United States Department of Agriculture

Conservation Effects Assessment Project (CEAP) WETLANDS

Science Note

Functional Assessment of Depressional Wetlands Using Remote Sensing

Key Takeaways

- The time and cost involved in field-based methods of wetland functional assessment make their use at the landscape scale impractical.
- While broad scale wetland assessment methods using remotely sensed data have been developed, testing their efficacy at the site-specific scale has been limited.
- In this study, remote sensing-based methods showed promise when compared to field-based methods for functional assessments of wetlands along a gradient of human disturbance, particularly for evaluating restoration practices.
- While results were promising, remotely sensed assessments need further refinement before they can be considered a replacement for on-site methods.
- Comparison of remotely sensed and field-based parameters revealed variables that can potentially be used to enhance future remote sensing-based functional assessments.

In this study, we correlated wetland assessment results from a remote sensing-based functional assessment known as the Watershed-based Preliminary Assessment of Wetland (W-PAWF) with those of field-based assessments. Study sites included restored wetlands like the one shown above as well as natural wetlands and highly disturbed prior converted croplands (PCCs).

Making Wetland Functional Assessments Cost Effective

Wetlands provide many ecosystem services that have been diminished by the loss and degradation of these important areas (Zedler and Kercher 2005; Mclaughlin and Cohen 2013). The goal of wetland conservation and restoration is to protect, restore, and enhance these vital services. In order to ensure the success of these efforts, it is critical to consider the natural processes and ecological functions that underlie ecosystem services, particularly when determining the placement, design, and monitoring of wetland restorations. For example, assessment of the types and levels of ecological functions prior to wetland restoration may reveal low-performing functions that should be targeted for enhancement. This also provides a baseline functional performance by which the criteria for a successful restoration can be established.

Wetland functional assessments are typically field-based, providing qualitative and/or quantitative scores resulting from site-level observations and measurements. Conducting assessments at this level has become increasingly cost-prohibitive due to the associated time and labor, particularly at broader geographic scales. Remote sensing-based functional assessments have become an attractive option at the landscape level, but results are more limited than those of field-based methods, due both to study design and the attributes of remotely sensed data. Remote assessments are typically restricted to generalized qualitative and/or categorical outputs as a result of the limited availability and resolution of data, lack of ground-truthing, and variability in wetland functional characteristics at the landscape scale.

A remote sensing-based functional assessment known as the Watershed-based Preliminary Assessment of Wetland Function (W-PAWF) was applied to wetlands on the Delmarva Peninsula in Maryland (Tiner 2003), but its usefulness at a site-specific scale had not been

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previously tested. W-PAWF adapts the principles of hydrogeomorphic (HGM) wetland classification (Brinson 1993) to spatial wetlands databases such as the U.S. Fish and Wildlife Service's National Wetland Inventory (NWI). Through remote sensing, landscape position, landform, water flow path, and waterbody type (LLWW) descriptors are appended to a wetland spatial database (Tiner 2014). Using combinations of these descriptors (as well as some NWI wetland characteristics), a potential performance category can be assigned to the 10 functions assessed.

While W-PAWF considers landscape position and landform, it does not explicitly address land use surrounding the wetland. In order to account for potential influence of stressors outside the wetland boundary and buffer zone, remotely sensed data in the National Land Cover Database (NLCD) can provide additional information for assessing wetland condition. Previous studies have used this approach to calculate a Landscape Development Index (LDI; Brown and Vivas 2005) to evaluate the intensity of alteration within the surrounding landscape that can help explain wetland functional differences.

Can Remote Sensing Replace On-site Assessments?

This study was a collaboration among researchers at the Riparia Center of Pennsylvania State University, University of Maryland College Park, and USDA-ARS Beltsville, and was designed to test the utility of remote sensing and specifically W-PAWF for evaluating functional differences among individual wetland sites. While W-PAWF has been used to inventory wetland functions around the country, including the Nanticoke River watershed (Tiner 2005) and the entire state of Delaware (Tiner et al. 2011), it has not been used for site-specific applications on the Delmarva Peninsula. In this study, we correlated W-PAWF results for wetlands along a disturbance gradient with those of several field-based assessment methods, including an index of biodiversity calculated from field observations. In order to test the full range of functional performance, study sites included restored wetlands of differing design and age, as well as natural wetlands and highly disturbed prior converted cropland (PCC).

Our study (Backhaus et al. 2020) focused on fifteen freshwater depressional sites from a previous CEAP-Wetlands study (Lang et al. 2015) in an area of the Coastal Plain of the Delmarva Peninsula (Figure 1). This area is characterized by a flat, agricultural landscape of mainly corn and soybean interspersed with small forested areas and low urban development. Study sites included five highly disturbed PCCs, six restored wetlands, and four low-disturbance forested wetlands (Figure 2 shows examples of what these sites look like). PCCs are defined as wetlands that were cleared and drained prior to December 23, 1985, have continued to be used for agricultural purposes, and do not flood more than 14 days during the growing season. The active agricultural practices on PCCs and the forested condition of natural wetlands provided reference domains against which the range of conditions found in the restored wetlands could be compared.

We tested W-PAWF for its ability to discern functional differences between the 15 freshwater wetland sites and, in particular, the restored sites of differing design and age. Eight of the 10 functions identified by W-PAWF (Table 1) were used since two hydrology functions (storm surge detention and shoreline stabilization) are intended for use in estuarine ecosystems and were not directly applicable to our sites.

Figure 1. Aerial image (from the 2017 USDA National Agriculture Imagery Program) of the study area. Most of the fifteen wetland sites were located within the Choptank River watershed.

Figure 2. Examples of a prior converted cropland (left), restored wetland (center), and natural wetland.

LLWW descriptors were remotely sensed through aerial imagery, including LiDAR, and supplemented with data from the NWI when that data existed. Combinations of the LLWW descriptors and a subset of NWI wetland characteristics were then used to assign a potential performance category to the functions assessed by W-PAWF. The functions and associated descriptor combinations were developed in consultation with wetland experts, but their definitions and rationales were based primarily on generalized relationships and not specific data.

To facilitate the remote assessment, W-PAWF functions were grouped into three categories for further interpretation: hydrology, biogeochemistry, and biodiversity (Table 1). A simple index was created to more easily interpret the results of the remote assessment. Functions with a high rating were given a score of 1.0, moderate ratings were given a 0.5, and functions deemed absent in the wetland were given a 0. These scores were not intended to quantify magnitudes of functional difference, but solely to differentiate the various functional assemblages and potential performance ratings of W-PAWF. The final index summarizing the functional status of each site was computed by averaging scores for each function within a category, then summing across the three categorical scores to derive a total.

Remote Sensing of Site-level Functions

The W-PAWF-based index scores showed potential for evaluating wetland restoration practices and as an exploratory means of wetland functional assessment. Higher site index scores indicate wetlands with a high number of functions at high performance levels, while lower scores characterize sites with fewer functions and/or lower performance levels. Along the spectrum of wetlands assessed, the W-PAWF index exhibited an inverse relationship with levels of human disturbance (Figure 3).

W-PAWF was able to detect functional differences among all three wetland disturbance groups and within restored and natural wetlands. Functional differences arose mainly through differences in biodiversity scores, as the index provided identical biogeochemistry scores for all wetlands and only a slight, but opposite, trend in hydrology scores (Table 2). As might be expected for restoration sites of varying ages, the scores of restored wetlands overlapped the ranges of both PCCs and natural wetlands (Figure 3); there was high variability among the six restored wetland sites, as opposed to the somewhat lower variability among the four natural wetland sites. All index scores for the five PCC sites in each functional category were identical.

Since W-PAWF does not explicitly address stressors outside the wetland boundary that are often included in field data, we evaluated the use of remote sensing estimates of surrounding land use within a 1-km radius around each wetland's centroid.

Table 1. Function of W-PAWF, grouped into functional categories for scoring.

Functional Category	W-PAWF Function
Hydrology	Surface Water Detention
	Coastal Storm Surge Detention
	Streamflow Maintenance
	Shoreline Stabilization
Biogeochemistry	Nutrient Transformation
	Retention of Sediments and Other Particulates
Biodiversity	Provision of Habitat for Fish and Other Aquatic Animals
	Provision of Waterfowl and Waterbird Habitat
	Provision of Other Wildlife Habitat
	Conservation of Biodiversity

Using NLCD data, we calculated LDI (Brown and Vivas 2005), road density (km/km2), and percent area of forest, agricultural, and developed land. LDI has been shown to be correlated with wildlife utilization, overstory/shrub canopy and vegetative ground cover, adjacent upland support/wetland buffer, field indicators of wetland hydrology, and water quality input and treatment systems (Brown and Vivas 2005). While these measures did not demonstrate significant differences among the disturbance categories, results were consistent with those based on stressors within a 100-meter buffer observed in the field and discussed below.

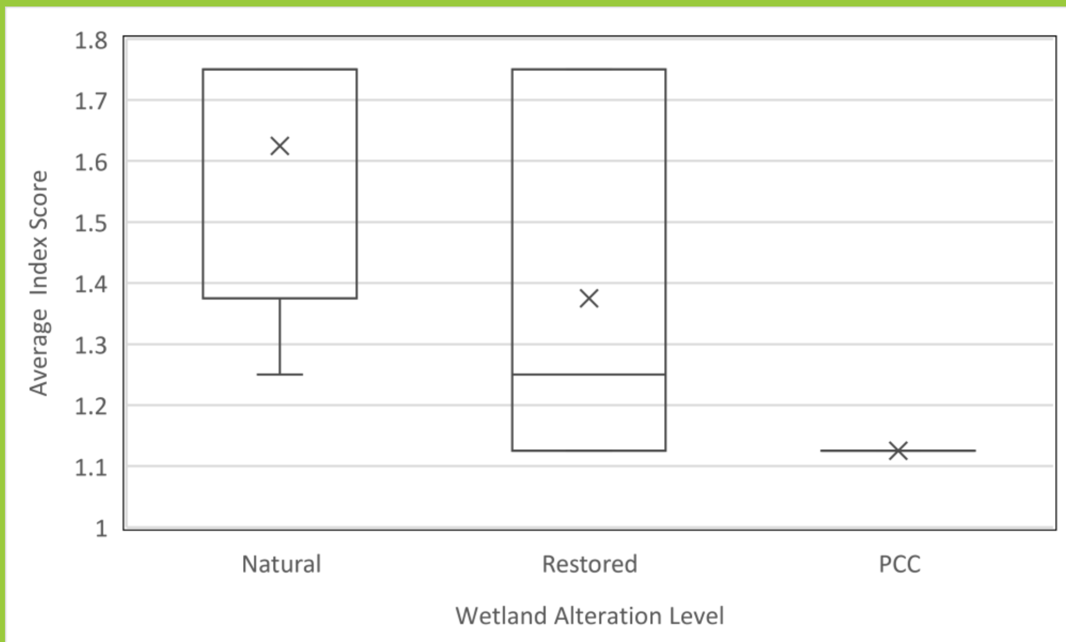

Figure 3. Boxplot of the total index scores for individual wetlands (total of average scores for each functional category) for each level of alteration gradient. Boundaries of the boxes represent the 25th and 75th percentiles; the horizontal line within the box represents the median, and "x" marks represent the mean.

Table 2. Average scores for each functional category of the W-PAWF and total indices for individual wetlands.

Restoration Level	Hydrology	Biogeochemistry	Biodiversity	Total Index
PCC	0.5	0.5	0.125	1.125
	0.5	0.5	0.125	1.125
	0.5	0.5	0.125	1.125
	0.5	0.5	0.125	1.125
	0.5	0.5	0.125	1.125
Restored	0.5	0.5	0.125	1.125
	0.5	0.5	0.25	1.25
	0.25	0.5	0.375	1.125
	0.25	0.5	0.5	1.25
	0.5	0.5	0.75	1.75
	0.5	0.5	0.75	1.75
Natural	0.25	0.5	0.5	1.25
	0.25	0.5	1	1.75
	0.25	1	1	1.75
	0.25	1	1	1.75

Site-level vs. Remote Assessments

We compared the W-PAWF-based index scores to a set of rapid field assessments designed for use in the Mid-Atlantic region, including protocols from the Stream-Wetland-Riparian (SWR) Index (Brooks et al. 2009), Level 3 Wetlands Sampling Protocol (Brooks 2004), and the Unified Mid-Atlantic Rapid Assessment Protocol for Wetlands (UMA RAP, Brooks et al. 2018). Measurements and observations were included that address biodiversity (vegetation assessment and habitat suitability indices, HSI, Brooks and Prosser 1995), biogeochemical potential (microtopographic and coarse woody debris transects, soil characterization), hydrology, and stressor checklists. Additionally, soil penetration resistance was measured, and soil samples were analyzed for Mehlich and total soil phosphorus.

Vegetation data was used to calculate the Adjusted Floristic Quality Assessment Index (FQAI, Miller and Wardrop 2006). Floristic quality assessment is a vegetation community monitoring system based on coefficients of conservatism for individual plant species that are assigned in accordance with their tolerance to degradation and the degree to which they are characteristic of natural remnant habitats (Freyman et al. 2015). The field assessments also included an evaluation of stressors within the wetland, as well as within a 100-meter buffer, that included measures of hydrologic modification, sedimentation, dissolved oxygen, contaminant toxicity, vegetation alteration, eutrophication, acidification, turbidity, thermal alteration, and salinity.

Findings

In general, the results of field assessments were consistent with W-PAWF but were less likely to distinguish PCC from restored wetlands. Remotely sensed biodiversity index scores distinguished all three disturbance categories, being highest in natural wetlands, followed by restored wetlands, with PCC having the lowest scores. FQAI calculated from the field assessment data was also highest for natural wetlands, indicating the presence of more narrow niche species, but unlike W-PAWF index scores, PCCs had a slightly higher mean FQAI score than restored sites (Fig. 4).

Comparisons between remotely sensed and field-based data were aimed at evaluating their relative ability to detect variation among wetlands, both between and within the disturbance gradient groups, but the fact that indices based on W-PAWF showed little or no variability in hydrology and biogeochemistry limits the ability to distinguish between wetland sites within a restoration level. The inclusion of stressors in the field assessments allows a more detailed evaluation of potential changes to hydrologic and biogeochemical functions as indicated by a positive relationship between stressor score and increasing human alteration (Fig. 4). Differences among the three restoration conditions were significant in both the SWR ($F = 5.43$, $p = 0.021$) and the UMA RAP ($F = 14.08$, $p = 0.001$) protocols. In addition to other stressors, PCCs had a higher percent cover of invasive species with 20-50%, compared with an average cover of less than 5% in natural sites and 5%-20% in restored sites.

A positive relationship was also observed in stressor scores observed in the wetland buffers (Fig. 4), although differences among scores for the alteration levels were only marginally significant for the SWR ($F = 3.91$, $p = 0.049$) and not significant for the UMA RAP ($F = 2.41$, $p = 0.132$). This lack of significance was consistent with the results of comparing LDI indices as well as percent of altered landscape within a 1-km radius buffer based on NLCD analysis. While these did not help distinguish among wetlands based on inferred alterations to biogeochemistry and hydrology in our study, landscape context may provide information on stressors in the contributing area and thus a surrogate for those observed in on-site assessments within the 100-meter buffer. Landuse in the wetland contributing area may thereby help distinguish both between and within disturbance categories in some cases.

Field Results Provide Detail

Some of the field assessments produced significant differences (as determined by Mood's Median Test) among the human disturbance groups, but trends differed depending on the type of observation. Total phosphorus and Mehlich phosphorus were greater in natural and restored wetlands, although differences in Mehlich phosphorus were not significant between disturbance groups. Soil penetration resistance was significantly different among the disturbance levels, with natural wetlands having lower resistances than PCCs and restored wetlands. As might be expected, coarse woody debris counts were significantly higher in natural wetlands, with an average transect count of 45 compared to 6 and 8 in PCCs and restored wetlands, respectively. There were no significant differences in microtopography scores.

While our results demonstrate the potential utility of W-PAWF to

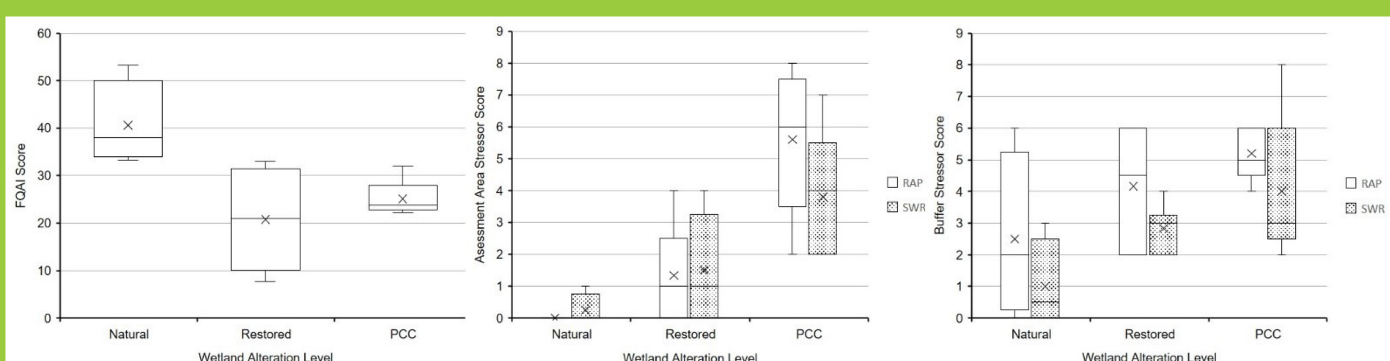

Figure 4. Boxplots of the FQAI results (left), UMA RAP and SWR stressor scores within the assessment area (center), and UMA RAP and SWR stressor scores within the assessment area buffers. Boundaries of the boxes represent the 25th and 75th percentiles; the horizontal line within the box represents the median, and "x" marks represent the mean.

detect functional differences among disturbance groups, it should not be considered a replacement for field-based assessments where they are required. Although the outcomes of the W-PAWF demonstrated similar overall relationships between disturbance categories as did the field assessments, comparisons of the two types of methods illustrated the limitations of remote sensing data for assessing wetland function. For example, field-based assessment of vegetation plots allowed identification of specific species and invasive plants and therefore calculation of the FQAI (Miller and Wardrop 2006), a measure of biodiversity, whereas W-PAWF assessment is limited to the habitat class and subclass levels as shown in Cowardin et al. (1979). Additionally, while W-PAWF gave general descriptions of water storage or nutrient transformation, field measurement of microtopography and coarse woody debris provided more specific insight into the minor differences occurring at a site-specific scale.

Implications for Conservation

In addition to the assessment of current functions, W-PAWF can be used throughout the process of wetland restoration. In searches for potential restoration sites, W-PAWF can be applied to a watershed or selected set of wetland sites to screen for wetlands performing a desired function at suboptimal levels. This can save time and labor costs by decreasing the number of site visits required. The use of historic spatial data, such as older aerial imagery or hydric soils as a proxy for lost wetland extent, can also be used to estimate loss of function or provide a pre-restoration baseline of function (Tiner 2005).

Despite its limitations, opportunities exist to improve W-PAWF and incorporate additional precision. By comparing W-PAWF with field-based methods, we identified remotely sensed variables that can potentially enhance future remote sensing-based functional assessments. Several of the field variables can be remotely sensed and incorporated into W-PAWF, and many items in the stressor checklists, such as roads, ditches, mowing, and algal mats, are directly observable in aerial imagery. Fine-resolution LiDAR may be able to detect microtopography to inform functions such as nutrient transformation and habitat. Existing spatial databases such as the USDA-NRCS Soil Survey Geographic Database (SSURGO) may also improve W-PAWF by adding an additional layer of detail useful in evaluating hydrology and biogeochemistry functions. Including characteristics of the surrounding area may provide additional detail not only to the scores of the current hydrology and biodiversity categories, but also help mitigate the issue of identical biogeochemistry results. Thus, while remote assessments are not a substitute for field-based methods in wetland restoration design and monitoring, they may be useful in screening potential restoration sites or for monitoring general trends in ecosystem services across a watershed over time.

Conclusions

This study explores the efficacy of the W-PAWF remote sensing assessment for site-specific evaluation of depressional wetlands in the Delmarva Peninsula (Backhaus et al. 2020). Given the availability of appropriate spatial data, this evaluation will be useful to support wetland restoration site selection, design, and monitoring. However, in order to approach the level of detail in field-based methods, our comparison demonstrated the need for refinement of W-PAWF, possibly through the adoption of remote sensing proxies for field-based parameters. Since groundwater hydrology and the flat topography of the Coastal Plain control much of the dynamics of the depressional wetlands in this study, future research should test W-PAWF in other geographic regions and wetland classifications where other drivers are present, such as riverine hydrology, more varied topography, or where urban development is more prominent in the landscape.

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Conservation Effects Assessment Project: Translating Science into Practice

The Conservation Effects Assessment Project (CEAP) is a multiagency effort to build the science base for conservation. Project findings will help to guide USDA conservation policy and program development and help farmers and ranchers make informed conservation choices.

One of CEAP's objectives is to quantify the environmental benefits of conservation practices for reporting at the national and regional levels. Because wetlands are affected by conservation actions taken on a variety of landscapes, the CEAP-Wetlands national component complements the national assessments for cropland, wildlife, and grazing lands. The wetlands national assessment works through numerous partnerships to support relevant assessments and focuses on regional scientific priorities.

This project was conducted through collaboration among researchers with Riparia of The Pennsylvania State University, University of Maryland (UMD) College Park, and USDA-ARS Beltsville. Primary investigators on this project were P.J. Backhaus, M.Q. Nassry, S. Lee, G.W. McCarty, M.W. Lang, and R.P. Brooks. This Science Note was compiled by Peter Backhaus and Joseph Prenger. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by USDA. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by USDA.

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