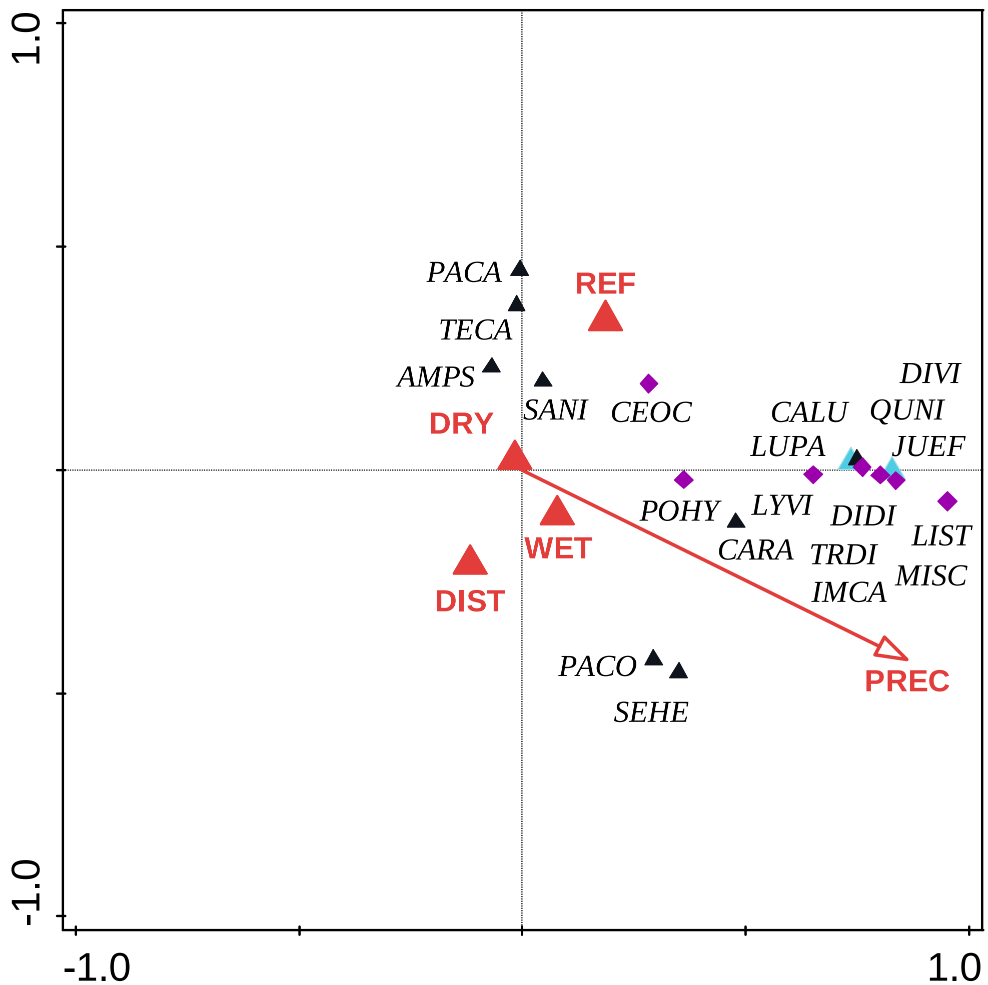


Table 1: Descriptions of depressional wetlands sampled across Oklahoma in 2014 and 2015. Wetlands were categorized by *a priori* classes based on the land-use types surrounding wetlands. Reference represents best attainable condition with minimal anthropogenic disturbance and no hydrological alterations, fair condition wetlands were moderately disturbed, and poor condition wetlands were significantly altered (e.g., agricultural or urban landscapes). Wetlands were further separated within eastern (high precipitation) and western (low precipitation) Oklahoma.

***A priori* Condition**	**Number of Wetlands**	**Wetland Size Range**	**Mean Size**	**Eastern**	**Western**
Reference	27	0.05 - 2.27	0.59	6	21
Fair	13	0.10 - 1.00	0.68	4	9
Poor	28	0.60 - 2.10	0.61	4	24

Table 2: Oklahoma land-use classes defined by National Land Cover Database (NLCD) and corresponding coefficients used to calculate Landscape Development Intensity Index (LDI) scores (Brown and Vivas 2005; Mack 2006)

Land-use Classification	**LDI Coefficient**
Natural System	1.00
Open Water	1.00
Pasture	3.41
Developed, Open Space	6.92
Cropland	7.00
Developed, Low Intensity	7.55
Barren Land	8.32
Developed, Medium Intensity	9.42
Developed, High Intensity	10.00

Table 3: Comparison of Floristic Quality Assessment (FQA) metric scores (e.g., Mean *C* and Floristic Quality Index [FQI]) calculated with transect data only and those calculated with transect data plus additional species collected during a five-minute survey. Paired *t*-test analyses were conducted using the Wilcoxon Signed-Rank Test and metric scores were considered to be significantly different at the α = 0.05 level.

FQA Metrics	**V**	**P-value**
$MeanC_{native}$	658.5	0.472
FQI_{native}	51.0	$\leq$0.001
$CoverMeanC_{native}$	778.0	0.703
$CoverFQI_{native}$	0.0	$\leq$0.001
$MeanC_{all}$	493.0	0.013
FQI_{all}	46.0	$\leq$0.001
$CoverMeanC_{all}$	599.0	0.071
$CoverFQI_{all}$	0.0	$\leq$0.001

Table 4: Comparison of four methods to calculate Floristic Quality Assessment metrics (Mean *C* and Floristic Quality Index [FQI]) such as, the inclusion and exclusion of non-native species and species cover. Paired t-test analyses were conducted using the Wilcoxon Signed-Rank Test and metric scores were considered to be significantly different at the α = 0.05 level.

Comparison	**V**	**P-value**
NSPR vs. SPR	0.0	$\leq$0.001
$MeanC_{native}$ vs. $MeanC_{all}$	1711.0	$\leq$0.001
FQI_{native} vs. FQI_{all}	1705.0	$\leq$0.001
$CoverMeanC_{native}$ vs. $CoverMeanC_{all}$	1711.0	$\leq$0.001
$CoverFQI_{native}$ vs. $CoverFQI_{all}$	1359.0	$\leq$0.001
FQI_{all} vs. $CoverFQI_{all}$	955.0	0.883
FQI_{native} vs. $CoverFQI_{native}$	775.0	0.304
$MeanC_{all}$ vs. $CoverMeanC_{all}$	1012.0	0.806
$MeanC_{native}$ vs. $CoverMeanC_{native}$	758.0	0.249

Table 5: The relationships of Floristic Quality Index (FQI) scores with Landscape Development Intensity Index (LDI) scores and Oklahoma Rapid Assessment Method (OKRAM) attribute and overall scores presented in terms of Spearman's r (ρ). All relationships that were significant at $\alpha = 0.05$ level are shown.

FQIs	**Level 1 and 2 Data**	ρ	**P-value**
FQI_{native}	LDI	-0.539	<0.0001
	A1: Hydrologic Condition	0.449	0.0001
	A2: Water Quality	0.612	<0.0001
	A3: Biotic Condition	0.811	<0.0001
	Overall OKRAM	0.717	<0.0001
FQI_{all}	LDI	-0.566	<0.0001
	A1: Hydrologic Condition	0.496	<0.0001
	A2: Water Quality	0.652	<0.0001
	A3: Biotic Condition	0.814	<0.0001
	Overall OKRAM	0.749	<0.0001
$CoverFQI_{native}$	LDI	-0.521	<0.0001
	A1: Hydrologic Condition	0.401	0.0007
	A2: Water Quality	0.601	<0.0001
	A3: Biotic Condition	0.793	<0.0001
	Overall OKRAM	0.688	< 0.0001
$CoverFQI_{all}$	LDI	-0.582	<0.0001
	A1: Hydrologic Condition	0.449	0.0001
	A2: Water Quality	0.627	<0.0001
	A3: Biotic Condition	0.823	<0.0001
	Overall OKRAM	0.733	< 0.0001

Table 6: The proportions of plant species with low, intermediate, and high *C*-values were determined for each reference wetland (i.e., 12 western [low] and 6 eastern [high precipitation] sites). The average proportion of each category for western and eastern wetlands is shown. Low *C*-values (0-3) represent widespread taxa that are very tolerant of disturbance, intermediate values (4-6) represent species that tolerate moderate disturbance, and high values (7-10) represent species that are found in a narrow range of plant communities in advanced stages of succession, with low disturbance tolerance (Andreas et al. 1995; Taft et al. 1997).

Reference Wetlands	% Low (0-3)	% Intermediate (4-6)	% High (7-10)
Western sites	63	34	3
Eastern sites	35	51	14

APPENDICES

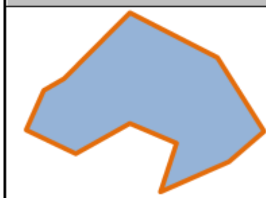
Appendix A: OKRAM datasheets

The Oklahoma Rapid Assessment Method (OKRAM) for Wetlands
IN THE OFFICE
Step 1: Assemble all the materials necessary to complete the assessment. Necessary geographic information systems (GIS) frame materials include: topographic quadrangles, aerial photographs, national wetlands inventory (NWI) maps, and land-use datasets. Additional relevant GIS data may be helpful and include soil maps, vegetation maps, geologic maps, hydrologic feature maps etc.
Step 2: Classify the wetland into the appropriate Hydrogeomorphic (HGM) subclass using the included dichotomous key (Worksheet II)
Step 3: Determine the boundary of the Assessment Area (AA). Ideally the assessment area will be 0.5 hectares. However, any assessment area size ranging from 0.1 to 0.5 hectares is acceptable. Delineate the boundary of the wetland. This can be completed using NWI maps or through visual assessment of aerial photography. Wetland boundary should only include one HGM subclass. If the entire wetland boundary is less than 0.5 hectares and greater than 0.1 hectare, conduct the assessment on the entire wetland. If the wetland is greater than 0.5 hectares randomly assign a point with wetland boundaries and delineate an assessment area that contains that point. The preferred method is to create a circle with the randomly chosen point at the center and a 40 meter radius. If this places a portion of the AA outside the wetland boundary, the point can be moved up to 60 meters in any direction. However, do not move the point more than is necessary to place the entire AA within the wetland boundaries. If the point cannot be move such that the circle fits within the wetland boundary, an irregular polygon can be used. This irregular polygon should include the randomly chosen point (not necessarily at the center) and be as close to 0.5 hectares as possible. See worksheet III for assessment area diagrams.
Step 4: Complete the site description sheet, and metrics: 1b. Water Source, 2d. Buffer Filter, 3b. Wetland Loss and 3c. Habitat Connectivity using GIS frame materials.
IN THE FIELD
Step 5. Ensure that the AA boundaries are appropriate, within the wetland and within one HGM subclass. Adjust the boundaries as necessary so AA is entirely contained within one HGM subclass and as close to 0.5 hectares as possible.
Step 6. Complete all OKRAM metric sheets. Check the accuracy of the metrics completed in the office and make changes to scores as necessary.
Step 7. Calculate the final site score by combining all the metrics on worksheet 4. Condition Score. Submetric scores are calculated for hydrology, water quality and biota. These submetric scores are then combined to produce a maximum condition score of 11 (0-4 for hydrology and water quality submetrics and 0-3 for the biota submetric).
Step 8. In worksheet 5 record where you believe the assessment was inaccurate and how the assessment could be improved for future users.
Step 9. Enter hard copies of data into an electronic format in excel and GIS. Archive hard copies.

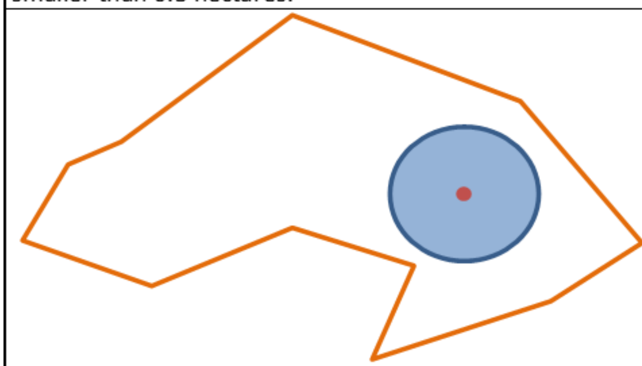
Hydrogeomorphic Wetland Subclassification Dichotomous Key	
1. Wetland is within the 5 year floodplain of a river but not fringing an impounded water body.	*Riverine* (5)
1. Wetland is associated with a topographic depression, flat or slope.	2
2. Wetland is located on a topographic slope (slight to steep) and has groundwater as the primary water source. Wetland does not occur in a basin with closed contours.	*Slope* (16)
2. Wetland is located in a natural or artificial (dammed/excavated) topographic depression or flat.	3
3. Wetland is located on a flat without major influence from groundwater.	*Flat* (**Hardwood Flat**)
3. Wetland is located in a natural or artificial (dammed/excavated) topographic depression.	4
4. Topographic depression has permanent water greater than 2 meters deep.	*Lacustrine Fringe* (10)
4. Topographic depression does not contain permanent water greater than 2 meters.	*Depression* (12)
5. The wetland is a remnant river channel that is periodically hydrologically connected to a river or stream every 5 years or more frequently.	**Connected Oxbow**
5. The wetland is not an abandoned river channel.	6
6. The hydrology of the wetland is impacted by beaver activity.	**Beaver Complex**
6. The hydrology of the wetland is not impacted by beaver activity.	7
7. The wetland occurs within the bankfull channel.	**In-channel**
7. The wetland occurs on the floodplain or is adjacent to the river channel.	8
8. The wetland occurs within a depression on the floodplain.	**Floodplain Depression**
8. The wetland occurs on a flat area on the floodplain or is adjacent to the river channel.	9
9. Wetland water source primarily from overbank flooding that falls with the stream water levels or lateral saturation from channel flow.	**Riparian**
9. Wetland water source is primarily from overbank flooding that remains in the wetland due to impeded drainage after stream water level falls.	**Floodplain**
10. Wetland is associated with a remnant river channel that is hydrologically disconnected from the stream or river of origin.	**Disconnected Oxbow**
10. Wetland is associated with a reservoir or pond created by impounded or excavation.	11
11. Wetland water source is primarily from a permanent river.	**Reservoir Fringe**
11. Wetland water source is primarily from a draw or overland flow.	**Pond Fringe**
12. Wetland was created by human activity.	13
12. Wetland was not created by human activity.	14
13. Wetland does not have discernible water outlets.	**Closed Impounded Depression**
13. Wetland has discernible water outlet.	**Open Impounded Depression**
14. Wetland primary water source is groundwater.	**Groundwater Depression**
14. Wetland primary water source is surface water.	15
15. Wetland does not have any discernible water outlets.	**Closed Surface Water Depression**
15. Wetland has discernible water outlets.	**Open Surface Water Depression**
16. Wetland is hydrologically connected to a low order (Strahler <=4), high gradient, or ephemeral stream.	**Headwater Slope**
16. Wetland is hydrologically connected to a high order (Strahler >=5), low gradient river. Slope may be imperceptible or extremely gradual (includes wet meadows).	**Low Gradient Slope**

Assessment Area Shape Dichotomous Key and Diagrams

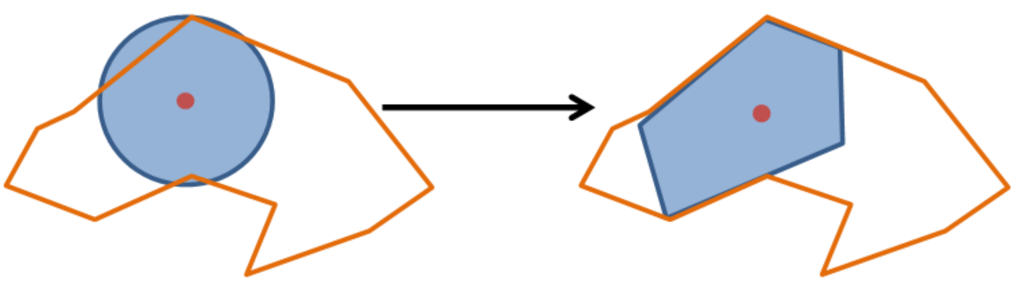
1. Is the wetland <0.5 hectares……………………………………………………………Use AA option (a)
1. Is the wetland >0.5 hectares…………………………………………………………………………………….2
2. A 40 meter radius circle, centered on a randomly assigned point will completely fit within the wetland boundary. The point can be moved up to 60 meters to make the circle fit within the wetland boundaries……………………………………………………………………….use AA option (b)
2. A 40 meter radius circle, centered on a randomly assigned point will not completely fit within the wetland boundary……………………………………………………………….use AA option (c)



(a) Assessment area is the determined by the boundary of the wetland when the wetland is smaller than 0.5 hectares.



(b) Assessment area is a 0.5 hectare circle with radius 40 meters with a randomly chosen point at it's center. The randomly chosen point can be moved up to 60 meters so that the AA will fit within the wetland boundary.



(c) When a circle with radius 40 meters cannot be fit within the wetland boundary within 50 meters of the randomly chosen point, an irregular polygon can be used that includes the randomly chosen point.

Legend

Wetland boundary — Assessment Area — Randomly selected point

Site Description

Site Name					
Date of Assessment					
Assessor Name(s)					
Assessor Affiliation(s)					
Site Latitude					
Site Longitude					
Coordinate System					
Ecoregion					
Directions					
Size of Wetland					
Assessment Area size					
Reason for Assessment					
Dominant Water Source	Surface Flow	Precipitation		Groundwater	Overbank Flooding
Hydrodynamics	Unidirectional	Bidirectional		Vertical	
Geomorphic Setting	Depression	Flat		Fringe	Slope
HGM Class	**Depression**	**Flat**	**Slope**	**Lacustrine**	**Riverine**
Regional Subclass	*Closed Impounded*	*Hardwood*	*Headwater*	*Disconnected Oxbow*	*Connected Oxbow*
	Open Impounded		*Low-gradient*	*Reservoir Fringe*	*Beaver Complex*
	Groundwater			*Pond Fringe*	*In-Channel*
	Open Surface Water				*Floodplain*
	Closed Surface Water				*Floodplain Depression*
					Riparian
Cowardin Class (four most dominant and area as a % of AA)	Class			% AA	
	Class			% AA	
	Class			% AA	
	Class			% AA	
Notes					

1. Hydrologic condition

a. Hydroperiod

Instructions:

1. On an aerial photograph in the field outline all areas within the AA where hydroperiod has been altered and severity of alteration. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos.
2. Severity of alteration is based on indicator severity on the following worksheet.
3. Fill in the area as a percent of the AA and severity for each indicator of altered hydroperiod. Overlapping areas of indicators are only counted once and for the highest level of severity. Describe the indicator and circle all indicators on the indicator worksheet.

4. The metric is calculated by applying severity weights to the impacted area. For example a severity weight of 0.25 is applied to minor sources of impacted hydroperiod. If 50% of the AA is affected by a minor source of altered hydroperiod, the metric score would be 0.875 (1-[0.50*0.25] = 0.875).

Indicators of Reduced hydroperiod	**Minor**	**Moderate**	**Major**	**Complete Loss**	**Indicator Description**
Upstream Dams					
Fill/sedimentation					
Water pumping out of the wetland					
Water control structures					
Culverts, discharges, ditches or tile drains out of the wetland					
Beaver dam removal					
Indicators of increased hydroperiod	**Minor**	**Moderate**	**Major**	**Complete Loss**	**Indicator Description**
Downstream dams					
Excavation/Dredging/Mining					
Water pumping into the wetland					
Water control structures					
Culverts, discharges, diversions or ditches into wetland					
TOTAL IMPACTED AREA	**0**	**0**	**0**	**0**	
SEVERITY WEIGHT	**0.25**	**0.5**	**0.75**	**1**	
SEVERITY WEIGHTED AREA	**0**	**0**	**0**	**0**	
METRIC SCORE 1A					**1**

1. Hydrologic condition

a. Hydroperiod	Severity			
Indicators of Reduced hydroperiod	**Minor**	**Moderate**	**Major**	**Complete Loss**
1. Upstream impoundments (Riverine wetlands only)	Impoundment within 500 meters upstream of wetland that likely alters wetland hydrology to some extent.	Only receives inflows from channel source during large flood events and retains wetland hydrology from other water inputs (e.g. precipitation, overland flow, groundwater).	Complete loss of inflows/ flooding from channel source but still retains wetland hydrology from other water inputs (e.g. precipitation, overland flow, groundwater).	Complete loss of inflows/ flooding and wetland dried.
2. Fill/sedimentation	Silt covered vegetation, extremely turbid water, rills on adjacent uplands	Sediment splays, completely buried vegetation, silt deposits around trees	Silt deposits or fill that have greatly reduced wetland volume	Complete loss of basin.
3. Water pumping out of the wetland	Water level is properly manipulated for wetland management activities including slow, cool-season drawdowns. Desirable annual moist soil plants present.	Water is pumped out of the wetland for agricultural or other human uses *or* Water level is poorly manipulated for wetland management activities including rapid, warm-season drawdowns. Undesirable weedy plants present (e.g. cocklebur).	n/a	n/a
4. Water control structures	Water level is properly manipulated for wetland management activities including slow, cool-season drawdowns. Desirable annual moist soil plants present.	Water level is poorly manipulated for wetland management activities including rapid, warm-season drawdowns. Undesirable weedy plants present (e.g. cocklebur).	n/a	n/a
5. Culverts, discharges, ditches or tile drains out of the wetland	Old drainages present that appear to have minor influences on current wetland hydrology (e.g. old ditches that have sedimented in or tile drains that have been damaged)	Water drained only during high water events.	Water is drained from wetland at all times of the year but still retains wetland hydrology	Wetland completely dried
6. Beaver dam removal	n/a	n/a	Still retains wetland hydrology	Wetland completely dried
7. Center of wetland excavated to dry remainder of wetland	n/a	n/a	Still retains wetland hydrology	Wetland completely dried

Indicators of increased hydroperiod	Minor	Moderate	Major	Complete Loss
8. Downstream impoundments	Impoundment within 500 meters downstream of wetland that likely alters wetland hydrology to some extent.	Impoundment within 100 meters downstream of wetland that likely alters wetland hydrology to some extent.	Still retains wetland hydrology but hydroperiod substantially lengthened.	Wetland converted to permanent deepwater
9. Excavation/ Dredging/ Mining	n/a	n/a	Wetland excavated but still retains wetland hydrology. Hydroperiod substantially lengthened.	Wetland converted to permanent deepwater
10. Water pumping into the wetland	Water level is properly manipulated for wetland management activities including slow, cool-season drawdowns. Desirable annual moist soil plants present.	Water level is poorly manipulated for wetland management activities including rapid, warm-season drawdowns. Undesirable weedy plants present (e.g. cocklebur).	n/a	n/a
11. Water control structures	Water level is properly manipulated for wetland management activities including slow, cool-season drawdowns. Desirable annual moist soil plants present.	Water level is poorly manipulated for wetland management activities including rapid, warm-season drawdowns. Undesirable weedy plants present (e.g. cocklebur).	n/a	n/a
12. Culverts, discharges, diversions or ditches into wetland	Old drainages present that appear to have minor influences on current wetland hydrology (e.g. old ditches that have sedimented in)	Water enters wetland from culverts, diversions or ditches only during large storm events.	Water from culvert, diversion, or ditch is the dominant water source for the wetland.	Wetland converted to permanent deepwater

1. Hydrologic condition

b. Water Source

Instructions:

1. Delineate the catchment for the wetland on an aerial photograph or in GIS. Ideally the catchment for the wetland can be delineated using topographic maps and hydrologic unit maps. However, a 2 km buffer can be substituted if it is not possible to delineate a catchment.

2. On an aerial photograph or in GIS determine the percent cover of indicators of altered water source in the catchment for the wetland.

3. Fill in the % Cover of each of the indicators of altered water source.

4. This metric is calculated by dividing the percentage of unaltered land-cover by 100% cover. For example, a catchment with 20% impervious surface and 40% irrigated agricultural land would receive a score of 0.4. ([100-40-20]/100 = 0.4)

Indicators of altered water source	**% Cover**	**Description**
Impervious surface (paved roads, parking lots, structures and compacted gravel and dirt roads)		
Irrigated agricultural land (center pivot, ditch, flood etc.)		
Dryland agricultural land that is tilled		
Woody encroachment (e.g. eastern red cedar (*Juniperus virginiana*) and salt cedar (*Tamarix* sp.))		
Impounded water		
Topographic alteration (leveling, excavation, mining)		
Total Altered Cover		0
METRIC SCORE 1b		**1**

1. Hydrologic condition

c. Hydrologic Connectivity- Depressions, Flats, Lacustrine Fringes and Slopes

Instructions:

1. On an aerial photograph in the field outline all areas within the AA where hydrologic connectivity has been altered. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos.
2. Fill in the percentage of the perimeter where hydrologic connectivity is impaired.

3. The metric is calculated as a percentage of unimpacted wetland perimeter. For example a wetland where 60% of the perimeter is bounded by a levee would receive a score of 0.4 ([100-60]/100 = 0.4).

Indicators of altered connectivity	Perimeter	Description
Levees, Berms, Dams, Weirs		
Road Grades		
Culverts		
METRIC SCORE 1C		**1**

2. Water Quality Condition

a. Nutrients/Eutrophication

1. On an aerial photograph in the field outline all areas within the AA where nutrient cycling has been altered and severity of alteration. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos.
2. Severity of alteration is based on indicator severity on the following worksheet.
3. Fill in the area as a percent of the AA and severity for each indicator of altered nutrient cycling. Overlapping areas of indicators are only counted once and for the highest level of severity. Describe the indicator and circle all indicators on the indicator worksheet.
4. The metric is calculated by applying severity weights to the impacted area. For example a severity weight of 0.25 is applied to minor sources of impacted nutrient cycling. If 50% of the AA is affected by a minor source of altered nutrient cycling, the metric score would be 0.875 (1-[0.50*0.25] = 0.875).

Indicators of Altered Nutrient Cycling	Minor	Moderate	Major	Indicator Description
Livestock/animal waste				
Septic/sewage discharge				
Excessive algae or Lemna sp. (Do not count this metric if algae or Lemna blooms are a result of evapoconcentration of nutrients as wetland is drying.)				
TOTAL IMPACTED AREA	**0**	**0**	**0**	
SEVERITY WEIGHT	**0.25**	**0.5**	**0.75**	
SEVERITY WEIGHTED AREA	**0**	**0**	**0**	
METRIC SCORE 2a				**1**

2.Water Quality

a. Nutrients	**Severity**		
Indicators of Altered Nutrient Cycling	**Minor**	**Moderate**	**Major**
Livestock/animal waste	Sparse domestic animal feces (e.g. cow pies), evidence of sparse feral pig activity (rooting, wallows, feces)	High concentration of domestic animal feces (e.g. cow pies), evidence of large scale feral pig activity (rooting, wallows, feces)	Runoff from wastewater lagoons into wetland, Evidence of manure piles, poultry litter piles draining to wetland
Septic/sewage discharge	Residential dwellings within 200 meters of wetland	Residential dwellings within 50 meters of wetland	Discharge from sewage treatment plant
Excessive algae or Lemna sp. (Do not count this metric if algae or *Lemna* blooms are a result of evapoconcentration of nutrients as wetland is drying.)	Sparse mats or blooms of filamentous algae, Lemna, or cyanobacteria. Small contiguous patches are less than 200 square meters	Mats or blooms of filamentous algae, *Lemna* , or cyanobacteria may cover large areas but will not be contiguous for more than 0.1 hectares and will contain intermittent gaps where no mats or blooms or present.	Mats or blooms of filamentous algae, *Lemna* , or cyanobacteria that are contiguous for areas larger than 0.1 hectares.

2. Water Quality Condition

b. Sediment

1. On an aerial photograph in the field outline all areas within the AA where sediment loading has been altered and severity of alteration. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos.
2. Severity of alteration is based on indicator severity on the following worksheet.
3. Fill in the area as a percent of the AA and severity for each indicator of altered sediment loading. Overlapping areas of indicators are only counted once and for the highest level of severity. Describe the indicator and circle all indicators on the indicator worksheet.

4. The metric is calculated by applying severity weights to the impacted area. For example a severity weight of 0.25 is applied to minor sources of impacted sediment loading. If 50% of the AA is affected by a minor source of altered sediment loading, the metric score would be 0.875 (1-[0.50*0.25] = 0.875).

Indicators of Altered Sediment loading	Minor	Moderate	Major	Indicator Description
Sedimentation (e.g. presence of sediment plumes, fans or deposits, turbidity, silt laden vegetation)				
Upland erosion (e.g. gullies, rills)				
TOTAL IMPACTED AREA	**0**	**0**	**0**	
SEVERITY WEIGHT	**0.25**	**0.5**	**0.75**	
SEVERITY WEIGHTED AREA	**0**	**0**	**0**	
METRIC SCORE 2b		**1**		

2.Water Quality			
b. Sediment	**Severity**		
Indicators of Altered Sediment Loading	**Minor**	**Moderate**	**Major**
Sedimentation (e.g. presence of sediment plumes, fans or deposits)	Excessive turbidity (in excess of expectation for the system), silt laden vegetation	Sediment plumes or fans, silt deposits less than 0.5 centimeters in thickness	Silt deposits greater than 0.5 centimeters in thickness
Upland erosion (e.g. gullies, rills)	Sparse rills connecting upland to wetland	Dense rills connecting upland to wetland	Gullies connecting upland to wetland

2. Water Quality Condition

c. Chemical contaminants

1. On an aerial photograph in the field outline all areas within the AA where chemical contaminants have been introduced and severity of alteration. For calculations, sketches on aerial photographs can be converted to GIS or estimated from aerial photos.
2. Severity of alteration is based on indicator severity on the following worksheet.
3. Fill in the area as a percent of the AA and severity for each indicator of introduced chemical contaminants. Overlapping areas of indicators are only counted once and for the highest level of severity. Describe the indicator and circle all indicators on the indicator worksheet.
4. The metric is calculated by applying severity weights to the impacted area. For example a severity weight of 0.25 is applied to minor sources of chemical contaminants. If 50% of the AA is affected by a minor source of chemical contaminants, the metric score would be 0.875 (1-[0.50*0.25] = 0.875).

Indicators of Chemical Contaminants	Minor	Moderate	Major	Indicator Description
Point source discharge (wastewater plant, factory etc.)				
Stormwater inputs (discharge pipes, culverts, adjacent impervious surface or railroads)				
Increased salinity (e.g. salt crust)				
Industrial spills or dumping				
Oil sheen*				
TOTAL IMPACTED AREA	0	0	0	
SEVERITY WEIGHT	0.25	0.5	0.75	
SEVERITY WEIGHTED AREA	0	0	0	
METRIC SCORE 2c				1

Notes:

*Oil sheen can result from petroleum spills or from a natural phenomena. If the oil sheen does not break apart when hit with a stick, it is a result of a petroleum spill and should be counted as an indicator of chemical contaminants. If the oil sheen does break apart when hit, do not count it as a chemical contaminant.

2.Water Quality			
c. Contaminants	**Severity**		
Indicators of Chemical Contaminants	**Minor**	**Moderate**	**Major**
Point source discharge (wastewater plant, factory etc.)	n/a	Discharge from wastewater/sewage treatment plant or industrial factor to adjacent water body that is intermittently connected to wetland	Direct discharge from wastewater treatment plant or industrial factory
Stormwater inputs (discharge pipes, culverts, adjacent impervious surface or railroads)	Adjacent impervious surfaces such as paved roads or railroads (within 10 meters of wetland)	Stormwater inputs from culverts or discharge pipes	n/a
Increased salinity (e.g. salt crust, excessively high conductivity)	Oil and gas exploration within 30 meters of wetland (e.g. pumpjacks, tank batteries)	Salt crust present on soil surface (excludes saline wetlands such as those in the Great Salt Plains of Alfalfa County)	n/a
Industrial spills or dumping	55 gallon drums present but otherwise no signs of chemical contamination, metal objects or other potentially harmful trash dumped within the wetland	n/a	Knowledge or evidence of industrial spill within or directly adjacent to the wetland
Oil sheen	Oil sheen present but not contiguous over areas exceeding 200 square meters, likely a result of motorcraft use within or adjacent to the wetland	Oil sheen contiguous over moderate areas within the wetland exceeding 200 square meters, likely a result of a spill or adjacent exploration	Oil sheen contiguous over large areas within the wetland exceeding 0.1 hectares, likely a result of a spill or adjacent exploration

2. Water Quality Condition

d. Buffer filter

Instructions:

1. On an aerial photograph or in GIS, draw eight evenly spaced 250 m lines emanating from the AA boundary starting at due North. If the AA is connected to permanent open water begin the line on the other side of the open water.
2. Calculate the distance until human impacted land-use (see table below). For high impact land-use the buffer must be 250 m in length to be fully functioning. For moderate impact land-use the buffer must be 100 m in length to be fully functioning and for low impact land-use the buffer must be 30 m to be considered fully functioning.
3. For each buffer line calculate the percentage of intact buffer distance. For example if the buffer is intact for 80 meters before intersecting a golf course the buffer is 80% of fully functioning (80/100). On the other hand, if the buffer is intact for 80 meters before intersecting a feedlot the buffer is only 32% functioning (80/250).
4. For the overall buffer filter score, take the average of all eight buffer lines.

Land-uses that can be included in a functioning buffer: natural uplands, water bodies, wildland parks, bike trails, foot trails, horse trails, gravel/dirt roads, railroads

Land use category	Types of Land-use Beyond Buffer	Buffer width
High Impact	Intensive livestock (feedlot, dairy farm, pig farm) or urban area	250m
Moderate Impact	Conventional tilled agriculture, landscaped park, golf course, suburban area, active construction sites, areas of vegetation removal, earth moving operations	100m
Low Impact	No till agriculture, pasture, hay meadow, paved road	30m

Buffer	Required Distance (based on first encountered land-use)	Intact Distance
1		
2		
3		
4		
5		
6		
7		
8		
METRIC SCORE 2d	**1**	

3. Biotic Condition

a. Vegetation condition

Instructions:

1. Conduct a visual assessment of the percent cover of each vegetation layer and % cover of indicators of altered vegetation community in each vegetation layer.

2. Vegetation condition score is based on the percent of unimpacted vegetation cover relative to the overall vegetation cover.

	Vegetation Layers			
Indicators of altered vegetation community (% cover in each layer)	**Tree**	**Shrub/sapling**	**Herbaceous/ Emergent**	**Submergent/ Floating leaved**
Invasive species and crop/pasture grasses*				
Native monoculture (only emergent and submergent layers) **				
Vegetation removal (e.g. tree harvest, brush hogging, haying, mowing) ***				
Excessive grazing (only emergent and submergent) ****				
Herbicide impacted area				
Mechanical disturbance from structures (e.g. rip-rap, right of ways and roads etc.)				
Percent Cover of Layer				
Percent disturbed cover per layer				
METRIC SCORE 4a	1			

Notes:

* Invasive species include all plant species listed on the Oklahoma Non-Native Invasive Plant Species List developed by OK Native Plant Society, OK Biological Survey and OSU Natural Resource Ecology and Management. A species is considered invasive if it is listed as a problem in border states as well. http://ok-invasive-plant-council.org/images/OKinvasivespp.pdf

** Native monocultures occur when more than 50% of a an assessment area is covered by one native perennial species including cattails (*Typha* sp.)*, river bulrush (Schoenoplecuts fluviatis)* , giant cutgrass (*Zizaniopsis miliacea)* , and reed canary grass (*Phalaris arundinacea).* Native monoculture cover is scored as the percent cover greater than 50%. For example a wetland with 70% cover reed canary grass would receive a score of 20% (70-50= 20).

*** Vegetation removal can be an effective management strategy for improving the quality of wetland vegetation by removing invasive species or native monocultures. Vegetation removal for invasive species or monoculture control should not be included in this field.

**** Excessive grazing represents areas where vegetation is eaten to the ground. Grazing can be an effective management strategy for improving the quality of wetland vegetation by removing invasive species or native monocultures. Grazing for invasive species or monoculture control should not be included in this field.

3. Biotic Condition c. Habitat connectivity	
Instructions: 1. On an aerial photograph or in GIS delineate the connected habitat surrounding the AA within a 2500 m buffer. Connected habitat does not include any of the dispersal barriers below. 2. Calculate the metric by dividing the total connected area by the total area in the 2500 m buffer.	
Included in connected habitat	
open water	
other wetlands	
natural uplands	
nature or wildland parks	
bike trails	
railroads	
roads not hazardous to wildlife	
swales and ditches	
vegetated levees	
open range land	
Dispersal Barriers not included in connected habitat	
Commercial Developments	
Fences that interfere with animal movements	
dryland farming	
intensive agriculture (e.g. row crops, orchards, vineyards)	
paved roads	
lawns	
parking lots	
intensive livestock production (e.g. horse paddocks, feedlots, chicken ranches etc.)	
residential areas	
sound walls	
sports fields	
traditional golf courses	
urbanized parks with active recreation	
pedestrian/bike trails with near constant traffic	
Area of Connected Habitat	
Area within 2500 m buffer	
METRIC SCORE 4c	1

4. OKRAM Overall Condition Score			
	Metric	**Score**	
1	***Hydrology***		
1a.	Hydroperiod	1	
1b.	Water source	1	
1c.	Hydrologic Connectivity	1	
	Hydrology Subscore	**1**	*(metric 1a +metric 1b + metric 1c)/3*
2	***Water Quality***		
2a.	Nutrients	1	
2b.	Sediment	1	
2c.	Contaminants	1	
2d.	Buffer Filter	1	
	Water Quality Subscore	**1**	*(metric 2a +metric 2b + metric 2c + metric 2d)/4*
3	***Biota***		
3a.	Vegetation	1	
3b.	Habitat Connectivity	1	
	Biota Subscore	**1**	*(metric 3a + metric 3b)/2*
	Overall Condition Score	**1**	*(Hydrology Subscore + Water Quality Subscore + Biota Subscore)/3*

Appendix B: List of plant species collected in 28 depressional wetlands across Oklahoma

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Acer negundo	boxelder	1	2
Acer rubrum	red maple	6	1
Acer saccharinum	silver maple	2 *	1
Acorus calamus	calamus	0	1
Alisma subcordatum	American water plantain	6	2
Amaranthus palmeri	carelessweed	0 *	3
Amaranthus tuberculatus	roughfruit amaranth	0 *	1
Ambrosia artemisiifolia	annual ragweed	3	7
Ambrosia trifida	great ragweed	2	3
Ammannia auriculata	eared redstem	6	2
Ammannia coccinea	valley redstem	6	8
Amorpha laevigata	smooth false indigo	6	1
Ampelopsis cordata	heartleaf peppervine	2	1
Andropogon glomeratus	bushy bluestem	3	1
Apios americana	groundnut	6	1
Arundinaria gigantea	giant cane	7	1
Asclepias incarnata	swamp milkweed	5	1
Baccharis salicina	willow baccharis	4 *	1
Bacopa rotundifolia	disk waterhyssop	6	3
Berchemia scandens	Alabama supplejack	6 **	1
Bolboschoenus fluviatilis	river bulrush	4	3
Bolboschoenus maritimus	cosmopolitan bulrush	6	1
Broussonetia papyrifera	paper mulberry	0	1
Brunnichia ovata	American buckwheat vine	6	1
Calamovilfa gigantea	giant sandreed	8 *	1
Campsis radicans	trumpet creeper	3	8
Cardiospermum halicacabum	balloon vine	0	3
Carex aureolensis	goldenfruit sedge	5	1
Carex davisii	Davis' sedge	4 *	1
Carex frankii	Frank's sedge	5	1
Carex hyalinolepis	shoreline sedge	5	1
Carex joorii	cypress swamp sedge	8	1
Carex lupuliformis	false hop sedge	8	2
Carex lupulina	hop sedge	6	1
Carex microdonta	littletooth sedge	7	1
Carya illinoinensis	pecan	6	4
Celtis laevigata	sugarberry	5 *	1
Cephalanthus occidentalis	common buttonbush	4	12
Chamaesyce humistrata	spreading sandmat	3 *	2
Chenopodium album	lambsquarters	0 *	1
Cinna arundinacea	sweet woodreed	5	1

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Clitoria mariana	Atlantic pigeonwings	7 *	1
Cocculus carolinus	Carolina coralbead	3	1
Commelina virginica	Virginia dayflower	4	1
Conyza canadensis	Canadian horseweed	1	1
Coreopsis tinctoria	golden tickseed	1 *	7
Cornus drummondii	roughleaf dogwood	3	1
Cornus foemina	stiff dogwood	6	1
Cuscuta cuspidata	cusp dodder	3 *	1
Cuscuta polygonorum	smartweed dodder	3 *	1
Cynodon dactylon	Bermudagrass	0	7
Cyperus acuminatus	tapertip flatsedge	3	10
Cyperus echinatus	globe flatsedge	3 *	2
Cyperus iria	ricefield flatsedge	0	2
Cyperus odoratus	fragrant flatsedge	3	5
Cyperus squarrosus	bearded flatsedge	4	1
Cyperus strigosus	strawcolored flatsedge	4	6
Cyperus surinamensis	tropical flatsedge	3	2
Cyperus pseudovegetus	marsh flatsedge	6	2
Desmodium canescens	hoary ticktrefoil	4 *	1
Dichanthelium aciculare	needleleaf rosette grass	8	1
Dichanthelium acuminatum	tapered rosette grass	4	1
Dichanthelium depauperatum	starved panicgrass	7 *	3
Dichanthelium dichotomum	cypress panicgrass	8 *	2
Dichanthelium scoparium	velvet panicum	7	1
Digitaria sanguinalis	hairy crabgrass	0	1
Diospyros virginiana	common persimmon	2	3
Distichlis spicata	saltgrass	4	1
Echinochloa colona	jungle rice	0	2
Echinochloa crus-galli	barnyardgrass	0	8
Echinochloa muricata	rough barnyardgrass	0	10
Echinodorus berteroi	upright burhead	8	4
Eleocharis engelmannii	Engelmann's spikerush	5	3
Eleocharis geniculata	Canada spikesedge	10	1
Eleocharis macrostachya	pale spikerush	6	1
Eleocharis obtusa	blunt spikerush	4	7
Eleocharis palustris	common spikerush	7	7
Eleocharis quadrangulata	squarestem spikerush	7	1
Eleusine indica	Indian goosegrass	0	2
Eragrostis pectinacea	tufted lovegrass	0 *	1
Equisetum laevigatum	smooth horsetail	3	1
Eragrostis secundiflora	red lovegrass	7 *	1
Eupatorium perfoliatum	common boneset	5	1
Eupatorium serotinum	lateflowering thoroughwort	3	1

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Eustoma exaltatum	catchfly prairie gentian	6	1
Euonymus kiautschovicus	creeping strawberry bush	0	1
Frangula caroliniana	Carolina buckthorn	6 **	1
Fraxinus pennsylvanica	green ash	3	3
Gleditsia triacanthos	honeylocust	2	1
Glycine max	soybean	0	1
Helianthus petiolaris	prairie sunflower	1 *	1
Heteranthera limosa	blue mudplantain	7	1
Heteranthera rotundifolia	roundleaf mudplantain	5	3
Hibiscus laevis	halberdleaf rosemallow	4	2
Hordeum jubatum	foxtail barley	2	2
Hydrolea ovata	ovate false fiddleleaf	8	1
Ilex vomitoria	yaupon	7	1
Impatiens capensis	jewelweed	5	2
Ipomoea lacunosa	whitestar	2	2
Juncus effusus	common rush	5	4
Juncus nodatus	stout rush	5	1
Juncus secundus	lopsided rush	5 **	2
Juncus torreyi	Torrey's rush	6	3
Juncus diffusissimus	slimpod rush	5	1
Juniperus virginiana	eastern redcedar	0	2
Justicia americana	American water-willow	5	1
Kummerowia striata	Japanese clover	0	2
Leersia oryzoides	rice cutgrass	4	5
Lemna minor	common duckweed	5	2
Leptochloa fusca	Malabar sprangletop	3	2
Lindernia dubia	yellowseed false pimpernel	4	8
Leptochloa panicea	mucronate sprangletop	3	1
Liquidambar styraciflua	sweetgum	6 **	2
Lonicera japonica	Japanese honeysuckle	0	1
Ludwigia alternifolia	seedbox	5	2
Ludwigia palustris	marsh seedbox	5	3
Lycopus americanus	American water horehound	4	2
Lycopus virginicus	Virginia water horehound	5	2
Lythrum alatum	winged lythrum	6	1
Melothria pendula	Guadeloupe cucumber	1	1
Mikania scandens	climbing hempvine	5	2
Mimulus alatus	sharpwing monkeyflower	5	2
Mollugo verticillata	green carpetweed	1	3
Muhlenbergia cuspidata	plains muhly	5 *	1
Panicum anceps	beaked panicgrass	4 *	3
Panicum capillare	witchgrass	1	2
Panicum coloratum	kleingrass	0	4

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Panicum dichotomiflorum	fall panicgrass	1	2
Panicum obtusum	vine mesquite	2 *	1
Panicum verrucosum	warty panicgrass	5	1
Panicum virgatum	switchgrass	4	1
Panicum miliaceum	proso millet	0	1
Panicum philadelphicum	Philadelphia panicgrass	4 *	3
Paspalum dilatatum	dallisgrass	0	2
Paspalum distichum	knotgrass	7	2
Paspalum floridanum	Florida paspalum	5	3
Passiflora incarnata	purple passionflower	4 *	1
Phyla lanceolata	lanceleaf fogfruit	3	6
Phyla nodiflora	turkey tangle fogfruit	3	2
Physalis virginiana	Virginia groundcherry	6 *	1
Pinus taeda	loblolly pine	2	1
Plantago lanceolata	narrowleaf plantain	0	1
Platanus occidentalis	American sycamore	4	1
Pluchea odorata	sweetscent	4	1
Polygonella americana	southern jointweed	5 **	1
Polygonum amphibium	water knotweed	7	2
Polygonum aviculare	prostrate knotweed	0	1
Polygonum hydropiperoides	swamp smartweed	4	14
Polygonum lapathifolium	curlytop knotweed	4	3
Polygonum persicaria	spotted ladysthumb	0	2
Polygonum pensylvanicum	Pennsylvania smartweed	2	4
Polygonum ramosissimum	bushy knotweed	1	1
Polygonum punctatum	dotted smartweed	4	1
Polygonum virginianum	jumpseed	5 ***	1
Polypremum procumbens	juniper leaf	4 **	1
Populus deltoides	eastern cottonwood	1	4
Quercus alba	white oak	3	1
Quercus marilandica	blackjack oak	4 *	1
Quercus nigra	water oak	5 **	2
Quercus phellos	willow oak	4	1
Quercus stellata	post oak	4 *	1
Rhus copallinum	winged sumac	7	1
Rhynchospora corniculata	shortbristle horned beaksedge	7	3
Rhynchospora macrostachya	tall horned beaksedge	6	1
Robinia pseudoacacia	black locust	1	1
Rubus trivialis	southern dewberry	4 *	1
Rumex altissimus	pale dock	0	3
Rumex crispus	curly dock	0	2
Rumex stenophyllus	narrowleaf dock	0	4
Sagittaria ambigua	Kansas arrowhead	8	1

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Sagittaria brevirostra	shortbeak arrowhead	4	1
Sagittaria graminea	grassy arrowhead	8	1
Salix babylonica	Weeping willow	0	1
Salix interior	sandbar willow	3 **	2
Salix nigra	black willow	2	9
Saururus cernuus	lizard's tail	6	1
Schoenoplectus acutus	hardstem bulrush	4	2
Schoenoplectus americanus	chairmaker's bulrush	6	3
Schoenoplectus pungens	common threesquare	6	1
Scirpus cyperinus	woolgrass	7	1
Sesbania herbacea	bigpod sesbania	2	4
Setaria parviflora	marsh bristlegrass	2	2
Sicyos angulatus	oneseed bur cucumber	3	1
Smilax bona-nox	saw greenbrier	5	1
Solanum carolinense	Carolina horsenettle	1	3
Solanum dimidiatum	western horsenettle	3 *	1
Sorghum halepense	Johnsongrass	0	9
Strophostyles leiosperma	slickseed fuzzybean	3 *	1
Symphyotrichum subulatum	eastern annual saltmarsh aster	4	3
Tamarix chinensis	five-stamen tamarisk	0	1
Taraxacum officinale	common dandelion	0	2
Teucrium canadense	Canada germander	3	7
Thalia dealbata	powdery alligator-flag	7	1
Toxicodendron radicans	eastern poison ivy	1	2
Trachelospermum difforme	climbing dogbane	6	2
Trifolium repens	white clover	0	3
Typha domingensis	southern cattail	2	3
Ulmus alata	winged elm	3	4
Ulmus americana	American elm	2	7
Urochloa platyphylla	broadleaf signalgrass	0	1
Vernonia missurica	Missouri ironweed	4	1
Vernonia texana	Texas ironweed	4	1
Viola sagittata	arrowleaf violet	7 *	2
Vitis riparia	riverbank grape	4	1
Vitis vulpina	frost grape	3 *	1
Xanthium strumarium	rough cocklebur	0	6
Zea mays	corn	0	1

Notes: * Kansas CoC; ** Missouri CoC, *** Iowa CoC

Appendix C: Metrics calculated for 28 depressional wetlands across Oklahoma

(a) Landscape Development Intensity Index (LDI) Scores

Site	LDI 100_B	LDI_500_B	LDI 1000m
1	2.47	2.48	2.24
2	2.90	3.05	2.86
3	3.77	3.36	2.98
4	4.56	8.00	7.83
5	1.04	1.90	2.40
6	5.37	4.53	4.20
7	2.69	2.85	3.25
8	7.00	7.00	6.78
9	4.01	5.57	4.94
10	7.49	7.96	8.32
11	3.74	4.62	4.30
12	7.65	7.31	7.03
13	9.01	9.00	8.63
14	6.15	5.56	5.46
15	7.85	8.40	7.85
16	3.19	3.03	3.27
17	5.71	3.89	2.86
18	7.04	5.58	4.49
19	2.28	3.78	3.14
20	7.00	6.34	5.20
21	3.24	3.57	4.11
22	6.43	5.31	4.73
23	7.17	7.39	7.37
24	1.35	2.68	2.61
25	1.59	2.27	2.20
26	3.66	2.99	2.75
27	1.51	1.51	1.66
28	1.82	1.24	1.35

(b) Plant Diversity, Richness, Native Richness, % WET, and FQI Scores

Site	Diversity	Species Richness	Native Species Richness	% WET	FQI_{all}
1	2.45	22	20	96.07	16.53
2	1.86	20	18	91.25	14.84
3	2.41	16	14	92.58	16.80
4	2.11	16	14	88.21	12.16
5	1.30	8	7	69.12	8.00
6	0.00	0	0	0	3.00
7	1.44	12	8	98.19	7.77
8	1.01	4	3	100	13.87
9	2.10	20	18	100	17.85
10	1.21	7	7	100	11.46
11	1.71	9	8	84.62	14.70
12	2.15	15	12	67.95	8.49
13	1.53	9	3	51.88	6.63
14	0.45	6	5	95.54	9.53
15	1.86	13	9	79.34	8.37
16	2.47	19	15	91.43	16.10
17	2.08	15	11	99.49	8.25
18	2.04	14	8	95.13	6.95
19	2.26	17	14	97.01	10.19
20	2.59	20	17	71.58	12.09
21	1.93	14	13	97.58	14.25
22	0.00	1	1	88.89	2.24
23	1.43	9	3	67.4	4.11
24	2.83	29	24	92.2	24.33
25	1.96	18	15	96.32	22.26
26	2.34	23	18	97.64	19.21
27	2.13	21	18	95.94	21.80
28	2.02	21	19	98.58	24.49

(c) Soil Metrics

Site	P (ppm)	NO3 (ppm)	NH4 (ppm)	Na (ppm)	TSS (ppm)	OM (%)	SAR (%)	pH
1	2.0	3.5	39.1	77.0	1320.7	3.5	1.6	8.3
2	28.5	3.5	31.5	177.0	1615.7	3.8	3.6	7.2
3	6.5	1.0	44.3	255.0	3415.5	4.7	3.3	8.1
4	21.0	2.0	21.3	23.0	550.4	2.8	0.7	8.2
5	50.5	9.0	6.4	7.0	1021.7	7.9	0.1	7.8
6	32.0	14.0	4.6	6.0	681.1	1.8	0.2	8.5
7	29.0	10.5	6.6	921.0	6831.0	3.5	8.6	8.1
8	60.5	1.5	17.8	41.0	1350.4	1.9	0.9	7.1
9	24.0	3.5	7.7	95.0	639.5	2.6	4.1	6.5
10	58.0	12.0	10.4	19.0	1057.3	4.0	0.4	7.4
11	11.0	2.5	36.6	14.0	354.4	3.5	0.7	6.0
12	29.5	15.0	6.3	9.0	902.9	2.6	0.2	7.9
13	34.0	23.0	8.9	22.0	1059.3	4.4	0.5	7.5
14	9.5	2.5	44.3	259.0	4613.4	4.6	2.5	8.0
15	27.0	4.5	13.8	12.0	750.4	7.8	0.3	6.6
16	9.5	25.0	14.7	41.0	912.8	3.9	1.1	5.8
17	83.0	3.5	11.8	21.0	344.1	2.1	1.2	5.9
18	67.0	2.0	4.5	14.0	269.7	1.7	0.7	6.4
19	100.0	25.0	11.2	33.0	891.0	5.9	0.9	5.2
20	85.5	17.0	8.3	24.0	778.1	4.2	0.7	6.7
21	15.5	7.5	17.3	13.0	335.6	2.4	0.7	5.2
22	54.0	10.0	37.5	18.0	497.0	2.5	0.9	5.6
23	88.5	7.5	16.4	12.0	564.3	4.1	0.4	6.4
24	22.5	0.0	51.0	80.0	817.7	8.8	3.0	5.1
25	19.5	0.5	24.3	18.0	260.4	1.6	1.4	5.5
26	25.0	10.0	34.8	30.0	799.9	6.2	0.9	5.9
27	15.0	1.5	12.6	13.0	281.4	4.2	0.7	4.9
28	13.0	0.5	32.0	79.0	1411.7	7.4	1.5	7.6

Appendix D: Comparison of Oklahoma Rapid Assessment Method, California Rapid Assessment Method, and Functional Assessment of Colorado Wetlands

RAM Components	OKRAM	CRAM	FACWet
Landscape Component	Buffer - 250 m Habitat Connectivity - 2500 m	Buffer - 250 m Aquatic Area - 500 m	Buffer - 250 m Aquatic Area - 500 m Habitat Connectivity - 500 m
Hydrology Component	Water Source Hydroperiod Hydrologic Connectivity	Water source Hydroperiod Hydrologic Connectivity	Water Source Hydroperiod Hydrologic Connectivity
Physical Component		Structural Patches Topographic Complexity	 Topographic Complexity Substrate Alterations
Biological Component	Plant Layers Plant Invasion Disturbance to Vegetation	Plant Layers Plant Invasion Co-dominant Species Horizontal Interspersion Vertical Biotic Structure	Plant Layers Plant Invasion Disturbance to Vegetation
Physiochemical Component	Nutrients/Eutrophication Sedimentation Contamination		Nutrients/Eutrophication Sedimentation Contamination Soil Chemistry Water Temperature

Note: RAM metrics were placed into five broad categories for a general comparison.

Appendix E: List of plant species collected in 30 lacustrine fringe wetlands in central Oklahoma

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Acalypha virginica	Virginia threeseed mercury	0 *	2
Acer negundo	boxelder	1	1
Acer saccharinum	silver maple	2 *	1
Achillea millefolium	common yarrow	5	1
Ambrosia artemisiifolia	annual ragweed	3	3
Ambrosia psilostachya	Cuman ragweed	3	9
Ambrosia trifida	great ragweed	2	4
Amorpha fruticosa	false indigo bush	6	9
Ampelopsis cordata	heartleaf peppervine	2	4
Andropogon gerardii	big bluestem	4 *	1
Andropogon glomeratus	bushy bluestem	3	2
Andropogon virginicus	broomsedge bluestem	0 *	1
Antennaria parlinii	Parlin's pussytoes	5 *	1
Apios americana	groundnut	6	1
Apocynum cannabinum	Indianhemp	1	4
Artemisia ludoviciana	white sagebrush	2 *	1
Arundo donax	giant reed	0	2
Bolboschoenus fluviatilis	river bulrush	4	1
Bolboschoenus maritimus	cosmopolitan bulrush	6	1
Bothriochloa ischaemum	yellow bluestem	0	2
Bothriochloa laguroides	silver beardgrass	1	5
Bouteloua dactyloides	buffalograss	3 *	2
Bromus arvensis	field brome	0	4
Campsis radicans	trumpet creeper	3	3
Carex annectens	yellowfruit sedge	4	3
Carex aureolensis	goldenfruit sedge	5	2
Carex cherokeensis	Cherokee sedge	6	1
Carex crus-corvi	ravenfoot sedge	7	1
Carex frankii	Frank's sedge	5	4
Carex lupuliformis	false hop sedge	8	1
Carya illinoinensis	pecan	6	3
Celtis laevigata	sugarberry	5 *	1
Cephalanthus occidentalis	common buttonbush	4	25
Ceratophyllum demersum	coon's tail	5	2
Cercis canadensis	eastern redbud	2	2
Chasmanthium latifolium	Indian woodoats	4	3
Chenopodium album	lambsquarters	0 *	1
Clematis versicolor	pale leather flower	9 **	1
Cocculus carolinus	Carolina coralbead	3	1
Commelina erecta	whitemouth dayflower	4	1

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Conium maculatum	poison hemlock	0	2
Convolvulus arvensis	field bindweed	0	1
Conyza canadensis	Canadian horseweed	1	18
Cornus drummondii	roughleaf dogwood	3	3
Cornus florida	flowering dogwood	6 *	1
Cynodon dactylon	Bermudagrass	0	25
Cyperus echinatus	globe flatsedge	3 *	2
Cyperus erythrorhizos	redroot flatsedge	3	1
Cyperus odoratus	fragrant flatsedge	3	16
Cyperus pseudovegetus	marsh flatsedge	6	2
Cyperus squarrosus	bearded flatsedge	4	7
Cyperus strigosus	strawcolored flatsedge	4	4
Datura stramonium	jimsonweed	0	2
Desmanthus illinoensis	Illinois bundleflower	3	8
Dichanthelium oligosanthes	Heller's rosette grass	5	7
Diospyros virginiana	common persimmon	2	8
Echinacea purpurea	eastern purple coneflower	5 *	1
Echinochloa spp.	barnyardgrass	0	22
Eclipta prostrata	false daisy	3	2
Eleocharis compressa	flatstem spikerush	6	2
Eleocharis engelmannii	Engelmann's spikerush	5	1
Eleocharis geniculata	Canada spikesedge	10	2
Eleocharis lanceolata	daggerleaf spikerush	7	1
Eleocharis obtusa	blunt spikerush	4	2
Eleocharis parvula	dwarf spikerush	8	3
Eleocharis quadrangulata	squarestem spikerush	7	1
Elymus canadensis	Canada wildrye	5 *	1
Elymus virginicus	Virginia wildrye	3	1
Equisetum laevigatum	smooth horsetail	3	2
Eragrostis reptans	creeping lovegrass	6	2
Eupatorium serotinum	lateflowering thoroughwort	3	8
Euphorbia marginata	snow on the mountain	3	2
Fimbristylis autumnalis	slender fimbry	6	1
Fraxinus americana	white ash	6	1
Fraxinus pennsylvanica	green ash	3	4
Fuirena simplex	western umbrella-sedge	6	1
Geum canadense	white avens	1 *	2
Gleditsia triacanthos	honeylocust	2	1
Grindelia squarrosa	curlycup gumweed	0 *	2
Helenium amarum	sneezeweed	1	6
Hordeum jubatum	foxtail barley	2	2
Hypericum drummondii	nits and lice	5 *	2
Hypericum mutilum	dwarf St. Johnswort	4	2

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Juncus acuminatus	tapertip rush	5	6
Juncus diffusissimus	slimpod rush	5	1
Juncus effusus	common rush	5	6
Juncus scirpoides	needlepod rush	7	2
Juncus torreyi	Torrey's rush	6	2
Juncus validus	roundhead rush	7	3
Juniperus virginiana	eastern redcedar	0	1
Justicia americana	American water-willow	5	8
Kummerowia stipulacea	Korean clover	0	1
Leersia oryzoides	rice cutgrass	4	15
Lemna minor	common duckweed	5	2
Lepidium virginicum	Virginia pepperweed	0 *	2
Leptochloa fusca	Malabar sprangletop	3	4
Lespedeza cuneata	serecia lespedeza	0	12
Lipocarpha aristulata	awned halfchaff sedge	6	1
Lonicera japonica	Japanese honeysuckle	0	1
Ludwigia peploides	floating primrose-willow	6	1
Lythrum alatum	winged lythrum	6	3
Melilotus officinalis	sweetclover	0	8
Melothria pendula	Guadeloupe cucumber	1	2
Mimosa nuttallii	Nuttall's sensitive-briar	6 *	2
Morus alba	white mulberry	0	2
Morus rubra	red mulberry	5	1
Panicum anceps	beaked panicgrass	4 *	4
Panicum philadelphicum	Philadelphia panicgrass	4 *	6
Panicum virgatum	switchgrass	4	1
Panicum capillare	witchgrass	1	1
Paspalum dilatatum	dallisgrass	0	5
Paspalum distichum	knotgrass	7	3
Paspalum floridanum	Florida paspalum	5	2
Paspalum pubiflorum	hairyseed paspalum	4	2
Paspalum setaceum	thin paspalum	9	1
Paspalum urvillei	Vasey's grass	0	1
Phyla lanceolata	lanceleaf fogfruit	3	16
Phyla nodiflora	turkey tangle fogfruit	3	4
Physalis pubescens	husk tomato	4 *	1
Pistacia chinensis	Chinese pistache	0	1
Platanus occidentalis	American sycamore	4	2
Pluchea odorata	sweetscent	4	8
Poa arachnifera	Texas bluegrass	5 *	5
Polygonum amphibium	water knotweed	7	7
Polygonum hydropiperoides	swamp smartweed	4	11
Polygonum lapathifolium	curlytop knotweed	4	14

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Polygonum pensylvanicum	Pennsylvania smartweed	2	1
Polygonum punctatum	dotted smartweed	4	1
Polygonum ramosissimum	bushy knotweed	1	2
Polypogon monspeliensis	annual rabbitsfoot grass	0	1
Polypremum procumbens	juniper leaf	4 **	1
Populus deltoides	eastern cottonwood	1	15
Potamogeton nodosus	longleaf pondweed	6	9
Potamogeton pusillus	small pondweed	5	4
Ptilimnium nuttallii	laceflower	4	1
Pyrrhopappus carolinianus	Carolina desert-chicory	3	1
Quercus lyrata	overcup oak	7	1
Quercus marilandica	blackjack oak	4 *	1
Quercus palustris	pin oak	3 *	1
Quercus stellata	post oak	4 *	2
Ranunculus sceleratus	cursed buttercup	3	2
Rorippa palustris	bog yellowcress	3	1
Rudbeckia hirta	blackeyed Susan	2 *	1
Rumex altissimus	pale dock	0	1
Rumex crispus	curly dock	0	11
Sabatia campestris	Texas star	6 *	2
Saccharum ravennae	ravennagrass	0	1
Salix interior	sandbar willow	3	1
Salix nigra	black willow	2	26
Samolus valerandi	seaside brookweed	5	1
Schizachyrium scoparium	little bluestem	5 *	6
Schoenoplectus americanus	chairmaker's bulrush	6	2
Schoenoplectus tabernaemontani	softstem bulrush	6	5
Sesuvium verrucosum	verrucose seapurslane	7	2
Setaria parviflora	marsh bristlegrass	2	3
Sideroxylon lanuginosum	gum bully	5	1
Smilax bona-nox	saw greenbrier	5	2
Solidago canadensis	Canada goldenrod	3	1
Sorghastrum nutans	Indiangrass	5 *	1
Sorghum halepense	Johnsongrass	0	7
Spermacoce glabra	smooth false buttonweed	6	3
Sporobolus compositus	composite dropseed	3 *	4
Strophostyles helvola	amberique-bean	2 **	2
Strophostyles leiosperma	slickseed fuzzybean	3 *	2
Symphoricarpos orbiculatus	coralberry	1	4
Symphyotrichum ericoides	white heath aster	5 *	2
Tamarix spp.	saltcedar spp.	0	4
Taxodium distichum	bald cypress	9	2
Teucrium canadense	Canada germander	3	16

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Toxicodendron radicans	eastern poison ivy	1	6
Tradescantia ohiensis	bluejacket	5 *	1
Tridens strictus	longspike tridens	6 *	1
Typha spp.	cattail spp.	3	7
Ulmus alata	winged elm	3	1
Ulmus americana	American elm	2	11
Ulmus rubra	slippery elm	3	2
Vitis aestivalis	summer grape	4	1
Xanthium strumarium	rough cocklebur	0	5
Zizaniopsis miliacea	giant cutgrass	9	20

Notes: * Kansas CoC; ** Missouri CoC

Appendix F: Metrics calculated for 30 lacustrine fringe wetland in central Oklahoma

(a) Landscape Development Intensity Index (LDI) Scores

Site	LDI 100 m	LDI 500 m	LDI 1000 m
1	1.05	2.05	2.52
2	3.43	2.95	2.99
3	3.63	4.35	4.87
4	6.62	6.36	5.83
5	3.24	2.22	2.23
6	3.39	2.08	2.44
7	3.41	2.93	2.75
8	3.21	3.21	3.32
9	5.98	3.09	2.54
10	2.27	4.14	2.87
11	5.84	4.70	4.00
12	2.06	3.45	3.22
13	6.81	5.29	3.57
14	5.52	4.73	3.79
15	4.98	6.24	6.51
16	7.78	7.10	6.60
17	5.12	3.69	3.74
18	5.77	4.14	3.74
19	5.32	5.25	5.57
20	4.81	5.03	5.97
21	3.78	2.82	2.29
22	4.29	2.63	2.35
23	3.41	3.35	3.39
24	3.41	3.38	3.34
25	3.26	3.22	2.68
26	4.05	2.16	1.96
27	3.41	2.86	2.96
28	3.35	2.62	2.92
29	3.41	4.14	3.78
30	4.43	4.09	3.77

(b) Plant Diversity, Richness, Native Richness, % WET, and FQI Scores

Site	Diversity	Species Richness	Native Species Richness	% WET	FQI_{all}
1	2.29	17	14	92.17	13.66
2	1.97	16	14	95.14	16.32
3	2.59	19	15	99.62	11.62
4	2.04	13	10	84.15	7.75
5	3.06	37	31	53.67	16.71
6	2.65	28	22	54.24	16.51
7	2.70	29	23	87.11	15.87
8	2.36	23	18	79.60	12.02
9	2.65	26	22	88.69	20.20
10	2.89	30	26	89.95	21.61
11	2.79	27	20	79.55	18.26
12	2.72	28	23	63.33	16.24
13	2.87	32	28	82.10	21.54
14	2.76	29	23	86.38	16.55
15	2.53	26	19	83.41	13.16
16	2.48	24	18	83.94	13.01
17	1.73	13	12	95.73	13.31
18	2.07	13	10	94.74	9.80
19	2.45	21	18	77.82	13.97
20	2.24	20	15	80.83	15.88
21	3.24	39	35	47.17	20.67
22	2.85	34	27	73.66	19.95
23	2.86	29	24	46.18	16.47
24	2.78	29	23	51.71	15.20
25	2.46	17	12	88.24	9.94
26	1.57	8	5	93.98	5.67
27	2.96	32	26	71.94	15.52
28	2.76	26	22	51.27	15.64
29	1.83	14	11	97.08	8.66
30	1.61	14	10	92.09	11.88

(c) Soil Metrics

Site	P (ppm)	NO3 (ppm)	NH4 (ppm)	Na (ppm)	TSS (ppm)	OM (%)	SAR (%)	pH
1	1.5	0.5	10.3	80.0	633.6	0.6	2.7	8.5
2	8.0	0.5	20.1	64.0	1166.2	1.5	1.5	8.3
3	23.0	0.5	32.3	622.0	4138.2	2.9	8.0	8.1
4	3.0	1.0	7.9	46.0	570.2	0.7	1.6	8.7
5	7.0	4.0	17.8	34.0	805.9	2.5	0.9	8.2
6	3.0	0.5	6.6	101.0	1053.4	1.2	2.4	8.0
7	8.0	1.0	13.6	54.0	817.7	1.7	1.4	7.4
8	5.0	1.0	6.0	25.0	453.4	1.0	0.9	7.7
9	3.5	0.5	13.8	29.0	491.0	1.7	1.0	8.1
10	2.5	0.5	13.7	52.0	586.1	0.8	1.7	8.4
11	2.0	0.5	23.2	129.0	1421.6	1.2	2.8	8.4
12	2.0	1.0	4.9	83.0	756.4	0.6	2.5	8.3
13	6.0	0.5	24.4	109.0	1213.7	4.1	2.4	8.1
14	6.0	1.5	41.4	281.0	1760.2	6.3	5.9	7.4
15	1.5	0.5	4.1	133.0	639.5	0.6	5.5	8.0
16	1.5	1.0	3.2	143.0	663.3	0.9	5.9	8.3
17	3.5	0.5	14.1	44.0	370.1	1.4	2.1	6.8
18	1.5	0.5	3.9	162.0	829.6	1.4	5.6	8.3
19	17.5	1.5	22.6	1136.0	5009.4	4.3	16.6	8.1
20	23.0	1.5	37.0	1313.0	6652.8	3.4	14.6	8.2
21	4.0	0.5	18.0	40.0	361.9	2.3	2.1	5.7
22	1.5	0.5	4.7	87.0	594.0	1.1	3.2	6.8
23	3.0	0.5	7.0	37.0	469.3	2.3	1.4	6.8
24	2.5	1.5	14.9	70.0	364.1	3.2	3.9	6.8
25	2.0	0.5	6.8	27.0	481.1	4.2	0.9	7.8
26	2.0	1.0	8.4	16.0	393.4	1.0	0.6	7.5
27	3.0	1.0	9.3	25.0	663.3	2.4	0.7	6.8
28	2.0	2.5	7.8	25.0	605.9	2.2	0.7	7.9
29	5.5	1.0	11.1	411.0	1740.4	1.9	12.8	8.3
30	2.5	0.5	7.8	416.0	1875.1	1.3	12.0	8.3

(d) Invertebrate Richness (SPR), Diversity (SWD), and % Functional Feeding Groups

Site	SPR	SWD	% Coleo	% Dipt	% Ephem	% Odon	% Chiron	% Filterer	% Gatherer	% Predator	% Scraper	% Shredder
1	24	1.17	0.88	7.02	1.40	0.35	5.61	0	81.6	9.5	8.2	0.7
2	34	2.11	1.31	13.43	4.94	4.38	12.31	0	23.83	69.31	6.11	0.75
4	20	0.81	0.32	1.22	0.00	0.05	0.85	0	0.85	98.57	0.42	0.16
8	24	1.10	3.39	3.80	2.44	0.95	3.12	0.27	86.84	7.87	4.21	0.81
9	30	0.70	0.75	2.88	1.67	1.17	0.71	0	88.75	4.92	6	0.33
10	22	0.34	0.27	1.49	0.00	0.35	0.55	0	95.28	2.61	2.04	0.08
13	23	2.13	2.38	19.35	6.25	8.33	8.33	0	54.61	15.18	29.91	0.3
17	19	1.93	6.70	54.90	3.09	0.89	53.35	1.03	82.47	10.82	5.41	0.26
20	19	1.54	0.12	37.36	28.48	0.25	37.24	0.62	78.98	5.18	15.23	0
23	17	2.40	2.42	20.97	22.58	10.48	16.13	4.84	50.81	33.06	10.48	0.81
24	27	1.73	3.83	7.15	25.62	6.66	3.16	0	61.81	12.73	23.96	1.5
25	19	1.33	0.00	61.85	6.15	3.08	59.69	0	88.77	6.62	4.62	0
26	15	1.69	2.62	15.18	29.32	7.33	14.66	1.57	69.9	12.04	15.97	0.52
29	21	1.62	3.21	1.40	8.42	3.61	1.20	23.85	57.72	8.62	9.82	0
30	18	1.29	1.71	2.99	2.99	4.27	0.43	9.4	74.57	11.97	3.63	0.43

Coleo = Coleoptera, Dipt = Diptera, Ephem = Ephemeroptera, Odon = Odonata, Chiron = Chironomidae

(e) Water Quality Metrics

Site	pH	Turbidity (NTU)	Conductivity (uS/cm)	Temperature (°C)	DO (mg/L)	Nitrate (mg/L)	Ammonia (mg/L)	Phosphorus (mg/L)
1	8.5	73.1	781.6	24.4	6.0	0.00	0.04	0.2
2	8.5	11.4	802.6	25.8	6.1	0.01	0.06	0.3
4	8.2	85.8	733.4	27.4	6.9	0.02	0.01	0.4
8	8.6	18.8	428.6	30.6	8.5	0.00	0.05	0.1
9	8.5	5.9	444.4	26.5	6.2	0.01	0.05	0.2
10	8.1	90.7	425.2	24.8	4.3	0.01	0.02	0.4
13	8.8	5.6	420.6	29.1	5.6	0.01	0.03	0.7
17	8.7	41.4	388.6	27.5	5.6	0.04	0.02	0.3
20	8.6	133.8	914.0	25.0	5.9	0.00	0.05	0.7
23	7.6	136.6	124.2	28.7	4.5	0.01	0.02	0.5
24	7.3	261.0	134.4	34.8	7.3	0.01	0.07	0.4
25	8.9	35.3	125.6	30.1	7.8	0.03	0.00	0.1
26	7.9	38.6	116.4	26.3	6.1	0.03	0.02	0.2
29	8.6	3.9	2400.0	30.0	6.6	0.01	0.01	0.1
30	8.4	3.1	2451.4	31.3	7.5	0.02	0.01	0.1

Appendix F: List of plant species collected from 68 depressional wetlands across Oklahoma

Scientific Name	**Common Name**	**Coefficient of Conservatism**	**Number of Sites**
Abutilon theophrasti	velvetleaf	0	2
Acer negundo	boxelder	1	2
Acer rubrum	red maple	6	1
Acer saccharinum	silver maple	2 *	1
Achillea millefolium	common yarrow	5	2
Acorus calamus	calamus	0	1
Agalinis fasciculata	beach false foxglove	6 *	5
Agrostis hyemalis	winter bentgrass	3	6
Agrostis perennans	upland bentgrass	5 *	1
Alisma subcordatum	American water plantain	6	2
Alopecurus carolinianus	Carolina foxtail	2	8
Amaranthus palmeri	carelessweed	0 *	8
Amaranthus retroflexus	redroot amaranth	1 *	7
Amaranthus tuberculatus	roughfruit amaranth	0 *	3
Ambrosia artemisiifolia	annual ragweed	3	9
Ambrosia psilostachya	Cuman ragweed	3	15
Ambrosia trifida	great ragweed	2	4
Ammannia auriculata	eared redstem	6	2
Ammannia coccinea	valley redstem	6	8
Amorpha fruticosa	false indigo bush	6	1
Amorpha laevigata	smooth false indigo	6	1
Ampelopsis cordata	heartleaf peppervine	2	1
Andropogon glomeratus	bushy bluestem	3	1
Andropogon virginicus	broomsedge bluestem	0 *	6
Aphanostephus ramosissimus	plains dozedaisy	5 *	1
Apios americana	groundnut	6	1
Artemisia ludoviciana	white sagebrush	2 *	2
Arundinaria gigantea	giant cane	7	1
Asclepias incarnata	swamp milkweed	5	1
Asclepias viridis	green antelopehorn	1 *	1
Baccharis salicina	willow baccharis	4 *	1
Bacopa rotundifolia	disk waterhyssop	6	3
Bassia scoparia	burningbush	0	4
Berchemia scandens	Alabama supplejack	6 **	1
Bolboschoenus fluviatilis	river bulrush	4	3
Bolboschoenus maritimus	cosmopolitan bulrush	6	1
Bromus arvensis	field brome	0	1
Bromus catharticus	rescuegrass	0	7
Bromus racemosus	bald brome	0	8
Bromus secalinus	rye brome	0	3
Bromus tectorum	cheatgrass	0	6
Broussonetia papyrifera	paper mulberry	0	1
Brunnichia ovata	American buckwheat vine	6	1
Buchloe dactyloides	buffalograss	3 *	1
Calamovilfa gigantea	giant sandreed	8 *	1
Campsis radicans	trumpet creeper	3	8

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Cardiospermum halicacabum	balloon vine	0	4
Carex aureolensis	goldenfruit sedge	5	1
Carex austrina	southern sedge	2 *	1
Carex davisii	Davis' sedge	4 *	1
Carex festucacea	fescue sedge	6 *	7
Carex frankii	Frank's sedge	5	1
Carex hyalinolepis	shoreline sedge	5	1
Carex joorii	cypress swamp sedge	8	1
Carex lupuliformis	false hop sedge	8	2
Carex lupulina	hop sedge	6	1
Carex microdonta	littletooth sedge	7	1
Carex pellita	woolly sedge	6	3
Carex tetrastachya	Britton's sedge	5	1
Carya illinoinensis	pecan	6	4
Celtis laevigata	sugarberry	5 *	1
Celtis occidentalis	common hackberry	5	3
Cenchrus longispinus	mat sandbur	0 *	1
Cenchrus spinifex	coastal sandbur	2 *	2
Cephalanthus occidentalis	common buttonbush	4	16
Chamaesyce humistrata	spreading sandmat	3 *	2
Chamaesyce prostrata	ground spurge	0 *	1
Chenopodium album	lambsquarters	0 *	13
Chenopodium berlandieri	pitseed goosefoot	0 *	3
Chenopodium leptophyllum	narrowleaf goosefoot	0 *	4
Chenopodium pallescens	slimleaf goosefoot	1 *	1
Chenopodium pratericola	desert goosefoot	3 *	7
Chenopodium standleyanum	Standley's goosefoot	3	1
Chrysopsis pilosa	soft goldenaster	4	1
Cinna arundinacea	sweet woodreed	5	1
Citrullus lanatus	watermelon	0	1
Clitoria mariana	Atlantic pigeonwings	7 *	1
Cocculus carolinus	Carolina coralbead	3	1
Commelina erecta	whitemouth dayflower	4	2
Commelina virginica	Virginia dayflower	4	1
Convolvulus arvensis	field bindweed	0	1
Conyza canadensis	Canadian horseweed	1	23
Coreopsis tinctoria	golden tickseed	1 *	14
Cornus drummondii	roughleaf dogwood	3	1
Cornus foemina	stiff dogwood	6	1
Croton glandulosus	vente conmigo	1 *	1
Croton lindheimerianus	threeseed croton	8 *	1
Croton texensis	Texas croton	1 *	2
Cuscuta cuspidata	cusp dodder	3 *	1
Cuscuta polygonorum	smartweed dodder	3 *	1
Cynodon dactylon	Bermudagrass	0	24
Cyperus acuminatus	tapertip flatsedge	3	10
Cyperus echinatus	globe flatsedge	3 *	2
Cyperus iria	ricefield flatsedge	0	2

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Cyperus pseudovegetus	marsh flatsedge	6	2
Cyperus rotundus	nutgrass	0	1
Cyperus squarrosus	bearded flatsedge	4	1
Cyperus strigosus	strawcolored flatsedge	4	7
Cyperus surinamensis	tropical flatsedge	3	2
Datura stramonium	jimsonweed	0	1
Desmodium canescens	hoary ticktrefoil	4 *	1
Dichanthelium aciculare	needleleaf rosette grass	8	1
Dichanthelium acuminatum	tapered rosette grass	4	7
Dichanthelium depauperatum	starved panicgrass	7 *	3
Dichanthelium dichotomum	cypress panicgrass	8 *	2
Dichanthelium oligosanthes	Heller's rosette grass	5	3
Dichanthelium scoparium	velvet panicum	7	1
Digitaria cognata	fall witchgrass	3 *	1
Digitaria pubiflora	Carolina crabgrass	3 *	1
Digitaria sanguinalis	hairy crabgrass	0	1
Diospyros virginiana	common persimmon	2	4
Distichlis spicata	saltgrass	4	4
Dysphania ambrosioides	Mexican tea	0	4
Echinochloa colona	jungle rice	0	2
Echinochloa crus-galli	barnyardgrass	0	18
Echinochloa muricata	rough barnyardgrass	0	23
Echinodorus berteroi	upright burhead	8	5
Eleocharis acicularis	needle spikerush	5	1
Eleocharis compressa	flatstem spikerush	6	2
Eleocharis engelmannii	Engelmann's spikerush	5	3
Eleocharis geniculata	Canada spikesedge	10	1
Eleocharis lanceolata	daggerleaf spikerush	7	2
Eleocharis macrostachaya	pale spikerush	6	5
Eleocharis obtusa	blunt spikerush	4	9
Eleocharis palustris	common spikerush	7	8
Eleocharis quadrangulata	squarestem spikerush	7	1
Eleusine indica	Indian goosegrass	0	2
Elymus canadensis	Canada wildrye	5 *	2
Equisetum laevigatum	smooth horsetail	3	1
Eragrostis cilianensis	stinkgrass	0	1
Eragrostis curvula	weeping lovegrass	0	4
Eragrostis frankii	snadbar lovegrass	6	1
Eragrostis pectinacea	tufted lovegrass	0 *	3
Eragrostis secundiflora	red lovegrass	7 *	2
Erigeron bellidiastrum	western daisy fleabane	4 *	1
Erigeron tenuis	slenderleaf fleabane	4 *	1
Euonymus kiautschovicus	creeping strawberry bush	0	1
Eupatorium perfoliatum	common boneset	5	1
Eupatorium serotinum	lateflowering thoroughwort	3	1
Euphorbia humistrata	spreading sandmat	3 **	3
Eustoma exaltatum	catchfly prairie gentian	6	1

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Frangula caroliniana	Carolina buckthorn	6 **	1
Geranium carolinianum	Carolina geranium	0 *	5
Geranium texanum	Texas geranium	0 *	2
Gleditsia triacanthos	honeylocust	2	1
Glycine max	soybean	0	4
Grindelia squarrosa	curlycup gumweed	0 *	2
Helianthus annuus	common sunflower	1	3
Helianthus petiolaris	prairie sunflower	1 *	3
Heliotropium curassavicum	salt heliotrope	5	2
Heteranthera limosa	blue mudplantain	7	1
Heteranthera rotundifolia	roundleaf mudplantain	5	3
Hibiscus laevis	halberdleaf rosemallow	4	2
Hordeum jubatum	foxtail barley	2	9
Hordeum pusillum	little barley	1	14
Hydrolea ovata	ovate false fiddleleaf	8	1
Ilex vomitoria	yaupon	7	1
Impatiens capensis	jewelweed	5	2
Ipomoea lacunosa	whitestar	2	2
Juncus diffusissimus	slimpod rush	5	1
Juncus effusus	common rush	5	4
Juncus interior	inland rush	2 *	6
Juncus nodatus	stout rush	5	1
Juncus secundus	lopsided rush	5 **	2
Juncus torreyi	Torrey's rush	6	3
Juniperus virginiana	eastern redcedar	0	4
Justicia americana	American water-willow	5	1
Koeleria macrantha	prairie Junegrass	6 *	2
Kummerowia striata	Japanese clover	0	2
Lactuca serriola	prickly lettuce	0	3
Leersia oryzoides	rice cutgrass	4	5
Lemna minor	common duckweed	5	2
Lepidium densiflorum	common pepperweed	0 *	16
Lepidium virginicum	Virginia pepperweed	0 *	5
Leptochloa fusca	Malabar sprangletop	3	10
Leptochloa panicea	mucronate sprangletop	3	1
Limnosciadium pinnatum	Arkansas dogshade	6	2
Lindernia dubia	yellowseed false pimpernel	4	8
Liquidambar styraciflua	sweetgum	6 **	2
Lolium perenne	perennial ryegrass	0	5
Lonicera japonica	Japanese honeysuckle	0	1
Lotus unifoliolatus	American bird's-foot trefoil	3 *	1
Ludwigia alternifolia	seedbox	5	2
Ludwigia palustris	marsh seedbox	5	3
Lycopus americanus	American water horehound	4	2
Lycopus virginicus	Virginia water horehound	5	2
Lythrum alatum	winged lythrum	6	1
Marsilea vestita	hairy waterclover	4	4
Melilotus officinalis	sweetclover	0	1

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Melothria pendula	Guadeloupe cucumber	1	3
Mikania scandens	climbing hempvine	5	2
Mimulus alatus	sharpwing monkeyflower	5	2
Mollugo verticillata	green carpetweed	1	15
Monarda punctata	spotted beebalm	5 *	2
Muhlenbergia cuspidata	plains muhly	5 *	1
Oenothera laciniata	cutleaf evening primrose	0 *	9
Oxalis dillenii	slender yellow woodsorrel	0 *	2
Oxalis stricta	common yellow woodsorrel	2 *	3
Panicum anceps	beaked panicgrass	4 *	4
Panicum capillare	witchgrass	1	5
Panicum coloratum	kleingrass	0	4
Panicum dichotomiflorum	fall panicgrass	1	7
Panicum obtusum	vine mesquite	2 *	1
Panicum verrucosum	warty panicgrass	5	1
Panicum virgatum	switchgrass	4	5
Panicum miliaceum	proso millet	0	1
Panicum philadelphicum	Philadelphia panicgrass	4 *	3
Parthenocissus quinquefolia	Virginia creeper	2	1
Paspalum dilatatum	dallisgrass	0	2
Paspalum distichum	knotgrass	7	5
Paspalum floridanum	Florida paspalum	5	3
Paspalum setaceum	thin paspalum	9	7
Passiflora incarnata	purple passionflower	4 *	1
Phyla lanceolata	lanceleaf fogfruit	3	6
Phyla nodiflora	turkey tangle fogfruit	3	12
Physalis heterophylla	clammy groundcherry	4 *	4
Physalis pumila	dwarf groundcherry	4 *	2
Physalis virginiana	Virginia groundcherry	6 *	1
Phytolacca americana	American pokeweed	0 *	5
Pinus taeda	loblolly pine	2	1
Plantago lanceolata	narrowleaf plantain	0	1
Plantago virginica	Virginia plantain	1	3
Platanus occidentalis	American sycamore	4	1
Pluchea odorata	sweetscent	4	1
Poa annua	annual bluegrass	0	1
Polygonella americana	southern jointweed	5 **	1
Polygonum amphibium	water knotweed	7	12
Polygonum aviculare	prostrate knotweed	0	1
Polygonum hydropiper	marshpepper knotweed	0	3
Polygonum hydropiperoides	swamp smartweed	4	14
Polygonum lapathifolium	curlytop knotweed	4	8
Polygonum pensylvanicum	Pennsylvania smartweed	2	13
Polygonum persicaria	spotted ladysthumb	0	13
Polygonum punctatum	dotted smartweed	4	2
Polygonum ramosissimum	bushy knotweed	1	3
Polygonum virginianum	jumpseed	5 ***	1
Polypogon monspeliensis	annual rabbitsfoot grass	0	2

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Polypremum procumbens	juniper leaf	4 **	1
Populus deltoides	eastern cottonwood	1	8
Pyrrhopappus carolinianus	Carolina desert-chicory	3	2
Pyrrhopappus grandiflorus	tuberous desert-chicory	4 *	1
Quercus alba	white oak	3	1
Quercus marilandica	blackjack oak	4 *	2
Quercus nigra	water oak	5 **	2
Quercus phellos	willow oak	4	1
Quercus stellata	post oak	4 *	1
Ranunculus sardous	hairy buttercup	0	2
Ranunculus sceleratus	cursed buttercup	3	5
Rayjacksonia annua	viscid tansyaster	3 *	2
Rhus copallinum	winged sumac	7	1
Rhus glabra	smooth sumac	1 *	1
Rhynchospora corniculata	shortbristle horned beaksedge	7	3
Rhynchospora macrostachya	tall horned beaksedge	6	1
Robinia pseudoacacia	black locust	1	1
Rorippa palustris	bog yellowcress	3	5
Rorippa sessilifloria	stalkless yellowcress	3	3
Rubus oklahomus	Oklahoma blackberry	4	2
Rubus trivialis	southern dewberry	4 *	1
Rudbeckia hirta	blackeyed Susan	2 *	2
Rumex altissimus	pale dock	0	4
Rumex crispus	curly dock	0	7
Rumex hastatulus	heartwing sorrel	1 *	1
Rumex stenophyllus	narrowleaf dock	0	4
Sagittaria ambigua	Kansas arrowhead	8	1
Sagittaria brevirostra	shortbeak arrowhead	4	1
Sagittaria graminea	grassy arrowhead	8	1
Salix babylonica	Weeping willow	0	1
Salix interior	sandbar willow	3 **	2
Salix nigra	black willow	2	22
Salsola iberica	russian thistle	0	1
Saururus cernuus	lizard's tail	6	1
Schedonorus pratensis	meadow fescue	0	1
Schoenoplectus acutus	hardstem bulrush	4	3
Schoenoplectus americanus	chairmaker's bulrush	6	3
Schoenoplectus pungens	common threesquare	4	4
Schoenoplectus tabernaemontani	softstem bulrush	6	5
Scirpus cyperinus	woolgrass	7	1
Secale cereale	cereal rye	0	8
Sesbania herbacea	bigpod sesbania	2	4
Setaria parviflora	marsh bristlegrass	2	2
Sibara virginica	Virginia winged rockcress	2 *	2
Sicyos angulatus	oneseed bur cucumber	3	1
Sideroxylon lanuginosum	chittamwood	5	1
Smilax bona-nox	saw greenbrier	5	1
Solanum carolinense	Carolina horsenettle	1	3

Scientific Name	Common Name	Coefficient of Conservatism	Number of Sites
Solanum dimidiatum	western horsenettle	3 *	2
Solanum physalifolium	hoe nightshade	0	2
Solanum rostratum	buffalobur nightshade	0 *	2
Solanum ptycanthum	West Indian nightshade	1 *	1
Solidago canadensis	Canada goldenrod	3	5
Sonchus asper	spiny sowthistle	0	1
Sorghum halepense	Johnsongrass	0	11
Sphenopholis obtusata	prairie wedgescale	2	1
Strophostyles leiosperma	slickseed fuzzybean	3 *	1
Symphoricarpos orbiculatus	coralberry	1	1
Symphyotrichum subulatum	eastern annual saltmarsh aster	4	4
Tamarix chinensis	five-stamen tamarisk	0	1
Taraxacum officinale	common dandelion	0	2
Teucrium canadense	Canada germander	3	14
Thalia dealbata	powdery alligator-flag	7	1
Toxicodendron radicans	eastern poison ivy	1	2
Trachelospermum difforme	climbing dogbane	6	2
Tragopogon dubius	yellow salsify	0	1
Tridens flavus	purpletop tridens	1	3
Trifolium repens	white clover	0	3
Triodanis holzingeri	Holzinger's Venus' looking-glass	5 *	3
Triticum aestivum	common wheat	0	6
Typha angustifolia	narrowleaf cattail	3	2
Typha domingensis	southern cattail	2	4
Ulmus alata	winged elm	3	4
Ulmus americana	American elm	2	8
Urochloa platyphylla	broadleaf signalgrass	0	1
Verbena bracteata	prostrate vervain	0 *	4
Vernonia missurica	Missouri ironweed	4	1
Vernonia texana	Texas ironweed	4	1
Veronica peregrina	neckweed	2	2
Vicia sativa	garden vetch	0	2
Viola sagittata	arrowleaf violet	7 *	2
Vitis aestivalis	summer grape	4	1
Vitis riparia	riverbank grape	4	2
Vitis vulpina	frost grape	3 *	1
Vulpia octoflora	sixweeks fescue	5 *	2
Xanthium strumarium	rough cocklebur	0	10
Zea mays	corn	0	3

Notes: * Kansas CoC; ** Missouri CoC, *** Iowa CoC

Appendix H: Floristic Quality Assessment metrics (i.e., Mean C and Floristic Quality Index [FQI]) calculated for 68 depressional wetlands

Site	$MeanC_{native}$	FQI_{native}	$MeanC_{all}$	FQI_{all}	$CoverMeanC_{native}$	$CoverFQI_{native}$	$CoverMeanC_{all}$	$CoverFQI_{all}$
1	3.68	17.27	3.38	16.53	4.07	19.10	3.99	19.55
2	3.58	15.60	3.24	14.84	4.65	20.25	4.49	20.58
3	4.16	18.12	3.76	17.24	3.02	13.17	3.00	13.73
4	3.12	12.85	2.79	12.16	3.65	15.07	3.29	14.34
5	3.00	8.49	2.67	8.00	3.70	10.47	2.69	8.08
6	3.00	3.00	3.00	3.00	3.00	3.00	3.00	3.00
7	2.64	8.74	2.23	8.04	3.06	10.16	3.04	10.95
8	4.89	14.67	4.00	13.27	5.11	15.33	2.95	9.78
9	3.79	18.58	3.50	17.85	3.71	18.15	3.66	18.65
10	3.80	12.02	3.45	11.46	4.81	15.22	4.79	15.88
11	4.00	14.42	4.00	14.42	4.42	15.95	4.42	15.95
12	2.57	9.62	2.12	8.73	2.13	7.97	1.09	4.49
13	4.40	9.84	2.00	6.63	4.40	9.84	0.09	0.31
14	3.30	10.44	2.75	9.53	4.79	15.16	4.58	15.87
15	3.11	9.33	2.33	8.08	2.28	6.83	1.92	6.67
16	4.50	18.00	3.60	16.10	4.85	19.39	4.27	19.10
17	3.00	9.95	1.94	8.00	3.66	12.14	3.25	13.40
18	3.25	9.19	1.86	6.95	3.60	10.19	2.52	9.41
19	2.80	10.84	2.47	10.19	2.93	11.35	2.83	11.69
20	3.00	12.73	2.45	11.51	2.71	11.49	2.06	9.68
21	3.38	13.50	3.38	13.50	3.29	13.16	3.29	13.16
22	1.25	2.50	1.00	2.24	1.63	3.25	1.44	3.23
23	4.33	7.51	1.30	4.11	4.99	8.65	3.15	9.95
24	4.45	25.59	4.08	24.50	4.49	25.78	4.31	25.87
25	4.86	22.26	4.86	22.26	5.64	25.86	5.64	25.86
26	3.82	20.22	3.45	19.22	3.36	17.80	3.32	18.46
27	4.54	22.25	4.36	21.80	3.78	18.50	3.73	18.64
28	5.00	24.49	5.00	24.49	4.61	22.59	4.61	22.59
38	1.80	4.02	1.13	3.18	0.39	0.88	0.06	0.18
39	2.41	9.94	1.71	8.37	3.00	12.39	2.14	10.50
42	1.00	2.65	0.64	2.11	1.13	3.00	0.10	0.33
43	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
46	2.42	8.37	1.38	6.33	2.49	8.62	0.45	2.06
59	3.38	15.49	2.96	14.49	3.15	14.45	3.10	15.18
71	2.84	12.39	2.25	11.02	2.32	10.11	1.80	8.81
72	2.35	11.96	1.74	10.31	2.63	13.40	2.08	12.32
62	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
64	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
85	1.33	2.31	0.80	1.79	1.40	2.42	0.15	0.32
86	1.75	3.50	0.88	2.47	1.83	3.67	0.41	1.16
96	1.00	2.00	0.57	1.51	0.80	1.60	0.40	1.06

Site	$MeanC_{native}$	FQI_{native}	$MeanC_{all}$	FQI_{all}	$CoverMeanC_{native}$	$CoverFQI_{native}$	$CoverMeanC_{all}$	$CoverFQI_{all}$
115	1.29	3.40	0.90	2.85	0.70	1.84	0.11	0.34
128	2.50	10.61	1.80	9.00	4.11	17.44	3.60	18.02
135	2.39	10.14	2.15	9.62	2.53	10.72	1.72	7.68
156	1.67	4.08	1.11	3.33	1.37	3.35	0.24	0.71
157	2.96	15.69	2.86	15.41	3.03	16.05	2.95	15.87
158	2.91	13.64	2.67	13.06	2.94	13.81	2.86	14.03
159	1.95	8.72	1.86	8.51	2.52	11.29	2.50	11.46
174	1.50	2.12	0.75	1.50	2.50	3.53	0.43	0.86
175	1.00	1.00	0.50	0.71	1.00	1.00	0.05	0.08
182	2.27	8.78	1.89	8.01	2.60	10.05	1.88	7.97
183	2.18	7.24	1.85	6.66	1.35	4.47	0.94	3.38
185	2.00	6.00	1.20	4.65	1.69	5.07	0.85	3.28
186	2.30	11.05	1.89	10.02	3.28	15.74	2.50	13.23
187	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
205	2.57	12.30	2.19	11.35	2.87	13.76	2.33	12.13
209	1.77	6.38	1.35	5.58	4.41	15.91	1.93	7.98
210	2.76	12.66	2.23	11.37	3.10	14.18	2.18	11.14
221	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
222	2.67	9.24	2.46	8.88	1.21	4.18	1.00	3.61
223	3.05	13.64	2.65	12.72	3.20	14.29	3.15	15.10
224	3.54	12.76	3.07	11.88	4.52	16.30	4.44	17.20
226	1.00	3.61	0.68	2.98	0.50	1.81	0.08	0.33
228	2.28	9.66	1.58	8.04	2.12	9.01	1.03	5.23
229	3.05	13.64	2.77	13.01	2.71	12.13	2.66	12.46
230	2.95	12.85	2.80	12.52	3.15	13.72	3.13	14.02
231	2.17	7.51	1.86	7.43	0.88	3.06	0.53	2.10
232	2.73	9.05	2.50	9.35	1.81	5.99	0.55	2.04

VITA

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Master of Science

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