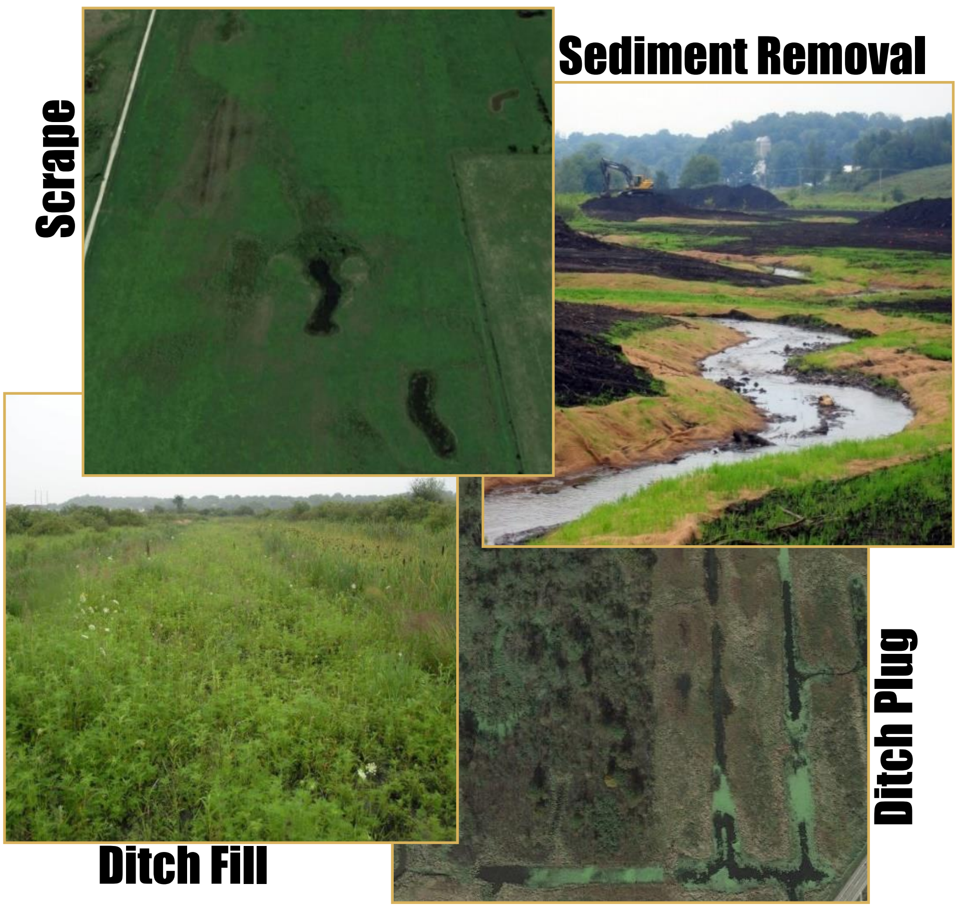
Condition Outcomes in Wetlands Restored Using a Variety of Hydrologic Restoration Techniques: An Application of Wisconsin DNR's FQA Methodology

May 2020



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3 INTRODUCTION

Alteration of wetland hydrology for crop production is the primary cause of wetland losses across the world and is common in Wisconsin (Zedler & Kercher 2005). These alterations most commonly take the form of above-and below- ground conduits (ditches and tile) installed to lower the water table, drawing water away from the upper soil horizons. Such drainage systems are common in Wisconsin and impact both land in agricultural production and adjacent remnant wetlands. Another common alteration to wetlands is sedimentation, or the burial of wetland soils by upland soil materials, usually comprised of silts. Sedimentation has been shown to increase soil bulk density, lower soil organic matter, and lead to increased invasive species cover (Werner & Zedler 2002).

Restoration has been defined as the "return of an ecosystem to a close approximation of its condition prior to disturbance" (National Research Council, 1992; NRCS, 2010). For wetlands, returning natural hydrology, including dominant water source, hydroperiod, and hydrodynamics is a key part of restoring a wetland's natural condition and function (NRCS, 2010). To return these wetlands to their pre-disturbance hydrological state, or at least their trajectory (SER 2004), undoing any and all reversible alterations is the ideal approach. In practice however, wetland restoration practitioners have a range of approaches to their projects, ranging from complete historical restoration, partial restoration, or minimal restoration (Thompson & Luthin, 2010). Complete historical restoration is not often attempted due to financial constraints, impacts to neighbors, legal restrictions, or because ecosystem restoration is not consistent with the desired result (e.g. persistent shallow open water for waterfowl habitat or stormwater infiltration).

Because hydrology is the "master variable" (Cronk & Fennessy 2001; Mitsch 2015; Doherty et al. 2014) that determines most wetland characteristics, it is expected that projects that use techniques designed to completely restore hydrology will achieve a closer approximation of pre-disturbance conditions than those that only partially or minimally restore hydrology. This study aims to compare different restoration techniques to better understand the consequences of returning hydrology completely or partially.

3.1 WETLAND RESTORATION TECHNIQUES: OPTIONS TO RESTORE HYDROLOGY PARTIALLY OR COMPLETELY

Ditches are utilized to convey surface and subsurface water usually from a farm field to create conditions more conducive for common agriculture crops; disabling ditches is utilized to reverse drainage efforts. When drainage ditches are present on a site proposed for wetland restoration, the practitioner has the choice to completely fill them along their length and recontour to match the original grade - a "**ditch fill**" – or dam the ditch at its lowest point with a "**ditch plug**," leaving the ditch channel open but preventing water from draining off-site. A third option is to leave the ditch in place. Ditch filling is the only option designed to attempt complete removal of the draining effect of the ditch. Ditch plugging and leaving the ditch in place will in theory leave some negative hydrologic impact due to its water storage capacity, depending on ditch size, depth, and soil type. However, whether this effect is important or negligible to the ultimate success of the restoration is not well known.

Subsurface drain tile lines are utilized to convey water from just below a farm field surface out to a nearby waterway with the purpose of creating conditions conducive to farming; disabling subsurface drain tiles is another form of reversing the drainage efforts of a farm field. As with ditches, subsurface drain tile lines (perforated, hollow tubes made of clay or plastic) are commonly present on farm fields converted from wetlands. They are placed 3 to 4 feet underground in parallel lines to collect water and convey it off the field to a larger tile line or drainage ditch, preventing the upper parts of the soil from becoming saturated. To completely remove the drainage effect, **tile removal** -the removal of all tile from the soil and filling in the remaining soil channel- is recommended (Thompson & Luthin 2004). However, the more widespread practice is **tile breaks** - leaving the tile in place but breaking or plugging the flow at strategic places along the line. Like ditch plugging, this method will prevent conveyance of water off the site but retains some degree of localized drainage.

"**Sediment removal**" is a technique used to restore wetlands that have been impacted by sedimentation, or burial of a wetland soil by siltation from uplands. The recently-deposited silt, also termed post-settlement alluvium or legacy sediments, is removed to restore historical topography. Sediment removal requires mapping of the sediment layer, removal of sediment across the site to expose the original wetland grade, and transportation of the sediment off-site (J. Nania, pers. comm). Many restoration projects do not address sedimentation, however, due to the large-scale earth-moving required which is generally perceived as too expensive an undertaking, especially on large sites. However, the silty, often nutrient-rich soils in post-settlement alluvium can favor invasive species and depending on depth can raise the upper layers of soil above their water sources causing wetland obligates to be displaced by facultative species (Werner & Zedler 2002).

Scrapes bypass the alterations to hydrology on the site and instead focus on creating standing water on smaller areas. Scrapes are excavations in the topsoil or subsoil level in a depressional basin. Excavated materials are used to form a low berm or embankment (NRCS 2016). Another technique is to create large berms, dikes, or other **impounding structures** to hold surface water**.** These projects are often designed to attract waterfowl and not are not intended to restore natural hydroperiods. However, they are commonly included under a broader definition of wetland restoration and are abundant throughout the state of Wisconsin.

3.2 Using FQA Methodology to Assess Restored Wetlands

The premise of bioassessments like floristic quality assessment (FQA) is that biological taxa can be used as indicators of altered conditions due to their differing capacities to withstand human-altered conditions (EPA 2002). As an ecosystem becomes more altered, species that are sensitive to disturbed conditions or "conservative" are expected to drop out and disturbance-tolerant species increase. More natural hydrologic conditions are expected to be reflected in the presence of more ecologically conservative plant species occurring in the wetland plant community which can be measured using floristic quality assessment (FQA) methodology.

The Wisconsin Department of Natural Resources (WDNR) began developing FQA methodology in 2002 with the assignment of Coefficients of Conservatism to Wisconsin's vascular plant flora (Bernthal 2003). Coefficients of Conservatism values (C-Values) rate the degree of conservatism or sensitivity of each plant species to alteration on a scale of 0 to 10, with non-native or very tolerant species at the low end and species that are restricted to intact natural areas given a 10. These ratings are the foundation of floristic quality assessments, allowing plant inventories to serve as estimates of site integrity.

The assignment of C-values to Wisconsin's flora was followed by the development of mean coefficient of conservatism ($\overline{C}$) and Floristic Quality Index (FQI) benchmarks for plant communities in Southeast Wisconsin in 2006 (Bernthal et al. 2007). These benchmarks were then applied to evaluate restored wetlands in 2008 in a project, "Improving Wisconsin's Wetland Compensatory Mitigation Program: Factors Influencing Floristic Quality and Methods for Monitoring Wildlife" (Wilcox 2009). Since that time the development of FQI benchmarks has been expanded across the state and quantitative estimates of plant cover were added, making cover-weighted metrics (denoted by adding a "*w*" to the beginning of the metric) such as weighted mean Coefficients of Conservatism ($w\overline{C}$) and *w*FQI ($w\overline{C}$ weighted by species richness) possible (Hlina *et al*. 2015, Marti & Bernthal 2019).

Through the process of developing floristic quality benchmarks WDNR has developed a database of vascular plant data and floristic quality metrics from over 1,100 natural wetlands across the state. Recently, accompanying soil data has been added to approximately one third of these wetlands, allowing comparisons of both floristic quality and soil parameters of natural wetlands to restored wetlands.

This study is the first to evaluate wetland restorations using WDNR's full FQA methodology, applicable to all areas of the state (Hlina *et al*. 2015, Marti & Bernthal 2019). We hope the results will help to refine the methodology for future use in evaluating restorations, developing performance standards for wetland vegetation, and understanding the effectiveness and limitations of wetland restoration in the state.

3.3 WDNR's Role in Wetland Restoration

The periodic study of historic wetland restoration efforts is a valuable tool to inform the standard practices accepted by restoration practitioners and regulators. WDNR staff often are called to assist with designs of wetland restoration efforts, advise on where and how restorations should be planned, and oversee the approval of regulated restoration such as those associated with wetland compensatory mitigation efforts. One purpose of this study is to examine restoration efforts of the past few decades and determine if the those undertaken by WDNR staff and its partners are effective in restoring valuable wetland functions back onto the landscape. The results of this study will be used to by WDNR staff to plan and communicate with WDNR partners methods to improve wetland restoration efforts.

3.4 Objectives

1. Use WDNR's FQA Methodology to evaluate wetland restoration using a variety of hydrologic restoration techniques including ditch and tile modifications, scrapes, and sediment removal.

2. Test for differences in floristic quality outcomes between restoration techniques with an emphasis on comparing techniques designed to restore hydrology more completely versus those that only partially restore hydrology.

3. Collect and analyze soil data look for patterns of floristic quality related to soil type and to compare levels of soil organic carbon in restorations with levels in natural wetlands.

4. Apply the findings of this study to Wisconsin Department of Natural Resources wetland restoration efforts, especially compensatory wetland mitigation designs and performance standards.

4 METHODS

4.1 SITE SELECTION

A pool of over 190 wetland restoration sites were evaluated as possible candidates for this study. Candidate wetland restorations came from multiple agencies including the Wisconsin Department of Natural Resources (WDNR), the USDA Natural Resource Conservation Service (NRCS), Madison Audubon Society, The Nature Conservancy, the Prairie Enthusiasts, and the Wisconsin Department of Transportation (WDOT). NRCS and DNR provided access to their databases of restorations which were sorted by restoration technique, ecoregion, and ease of access. Restorations from other organizations were found by reaching out to known wetland restoration practitioners requesting restorations of known technique. Thirty-nine (39) restorations were selected for this study based on meeting the following criteria:

1. The hydrologic restoration technique(s) were known and included at least one of the following (a sample size of n=10 for each technique was desired):

    - Tile removal: removal of the subsurface drain tile system from the soil and ideally back-filling the remaining underground conduit.
    - Tile break: breaking or disabling the subsurface drain tile system in one or more places to interrupt flow.
    - Ditch fill: filling a drainage ditch along its length, ideally to match grade on either side.
    - Ditch plug: installation of structures intended to dam a drainage ditch in one or more places to stop flow.
    - Scrapes: excavation of small areas to hold shallow water; excavated soil is retained on site as an impounding feature.
    - Sediment Removal: excavation to expose the original hydric soil layer or pre-European settlement topography; excavated soil is removed from the wetland restoration area.

2. Dikes or impounding structures were not the primary method of restoring site hydrology. The exception was low berms (<3 ft) associated with scrapes.

3. More than 4 years had passed since restoration work was completed.

4. Sites were wetlands historically and not the result of wetland creation.

4.2 Data Collection

4.2.1 Floristic Quality Assessments

Identifying the assessment area

Assessment Area's (AA's) are the areas within the restoration site that were thought to be directly affected by the hydrologic restoration technique. However, assessment areas are defined as a single homogeneous wetland community type so when more than one wetland community type existed in each restoration site, they were surveyed as separate AA's. For example, if one restoration site had two distinct community types, such as a southern sedge meadow and a shrub carr, the single restoration site had two AA's established. Hereafter "site" will be used to describe the larger restoration and "AA" will be used to describe the smaller community units. Submergent marsh, or "open-water" communities, were not surveyed due to a lack of consistent sampling methodology and floristic quality benchmarks to assess these communities.

Information concerning the location and nature of restoration techniques employed was easiest to obtain from compensatory mitigation projects due to the extensive reporting required, the most useful of which were site construction plans and written descriptions or logs of restoration activities. Non-profit restoration projects had the least amount of documentation, requiring interviews with the restorationist and/or current land manager, the use of historical imagery and in some cases, LiDAR imagery.

Timed Meander Surveys

Once the AA(s) were identified, field crews followed the WDNR Timed-Meander Sampling Protocol for Wetland Floristic Quality Assessment (Trochlell 2016). First, a complete or near-complete inventory of the vascular plants found within the plant community was generated by meandering through the community actively searching for and recording new species. New species discovered in each 5-minute interval were recorded. The survey was stopped once the number of new species per interval declined to zero or one, with no new areas of diversity apparent, or the end of the AA was reached. Second, each species was assigned an estimate of percent areal cover from 1 to 100. Species that could not be identified in the field were collected and pressed for later identification.

Soil Description and Sample Collection

At each site, a representative location was selected to describe and sample the soil. A hand auger was used to obtain a description of the profile down to 60 cm (24 inches), including texture, color, and redox features. Observations of hydrology, depth to saturation, and depth to groundwater table, were also recorded. Soil samples were collected from the surface (top 10 inches) using a spade and/or soil core and then placed in a plastic bag and stored in a cooler until they could be brought to the laboratory and refrigerated.

Maintenance and Pre-restoration Drainage Data

Information about maintenance practices and pre-restoration drainage status were obtained from the following sources:

1. Personal interviews of land managers and restoration practitioners.
2. Construction plans, wetland delineation reports, and monitoring reports prepared for compensatory mitigation projects.
3. Imagery:
    a. Google Earth current and historical imagery.
    b. 1937-41 aerial imagery was accessed from the Wisconsin State Cartographer's office https://maps.sco.wisc.edu/WHAIFinder/#7/44.750/-89.750,
    c. Wisconsin Regional Orthophoto Consortium (WROC) Spring leaf-off aerial images (2010) 12-18" resolution. http://relief.ersc.wisc.edu/wisconsinview/session3.php
    d. LiDAR (Light Detection and Ranging) imagery: Digital Elevation Models (DEMs) and Hillshade data, when available, was accessed for select counties in Wisconsin. http://relief.ersc.wisc.edu/wisconsinview/session3.php

4.3 Analysis

4.3.1 Floristic Quality Metrics

Results of timed meander surveys, i.e. a plant species inventory and percent areal cover estimates, were entered into the WDNR Floristic Quality Calculator, 2017 version (WDNR 2017). Floristic quality metrics were calculated based on the Coefficient of Conservatism (C-Value) pre-assigned to each vascular plant species in the flora (see Bernthal 2003), using the following formulas (Bernthal 2003; Milburn et al 2007; DeBerry 2015).

Native Species Richness (N_n) = number of native species in the assessment area.
Relative Non-Native Cover **=** % absolute cover non-native species/ total cover by all species.
Mean C ($\overline{C}$) = Coefficient of conservatism value averaged across all species (native and non-native) within a community. Non-native species are given a C-value of 0.

$$\bar{C} = \frac{\sum_{i=1}^{N} C_i}{\mathrm{N}}$$

where C_i = C-value for *i*th species; N = species richness

Weighted Mean C ($w\overline{C}$) is mean C ($\overline{\mathbf{C}}$) calculated as the sum of the product of each species' C-Value and its proportional cover, i.e. mean C weighted by each species' relative cover.

$$w\overline{\mathrm{C}} = \sum_{i=1}^{N} p_i \, C_i$$

where C_i = C-value for *i*th species; N = species richness; p_i = relative cover of species *i*

Floristic Quality Index (FQI) is the Mean C ($\bar{C}$)of a plant community multiplied by the square root of the total number of species. ***w*FQI** uses Weighted Mean C in this calculation.

$$w\text{FQI} = w\bar{C} \times \sqrt{N}$$

where N = species richness; $w\bar{C}$ = weighted mean C-value of all species in a community.

4.3.2 Average Wetland Indicator Score:

To explore any trends in overall site wetness as indicated by plant community composition that might be attributed to restoration technique, a wetness metric was calculated by assigning numerical values to the wetland indicator status of each plant species present in the AA where OBL = -2; FACW = -1; FAC = 0; FACU = +1; and UPL = +2.

4.3.3 Assessment Area Size

AAs were mapped using ArcGIS after timed-meander surveys were completed using a combination of the survey track gathered during the survey and aerial imagery to delineate the broad outline of the plant community. Because timed-meander surveys are normally stopped when new species run out rather than when the community ends, extrapolation of a meander track to the community being sampled is necessary and subject to interpretation. This causes some variability between surveyors but in general tends to under-estimate the true size of communities, especially larger ones.

4.3.4 Community Classification

Restored wetland AAs were assigned to a plant community based on the WDNR Natural Heritage Conservation's Natural Community Classification and associated Key to Wetland Natural Communities (O'Connor 2018). This classification recognizes 41 wetland communities, including 4 ruderal (i.e. disturbed) community types. The key is shown in Appendix A. Community assignments for AA's were based on the composition of the plant community at the time of the survey, and not the community targeted for restoration since this was unknown or unspecified in many cases.

To explore the effects of techniques on floristic quality, natural communities were also grouped according to a more generic classification: Prairie (Wet-mesic Prairie + Wet Prairie + drier-end Ruderal Wet Meadows), Meadow (Southern Sedge Meadow + Northern Sedge Meadow + wetter-end Ruderal Wet Meadows), Marsh (Emergent Marsh + Ruderal Marsh), Shrub (Shrub-carr + Ruderal Shrub Swamp), and Forest (Black-spruce/Tamarack Swamp + Southern Hardwood Swamp).

4.3.5 Wetland Condition Category Assignment

Restored wetland community AAs were assigned one of five condition categories (Excellent, Very Good, Fair, Poor, and Very Poor) based on recommended benchmarks of floristic quality calculated in Hlina et al (2015) and Marti & Bernthal (2019). Condition categories were assigned based on Mean C-Values weighted by percent areal cover ($w\bar{C}$). In cases where no benchmarks had been developed for a community/ecoregion combination, the closest available benchmarks geographically and ecologically were substituted. Ruderal communities do not have their own benchmarks, instead the floristic quality benchmarks for the most similar undisturbed communities were used. Condition benchmarks used for this study are shown in Appendix B.

Results at the site level were calculated using a weighted average approach, where the condition of individual AAs were weighted by their proportional size within a site (MPCA 2014). Condition tiers for individual AAs were given numbers, (3 = Fair, 4 = Poor, etc.) and the area of each AA in hectares was measured using ArcGIS as shown on individual site maps (See Appendix C). The proportional area of each AA was calculated by dividing the AA size by the total area of all assessed wetlands on the site. Condition scores for each AA were multiplied by the proportional size and added together for a total site condition score. This was then rounded to the nearest whole number to give an overall site condition. Table 5 shows overall site condition scores for the 39 selected sites.

4.3.6 Additional Site Factors

Active Site Maintenance: Information about site maintenance conducted after construction of the restoration was obtained by interviewing the site manager. Managers were asked if there was any ongoing maintenance to the plant community (e.g. invasive species control, burning, or mowing) and their answers recorded as “Yes” or “No.” Maintenance activities that only occurred once or a few times and weren’t ongoing or recent (within the past 5 years) were recorded as a “No.”

Pre-Restoration Drainage:
All restoration sites included in this study began as historic wetlands; any projects which created wetlands from historic uplands were not included. It was assumed that these historic wetlands were drained or buried either fully or partially due to the presence of ditches, tile, row cropping, or sedimentation. Each restoration site was categorized as either **fully-drained** or **partially-drained** prior to restoration activities using the following evidence:

1. Wetland delineation reports of the site prior to restoration activities were the best source of information on wetland status prior to restoration. Areas designated as upland or “prior converted” in delineations were categorized as “fully drained”. Areas delineated as wetland on pre-restoration reports were categorized as “partially drained”.

2. When a wetland delineation prior to restoration was not available, historical imagery (e.g. 1937-41 aerial imagery and Google Earth historical imagery) was used to assess drainage conditions. If prior to being restored the area was fallow or appeared to have natural vegetation when the rest of the field was cropped in, (normally 3 years of images were available), the area was categorized as “partially-drained”. When the area was plowed in the majority of images, it was categorized as “fully drained”. Cranberry farms were an exception in that cultivation was not assumed to indicate drained conditions. When using aerial imagery alone to delineate wetland conditions there was a risk of missing cultivation in wetland soils (farmed wetlands) therefore it was more likely to have underestimated rather than overestimated wetland conditions prior to restoration.

Soil Analysis

Laboratory Analysis

Soil samples (59) were sent to University of Wisconsin – Madison's Soil and Forage Analysis Laboratory in Marshfield, WI, in November of 2017. Samples were analyzed for pH using a 1:2 soil to water extraction; percent total phosphorus (TP) using a nitric/peroxide method; percent organic matter (%OM) using the weight loss-on-ignition (LOI 360 degrees) technique. Total nitrogen (Organic N + NH4N + NO3-N +NO2-N), total carbon (TC) and total organic carbon (TOC) percent dry weight was determined using dry combustion.

Comparison with datasets from natural wetlands:

Soil chemistry and floristic quality metrics from two natural wetlands datasets in Wisconsin were used for comparison. The 2011 National Wetland Condition Assessment (NWCA) contains data from 29 wetlands selected using a probabilistic method from across the nation. NWCA 2011 data is freely available on the National Aquatic Resource Survey (NARS) website. The 2011 - 2012 Wisconsin Intensification Study, which includes data from 50 wetlands selected probabilistically from Wisconsin's Lake Michigan basin, was provided by Aaron Marti, WDNR.

Mineral vs Organic Soil Classification:

Soils were classified as mineral or organic using two methods: in-field soil profile descriptions and laboratory measurement of total organic carbon (TOC) and/or total carbon (TC) from the top 10 cm of soil. Using in-field texturing, soils described as "Peat" "Muck" or "Mucky Peat" in the upper horizons of the soil profile were classified as organic soil. All other textures (loam, clay, mucky mineral) were considered mineral. At least on sample was taken from each site. AAs with missing soil data used results from an adjacent AA within the same site.

Lab results for TOC or TC were used to classify soils as mineral or organic based on the following guidelines (NRCS 2018), (Marti, 2016):

- Soils with TOC by percent dry weight data (only available for restored sites) of at least 18% were classified as organic; amounts from 12-18% were considered organic only if the soil profile described the upper part as peat, muck, or mucky peat; TOC less than 12% was classified as mineral.
- Soils with TC data (restored sites and all NWCA data) in amounts of 20% or greater were classified as organic; amounts from 12-20% were considered organic only if the clay content was known (NWCA 2011 data) or the field soil description was available and indicated organic soils (restored sites and NWCA Intensification).

4.3.7 Statistics

FQA results, soil data, and site data were entered into the WDNR Wetland Restoration FQA database in Microsoft Access (2007 version in 2016 file format). Data from exported spreadsheets was manipulated in Microsoft Excel (2016 version) and imported into RStudio while running R (Version 3.6.1 R Core Team 2019). Variation in floristic quality metrics were analyzed to look for differences between groups using Welch's T-tests, Analysis of Variance (ANOVA), or Fisher's Exact Test for Count data. Tukey multiple comparisons of means was then applied to identify the source of differences when more than two groups were involved.

Restoration Technique Comparisons

- **Three pairs of contrasting stand-alone techniques**: Ditch Fill vs Ditch Plug; Tile Removal vs. Tile Break, and Sediment Removal vs. Scrape. These analyses were limited to restorations that used only a single technique to restore hydrology.
- **Ditch Modifications vs Tile Modifications vs Scrapes vs Sediment Removal**: Restored wetlands were grouped according to their use of either a ditch modification (Ditch Fill or Ditch Plug), a Tile modification (Tile Removal or Tile Break), and Scrape or Sediment Removal.
- **Multiple techniques**: Wetlands restored using more than one technique were grouped according to the completeness of the hydrological modification into either a "Mixed Complete" or "Mixed Partial" group. Although not targeted as part of this study, Dike Removal is an added technique in the Mixed Complete group. Mixed-technique restorations that did not use either all complete or all partial techniques were dropped from this analysis.
- **Complete vs. Partial Hydrologic Restoration Techniques**: All restoration sites that used single techniques designed to fully restore hydrology (Ditch Fill, Tile Removal, Sediment Removal, or Multiple Complete) were combined to form the "Complete Techniques" group and compared with all restorations that used only partial hydrologic restoration techniques (Ditch Plug, Tile Break, Scrape, and Multiple Partial).
- **Other factors**: The same analyses were used to look for differences between maintenance groups, pre-restoration drainage groups, soil types, community groups, and restoration organization.

Linear Mixed Effects Models

For the previously mentioned analyses, all individual wetland AA datasets were treated as independent despite many being from the same site, a violation of the assumption of random sampling. A method to overcome this problem inherent in hierarchical data sets was the use of linear mixed effects models. Linear mixed effects models incorporate the site of each AA as a random effect, with restoration technique, pre-restoration drainage, maintenance, soil type, community group, and restoration organization as fixed effects. Another benefit of using a linear regression model is the ability estimate effect sizes of the variables we measured and compare the strength of hydrologic restoration technique with that of maintenance and initial condition. We used the linear mixed-effects model (lme4; Bates et al. 2015). Additionally, the Psych package (psych; Makowski 2018) was used to aide in interpretation of lme4 outputs.

Results of T-Tests and ANOVAs were used to determine which fixed effects should be included in initial models. Only factors that were significant at the 0.05 level were included. For instance, Technique (Complete vs Partial), Start Drainage (Full or Partial), Maintenance (Yes or No), and Community Type showed significant differences in $w\bar{C}$ when tested separately. These four factors were added to the linear mixed effects model. Factors that showed an insignificant p-value ($p>0.1$) in the linear mixed effects model were then removed, leaving only the strongest factors as part of the final model. Interactions between the strongest factors were also tested and kept in the final model when significant.

5 RESULTS

5.1 GENERAL RESULTS

5.1.1 Site Selection -Wetland Restoration Techniques Represented

A total of 39 wetland restoration sites with 73 AAs (Assessment Areas) were selected and surveyed for this study (Table 1). Study sites were distributed among 19 counties but were concentrated in the Southeast WI Till Plains and scarce in the Northern Lakes and Forests Ecoregion (Fig 1). Sites were selected in roughly equal numbers from compensatory mitigation projects, non-profit groups, and DNR wildlife habitat restoration projects, with an additional three Wetland Reserve Program restorations selected. Two sites were included from Illinois (Kane County) due to prior knowledge of these projects and the need for more restorations that employed sediment removal and tile removal practices.

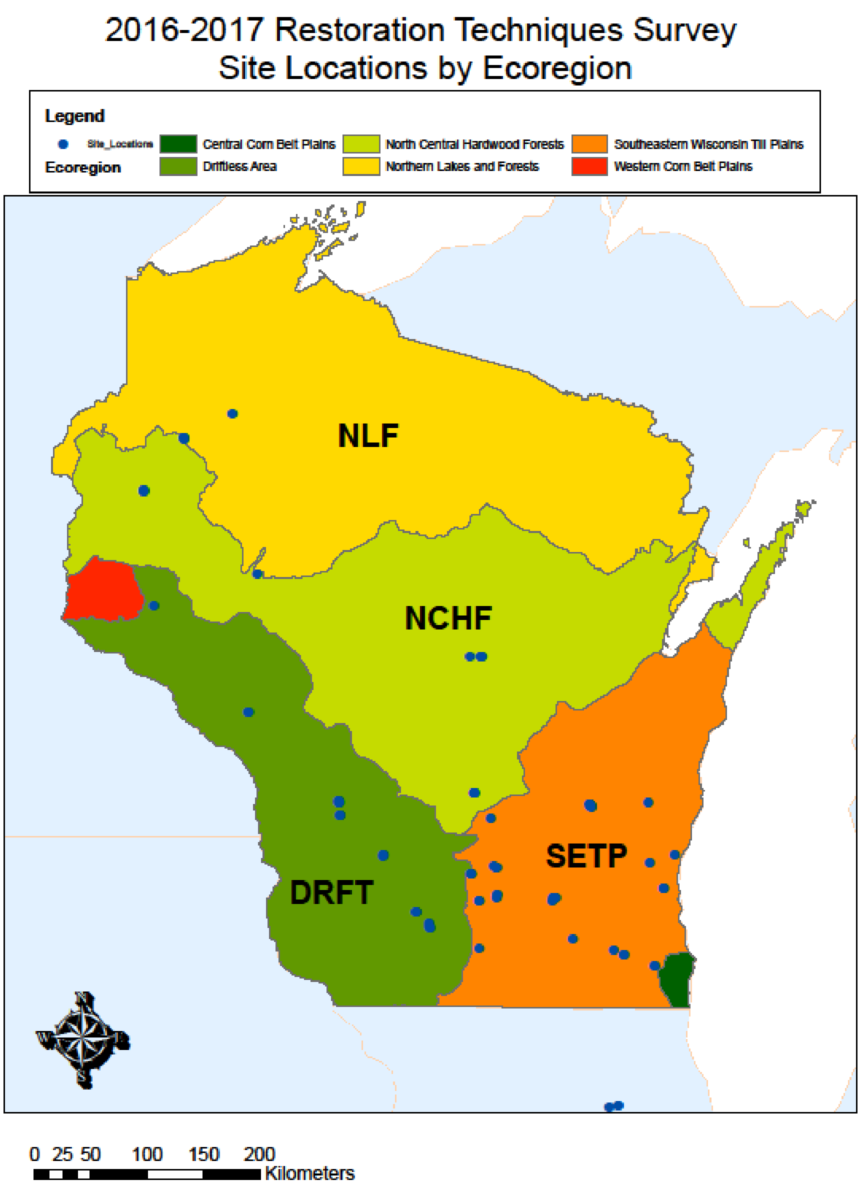


Figure 1. Locations of 39 wetland restoration sites surveyed for this study with Omernik Level III Ecoregions shown.

Table 1. List of restoration sites selected surveyed by organization type, years since restoration began, county, number of wetlands assessed per site, and hydrologic restoration techniques employed.

Restoration Site Name	Restoration Organization Type	Restoration Age (yrs)	County	Communities Surveyed	Hydrologic Restoration Technique(s)
Ashley Furniture	Compensatory Mitigation	10	Trempealeau	2	Ditch Fill, Sediment Removal
Beaver Brook	Compensatory Mitigation	7	Washburn	4	Ditch Fill, Dike Removal
Brooklyn W.A.	Wildlife Habitat Restoration	6	Green	1	Tile Break
Dane Co. Cherokee Marsh	Compensatory Mitigation	11	Dane	2	Sediment Removal
Dane Co. Starkweather Creek	Compensatory Mitigation	13	Dane	1	Sediment Removal
Drost WRP	Wetland Reserve Program	5	Jefferson	1	Tile Break, Scrape
East Troy Sod WRP	Wetland Reserve Program	4	Walworth	2	Tile Break, Scrape, Berm
Faville Grove Ledge Lowland	Non-Profit	13	Jefferson	2	Ditch Fill
Faville Grove Snake Marsh	Non-Profit	10	Jefferson	1	Scrape
Faville Grove Tillotson Prairie	Non-Profit	17	Jefferson	1	Ditch Fill
Faville Grove Tillotson Floodplain	Non-Profit	15	Jefferson	1	Ditch Fill
GHRA Spirit Enterprises	Wildlife Habitat Restoration	11	Fond du Lac	8	Scrape, Berm
GHRA Stoppleworth	Wildlife Habitat Restoration	7	Fond du Lac	1	Scrape, Berm
Goose Pond Hopkins Rd. Prairie	Non-Profit	15	Columbia	1	Sediment Removal
Goose Pond Lapinski-Kitze Prairie	Non-Profit	12	Columbia	1	Sediment Removal
Goose Pond Sue Ames Prairie	Non-Profit	20	Columbia	1	Sediment Removal
Headwaters	Compensatory Mitigation	11	Kane	1	Tile Removal
Heritage Crossing	Compensatory Mitigation	8	Ozaukee	1	Tile Removal
Hickory Knolls- Carol's Wetland	Non-Profit	22	Kane	2	Sediment Removal
Jackson Marsh Wildlife Area	Wildlife Habitat Restoration	9	Washington	1	Scrape, Berm
Kettle Moraine SF Mukwonago Unit	Wildlife Habitat Restoration	7	Walworth	1	Ditch Plug
Kettle Moraine SF Northern Unit	Wildlife Habitat Restoration	6	Sheboygan	1	Scrape
Knights Creek WisDOT Mitigation	Compensatory Mitigation	15	Dunn	1	Ditch Plug, Tile Break
Lodi Marsh Mitigation Bank	Compensatory Mitigation	18	Dane	3	Tile Break, Sediment Removal, Stream Re-meander
Loon Lake Wildlife Area North	Wildlife Habitat Restoration	4	Polk	3	Ditch Plug, Tile Break, Scrape
Loon Lake Wildlife Area South	Wildlife Habitat Restoration	5	Polk	1	Berm
Lost Creek WisDOT Mitigation	Compensatory Mitigation	7	Portage	3	Ditch Fill, Tile Break, Scrape
McDonald WRP	Wetland Reserve Program	10	Iowa	3	Ditch Plug, Scrape
Mequon Nature Preserve	Non-Profit	12	Ozaukee	2	Tile Break, Berm
Moses Creek WisDOT Mitigation	Compensatory Mitigation	6	Portage	1	Scrape
Mueller/Shea Prairie	Non-Profit	4	Iowa	2	Sediment Removal, Tile Removal
Neptune WisDOT Mitigation	Compensatory Mitigation	14	Richland	3	Ditch Plug, Tile Break, Scrape
Pecatonica 2006	Non-Profit	11	Iowa	1	Sediment Removal, Scrape
Pecatonica 2008	Non-Profit	9	Iowa	1	Sediment Removal
Pheasant Branch Conservancy	Non-Profit	13	Dane	1	Ditch Fill
Summerton Bog SNA	Non-Profit	12	Marquette	7	Ditch Fill, Tile Removal, Sediment Removal
Tom Lawin Wildlife Area	Wildlife Habitat Restoration	11	Chippewa	1	Ditch Plug
Upper Chippewa Mitigation Bank	Compensatory Mitigation	11	Sawyer	1	Ditch Fill, Dike Removal
Walkerwin Mitigation Bank	Compensatory Mitigation	20	Columbia	1	Ditch Fill, Ditch Plug, Berm
Total Surveyed Communities:				72	

Of the pool of restorations available, scrapes, berms, ditch plugs and tile breaks were the most common techniques (Table 2). Ditch fill and sediment removal were less common and complete tile removal was hardest to find. Many restorations were rejected because they combined too many techniques or included an impounding structure (dike, berm, or water-control structure) -a common technique not targeted for this study.

Restoration sites that used only one technique were sought out but proved difficult to find. Of the 73 AA's surveyed, 20 used multiple techniques. Those that used multiple techniques were separated into 2 groups: those that used a combination of techniques associated with complete hydrological restoration were labelled "Multiple-Complete" and those that used combinations associated with partial hydrological restoration, "Multiple-Partial". Two restorations used a combination of techniques that could not be categorized as either all "complete" or all "partial" and were excluded from analyses that compared techniques. In addition, three wetland surveys were disqualified for other reasons, one was drained since restoration, one was a multi-year replicate, and one could not be categorized by technique. The final number used in any analysis involving technique was 68.

Table 2. Restoration techniques sampled for this study, including restorations using only a single technique and those combining multiple techniques. "n" is the number of wetland AAs surveyed per target restoration technique selected for study; "Site n" is the number of restoration sites or projects using the technique. Total site number is greater than the number of sites (39) because some sites contained multiple technique types.

Technique	n	Site n
Complete:		
Ditch Fill	10	6
Sediment Removal	11	8
Tile Removal	4	4
Partial:		
Ditch Plugs	6	5
Scrape	16	8
Tile Break	5	4
Multiple-Complete:		
Ditch Fill + Dike Removal	5	2
Ditch Fill + Sed. Removal	2	2
Ditch Fill + Tile Removal	3	2
Multiple-Partial:		
Tile Break + Scrape	2	2
Ditch Plug + Tile Break	2	2
Ditch Plug+ Tile Break + Scrape	2	2
Other:	5	3
Total	**73**	**50**

5.1.2 Community Classification Results

A total of 11 different natural community types were recognized among the restored wetlands assessed for this study (Fig. 2; Table 3). Dominant plants were identified as the species with the highest absolute areal cover, which when combined, comprised at least 50% cover, or had a minimum of 20% cover. The most common wetland community restored was Ruderal Wet Meadow (n = 24). This classification was assigned to herbaceous plant assemblages that did not fit a description of either a Northern or Southern Sedge Meadow, Wet or Wet-mesic Prairie, or Emergent Marsh due to the absence of species characteristic of these communities. Most were dominated by reed canary grass (*Phalaris arundinacea),* but other common dominants were hybrid cat-tail (*Typha X glauca)* or wool grass (*Scirpus cyperinus)*.

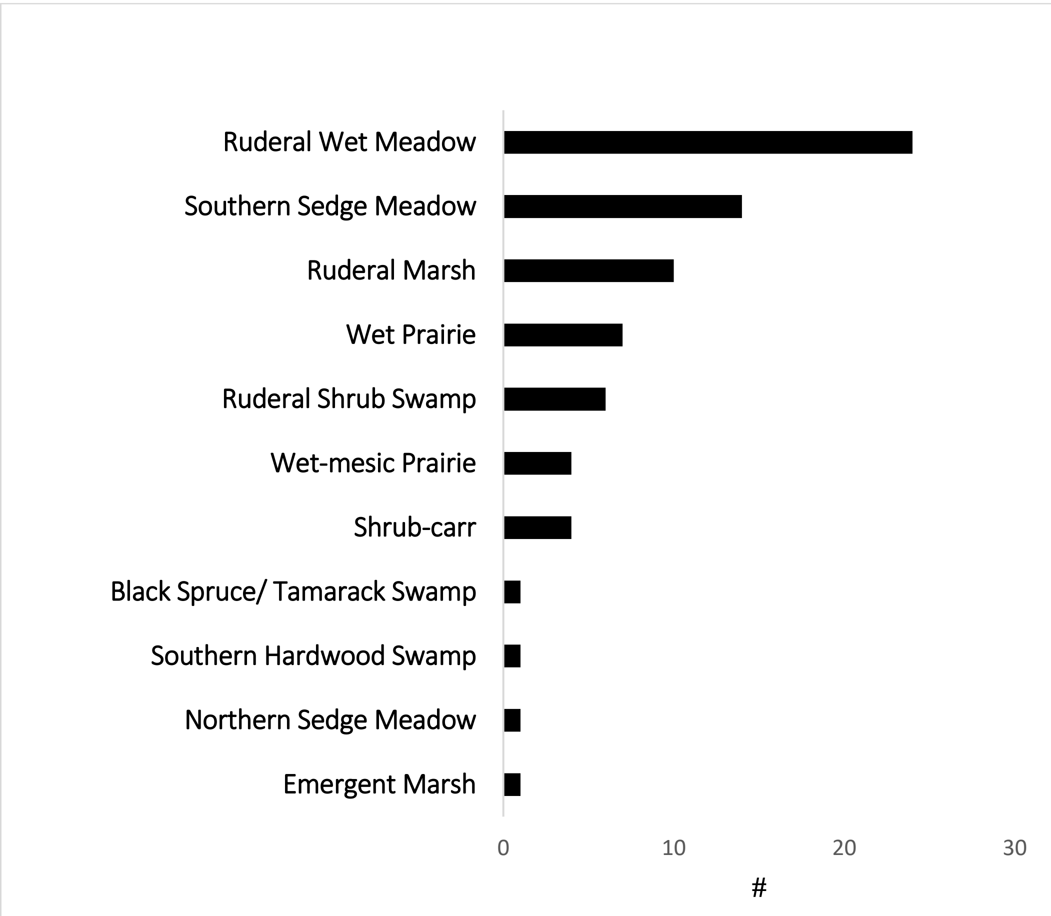


Figure 2: Percentage of assessment areas surveyed for this study by Wisconsin Natural Community Classification. See Appendix A for Key to Wisconsin Wetland Communities.

Table 3. Natural community classifications of restored wetlands in this study with the dominant plants found in communities of that type; “n” is the number of wetland communities assigned that community; the final column shows the community/ecoregion combinations used to assign a condition category from WDNRs preliminary FQA condition benchmarks. When condition benchmarks were not available for a particular community the closest community geographically or compositionally was substituted. Omernik Level 3 Ecoregions are shown as SETP (SE WI Till Plains); DRFT (Driftless Area); NCHF (North Central Hardwood Forests); and NLF (Northern Lakes and Forests).

Natural Community Assignment	Dominant plant(s) in AA	n	Available Preliminary Benchmarks
Ruderal Wet Meadow	Reed canary grass (*Phalaris arundinacea*) Hybrid cattail (*Typha x glauca*) Timothy (*Phleum pratense*) Wool grass (*Scirpus cyperinus*) Spikerush (*Eleocharis* spp.) Boneset (*Eupatorium perfoliatum*) Marsh bluegrass (*Poa palustris*) Sweet black-eyed Susan (*Rudbeckia subtomentosa*) Hairy-fruit sedge (*Carex trichocarpa*) Canada manna grass (*Glyceria canadensis*)	24	Southern Sedge Meadow (**SETP**, **DRFT**, **NCHF**) Wet-Mesic Prairie (**SETP**) Northern Sedge Meadow (**NLF**, **NCHF**)
Southern Sedge Meadow	Tussock sedge (*Carex stricta*) Blue-joint grass (*Calamagrostis canadensis*) Lake sedge (*Carex lacustris*)	13	Southern Sedge Meadow (**SETP**, **DRFT**, **NCHF**)
Ruderal Marsh	Narrow-leaved cattail (*Typha angustifolia*) Hybrid cattail (*Typha x glauca*) Rice cut-grass (*Leersia oryzoides*) Spikerush (*Eleocharis* spp.)	10	Emergent Marsh (**All Ecoregions**)
Wet Prairie	Cordgrass (*Spartina pectinata*) Wool grass (*Scirpus cyperinus*) Sneezeweed (*Helenium autumnale*) Hairy-fruit sedge (*Carex trichocarpa*)	7	Wet-mesic Prairie (**SETP**) Southern Sedge Meadow (**NCHR**, **DRFT**, **SETP**)
Ruderal Shrub Swamp	Sandbar willow (*Salix interior*)	6	Shrub-carr (**All Ecoregions**)
Shrub-carr	Meadow willow (*Salix petiolaris*) Bebb’s willow (*Salix bebbiana*) Pussy willow (*Salix discolor*)	4	Shrub-carr (**All Ecoregions**)
Wet-mesic Prairie	Big bluestem (*Andropogon geradii*) Switchgrass (*Panicum virgatum*) Small-headed rush (*Juncus brachycephalus*) Saw-tooth sunflower (*Helianthus grossesserratus*)	4	Wet-mesic Prairie (**SETP**)
Northern Sedge Meadow	Tussock sedge (*Carex stricta*)	1	Northern Sedge Meadow (**NLF**, **NCHF**)
Emergent Marsh	Broad-leaved cattail (*Typha latifolia*)	1	Emergent Marsh (**All Ecoregions**)
Black Spruce Swamp	Black spruce (*Picea mariana*) Tamarack (*Larix laricina*)	1	Black Spruce/Tamarack Swamp (**NLF**)
Southern Hardwood Swamp	Silver maple (*Acer saccharinum*) River birch (*Betula nigra*)	1	Southern Hardwood Swamp (**SETP**)

5.1.3 Soil Sampling Results: Mineral vs. Organic soils.

In-field texturing of the top 10 cm of soil from 59 AAs found the majority (63%) of samples to fall in the fine-grained mineral category, comprised for the most part of silt loams and silty clay loams. The remaining soils were roughly equally divided between organic and course-grained mineral (sandy) soils (Table 4). Based on field texturing 20% of restored wetland AAs in the study had organic soils and the remaining 80% were mineral or mucky mineral.

Table 4. Soil texture from in-field observations of 59 AAs.

Field Soil Texture (top 10 cm)	Count of Lumped Soil Texture	
Coarse-Grained Mineral	**17%**	
Sand		2%
Sandy Loam		2%
Sandy Muck		14%
Fine-Grained Mineral	**63%**	
Clay Loam		5%
Loam		8%
Mucky Mineral		10%
Sandy Clay Loam		3%
Silt Loam		19%
Silty Clay		2%
Silty clay loam		14%
Very Fine Sandy Loam		2%
Organic	**20%**	
Muck		12%
Mucky Peat		3%
Peat		5%
Grand Total		**100%**

Soils classified as organic or mineral based on laboratory soil analysis of TOC using the standard definitions resulted in a split of 18% organic soils and 82% mineral soils. The higher numbers of mineral soils from laboratory analysis suggest that in-field soil texturing may have resulted in a mineral soil mistakenly being called an organic soil in few cases. Comparing these results with natural wetlands probabilistically selected from across the nation, including Wisconsin and from Wisconsin's Lake Michigan Basin shows a higher representation of mineral soils in the restored wetland dataset than either natural wetland dataset.

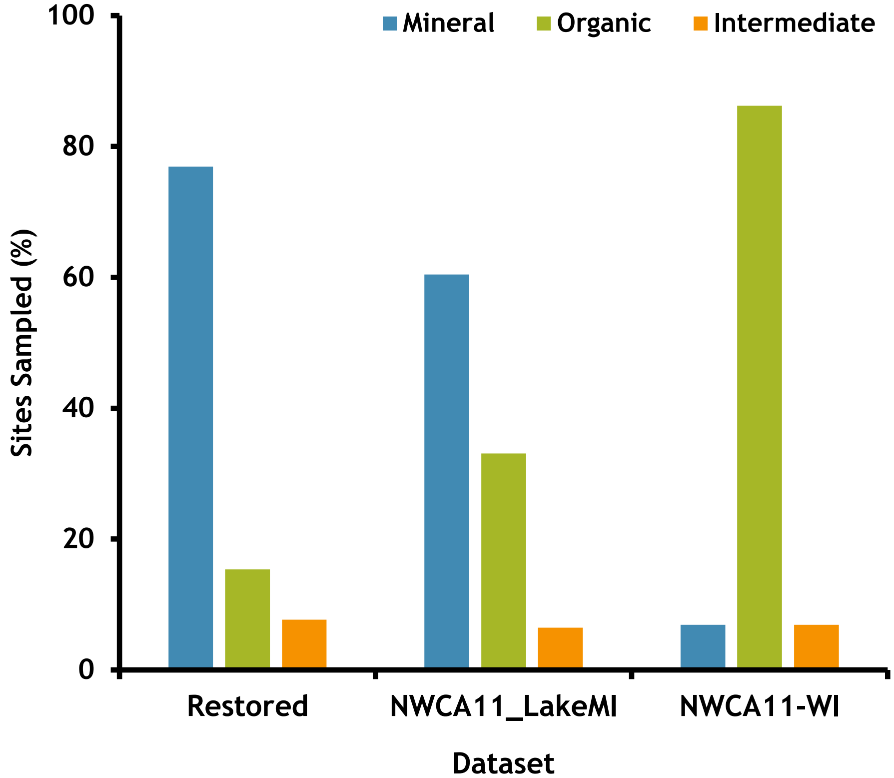


Figure 3. Percentage of mineral and organic soil wetlands in restored vs. natural wetland datasets. Source of natural wetlands data: NWCA 2011 (29 sites across WI) and NWCA 2011-2012 Intensification (50 Sites in the Lake MI Basin of WI).

<u>5.1.4 Organic Matter and Total Soil Carbon Results</u>

Percent organic matter (OM) in sampled soils ranged from 1.2% to 64.9% with a mean of 13.2%. Total soil carbon was significantly lower in restored wetlands than in natural wetlands in all regions (Figure 4), with the largest disparity in the northern region (45% total carbon in natural wetlands vs 8% in restored wetlands). Comparisons of natural and restored organic carbon within three community types show differing patterns by community, with wet/wet-mesic prairie having the least disparity and shrub-carr the most (Figure 5). Organic matter was also significantly different between restorations starting on fully-drained (mean OM =10.2%) and partially drained conditions (mean OM = 27.2%) (Figure 6).

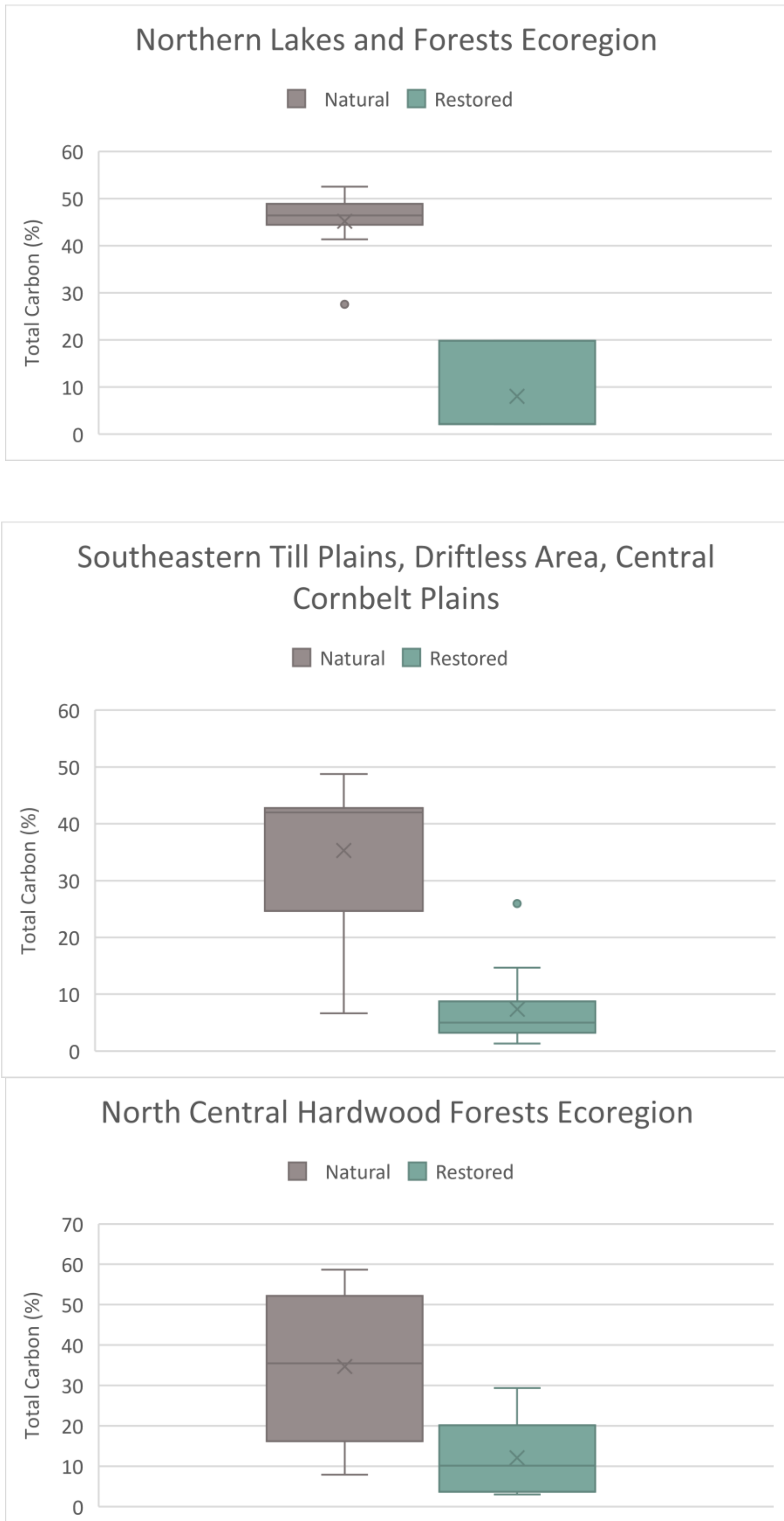


Figure 4: Total Carbon in Restored vs Natural Wetlands by Omernik Level III Ecoregion. Data from natural wetlands from NWCA 2011 (29 sites). Mean percent total carbon was significantly lower in restored wetlands in all ecoregions. (p-value = 0.01 (Southeastern Till Plains and North Central Hardwood Forests), and p-value = <0.001 (Northern Lakes and Forests).

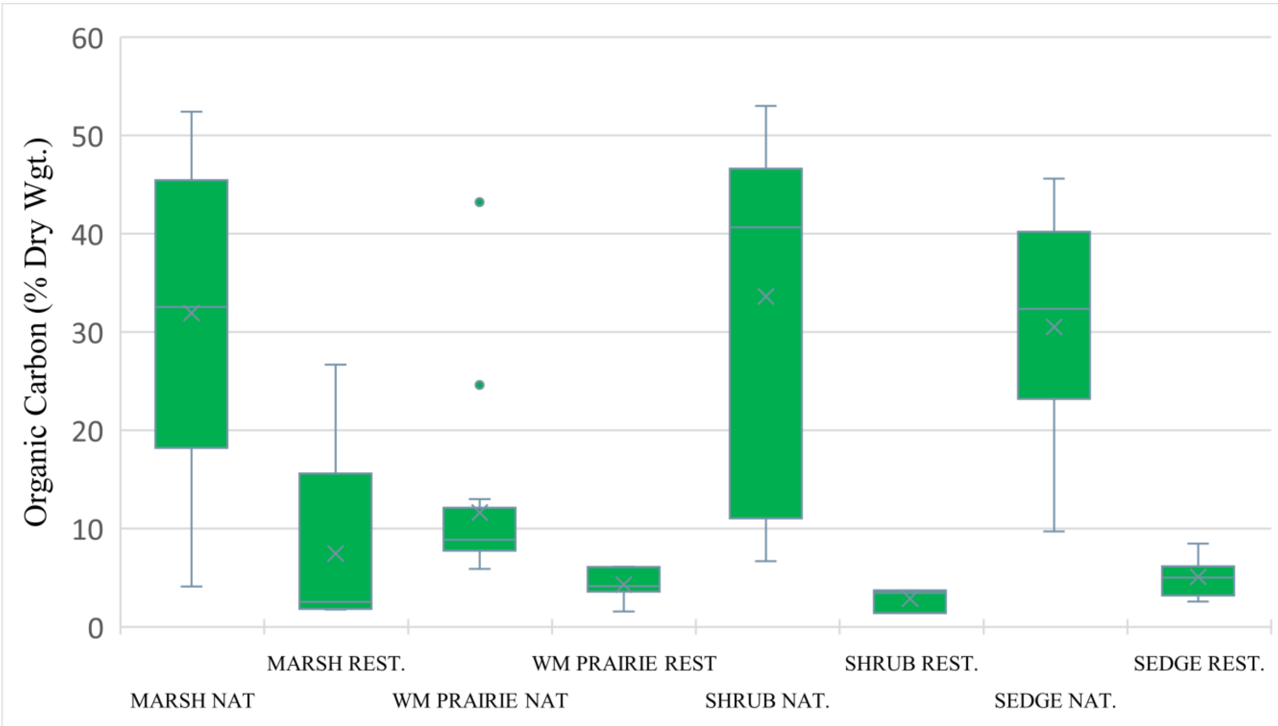


Figure 5. Organic carbon in natural wetlands (WDNR's FQA benchmark wetland survey soil samples) and restored wetlands (this study) from four communities in the Southeastern WI Till Plains ecoregion: Emergent Marsh, Wet/Wet-mesic Prairie, Shrub-carr, and Southern Sedge Meadow.

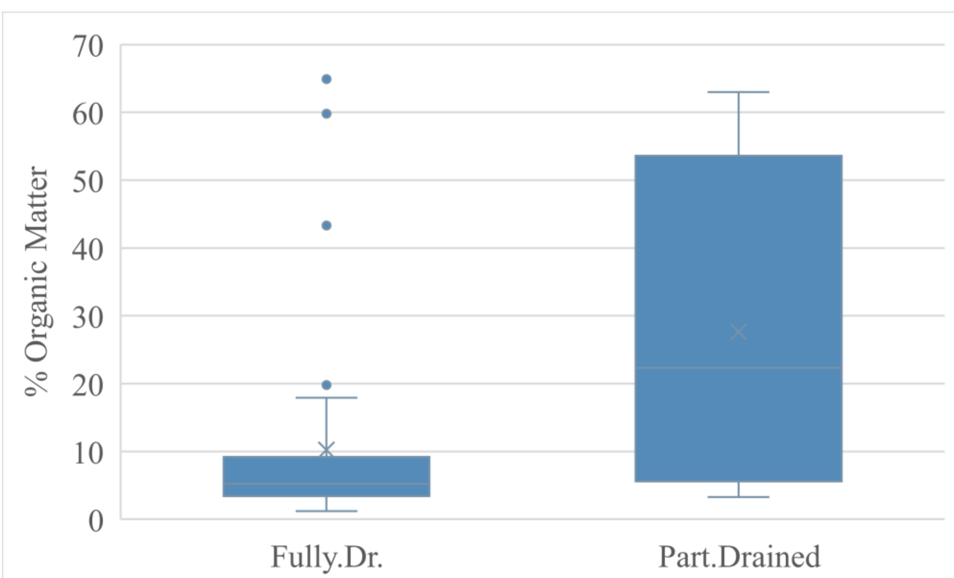


Figure 6. Organic Matter content from 51 restored wetlands from this study by initial condition: Fully-drained or Partially-drained. The top three outliers among the Fully-drained group represent restorations from farmed muck soils.

5.1.4 Overall Wetland Condition Results

Condition of Individual Assessment Areas

Of the 72 unique wetland AAs, 14 (19.4%) did not have condition benchmarks either for that specific community type or for that community type in that ecoregion. The following community types from this study have no preliminary condition benchmarks currently:

- Wet Prairie (n = 9) has no condition benchmarks in Wisconsin. Southern Sedge Meadow or Wet-mesic Prairie condition benchmarks from Southeastern Till Plains (SETP) were substituted instead, depending on species composition.
- Wet-mesic Prairie restorations from the Driftless Area and NCHF (n = 2) used SETP Wet-mesic Prairie condition benchmarks.
- Southern Hardwood Swamp (n = 1) does not have condition benchmarks in Driftless Area, SETP ecoregion benchmarks were substituted.
- Ruderal Wet Meadows in NCHF (n = 2) that compositionally resembled disturbed prairie rather than Southern Sedge Meadow used Wet-mesic Prairie condition benchmarks from SETP.
- Submergent Marsh (n = 11) also currently have no condition benchmarks or sampling protocol in Wisconsin. These communities were noted but not surveyed.

Using weighted mean coefficient of conservatism scores (w$\bar{C}$) to compare with preliminary condition benchmarks (Appendix B), 51% of wetlands fell within Tier 3, - "Fair" - of the 5-tier system, with another 32% falling in the "Poor" category. No restored wetlands fell in the "Excellent" category, 10% were in "Good" condition, and 7% fell in the "Very Poor" condition category (Figure 7). Overall 61% were in "Fair" or better condition and 39% in "Poor" or worse condition.

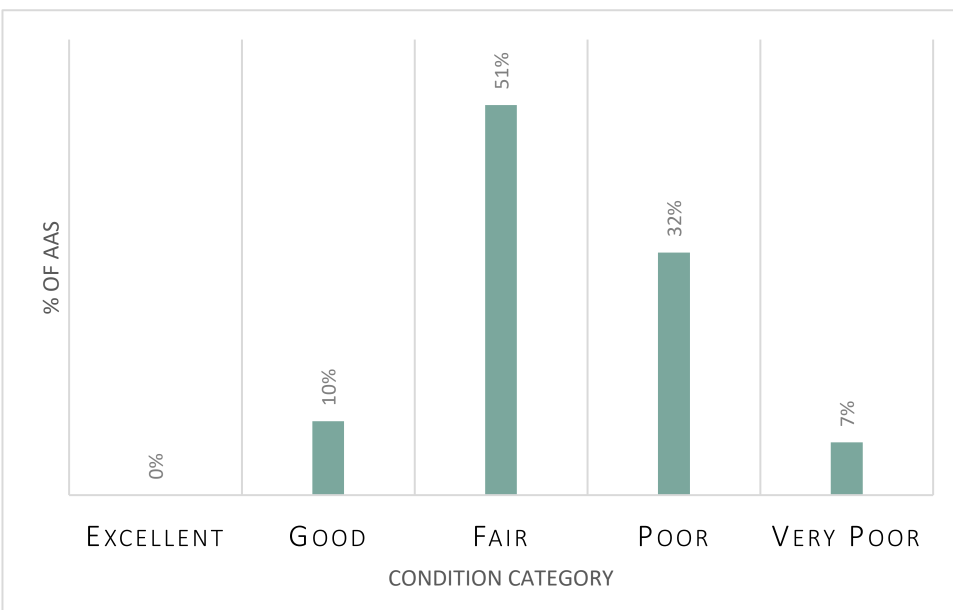


Figure 7. Condition categories of 72 restored wetland AAs surveyed as part of this study using benchmarks for $w\bar{C}$.

Condition by organization type

Condition at Site Level

Condition results averaged at the site level were more likely to be in “Fair” condition, with 64% of 39 sites falling in the “fair” category and with reductions in all other condition categories (Figure 8). Site level results are also listed in Appendix C.

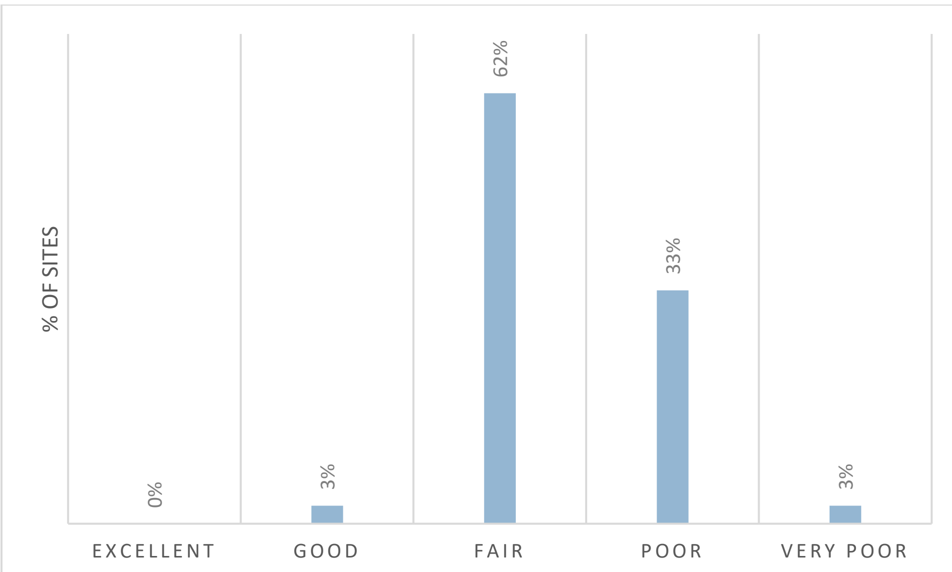


Figure 8. Condition results of 39 restoration sites. Condition results from sites where multiple AAs were surveyed were averaged based on AA size. These results do not represent all the restored wetlands on the site, only those associated with techniques of interest for this study.

5.2 Hydrologic Restoration Technique Comparisons

5.2.1 Comparisons between contrasting techniques (T-Tests):

Floristic quality metrics were significantly higher for complete hydrologic restoration techniques compared to partial hydrologic restoration techniques, although results were not significant for most pairwise comparisons of specific techniques (Table 5).

Table 5. Mean values ± SE of variables by technique in AAs that used one of six techniques (top 6 rows) and restorations that used multiple techniques separated into two groups. P-values from T-tests are given as *** P <0.001; **P< 0.01; *P<0.05. Shaded boxes indicate significantly different pairs.

	Technique	N	Native Species Richness	Non-Native Rel Cover	Mean C	wC	wFQI	Ave. Area (Acres)
Ditch Modifications	**Ditch Plug**	6	40.7 ± 6.04	28.3 ± 6.24	3.6 ± 0.14	3.3 ± 0.25	22.2 ± 2.53	3.3 ± 0.93
	Ditch Fill	9	55.9 ± 8.77	17.1 ± 5.05	3.9 ± 0.21	3.8 ± 0.37	28.0 ± 3.14	4.4 ± 1.25
Tile Modifications	**Tile Break**	5	42.0 ± 7.50	25.4 ± 14.13	3.4 ±0.12	3.2 ± 0.65	23.4 ± 4.93	3.3 ± 0.40
	Tile Removal	4	61 ± 8.82	21.3 ± 5.65	3.6 ± 0.28	3.2 ± 0.54	27.2 ± 5.12	3.8 ± 1.51
Surface Modifications	**Scrape**	16	32.7 ± 4.64*	28.7 ± 5.76	3.4 ± 0.12	2.9 ± 0.29	17.2 ± 1.99*	1.9 ± 0.94
	Sediment Removal	10	55.4 ± 8.36	21.4 ± 5.7	3.6 ± 0.23	3.6 ± 0.32	29.3 ± 3.67	3.9 ± 1.27
Multiple Techniques	**Multiple- Partial**	6	44.0 ±5.74	31.8 ± 8.54	3.3 ± 0.18**	2.9 ± 0.5	21.8 ± 0 4.66	5.7 ± 1.61
	Multiple -Complete	10	53.9 ± 3.27	15.7 ± 6.18	4.1 ± 0.15	4.1 ± 0.5	32.4 ± 4.53	6.7 ± 1.93
	All Partial	34	37.5 ± 2.97***	28.8 ± 3.83*	3.4 ± 0.07**	3.0 ± 0.19*	19.8 ± 1.54***	3.0 ± 0.60
	All Complete	33	55.8 ± 3.62	18.5 ± 2.89	3.8 ± 0.11	3.8 ± 0.21	29.6 ± 2.00	4.9 ± 0.80

Ditch Fill vs Ditch Plug

Mean values of native species richness (N_n), Mean C, $w\bar{C}$, and *w*FQI were higher, and non-native cover lower, in wetlands restored using Ditch Fills in comparison to Ditch Plugs. Average size of AAs was larger in restorations using Ditch Fill (4.4 ± 1.25 acres) than Ditch Plug (3.3 ± 0.93 acres). Average wC was 3.8 ± 0.37 for Ditch Fill and 3.3 ± 0.25 for Ditch Plug. However, no significant differences in the means of any floristic quality measures were detected (Figure 8).

Tile Removal vs Tile Break

Tile Removal showed higher mean native species richness, mean C, wFQI, and AA size, in addition to slightly lower non-native cover than Tile Breaks. However, sample sizes were limited for these groups (n = 4 and 5 respectively), and no statistically significant differences in any measures were found (Figure 8).

Scrape and Sediment Removal

Sediment Removal restorations had higher floristic quality values for all metrics. Two metrics were different enough to pass statistical tests: N_n and *w*FQI were both significantly higher in restorations that used sediment removal. However, no significant differences were detected in non-native relative cover, Mean C, or $w\bar{C}$.

Multiple-Technique Comparisons:

Multiple-Complete restorations had higher floristic quality scores than Multiple-Partial restorations for all metrics. One comparison was significantly higher: Mean C averaged 4.1 ± 0.15 in Multiple-Complete restorations and 3.3± 0.18 in Multiple-Partial restorations (Figure 8).

All Partial vs All Complete Comparison:

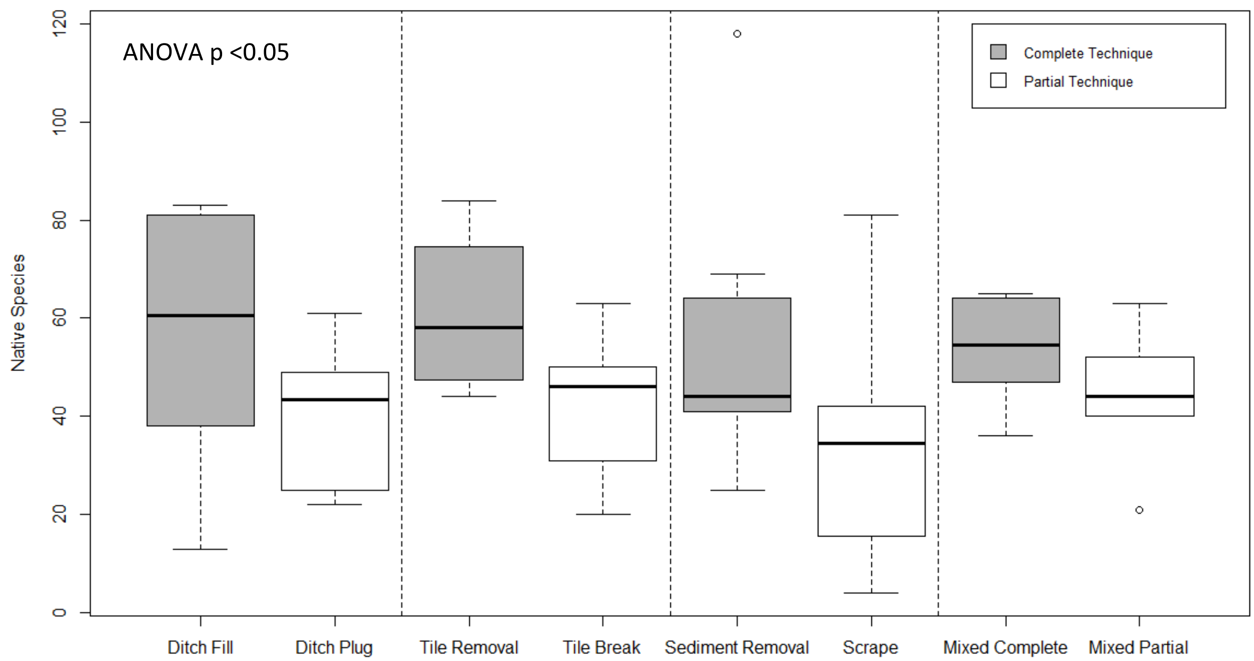
The group of all restorations using Complete techniques had higher mean native species richness (55.8 ±3.6 vs. 37.5 ± 3.0); lower non-native cover (18.5 ± 2.9 vs. 28.8 ± 3.8); higher Mean C (3.8 ± 0.1 vs 3.4 ± 0.1); higher wC (3.8 ± 0.1 vs 3.4 ± 0.2); higher wFQI (29.6 ± 2.0 vs 19.8 ± 1.5) and larger AA size (4.9 acres ± 0.8 vs 3.0 ± 0.6), than the Partial restoration technique group. All comparisons were significant except AA size.

<u>5.2.2 Comparisons across all single technique groups (ANOVA):</u>

A comparison of mean values in floristic quality metrics across all six technique groups found significant differences in *w*FQI and wetland indicator scores. Scrapes had the lowest wFQI (mean wFQI = 17.2 ± 1.99) and sediment removal the highest (mean wFQI = 29.3 ± 3.67). Sediment Removal wetlands had significantly "drier" average wetland indicator status of plants, particularly in comparison to Ditch Plug and Scrape techniques. Native species richness (N_n) was marginally significant with a similar pattern as wFQI ($p = 0.055$). No differences were detected in other measures, Mean C, $w\bar{C}$, or size.

When Mixed-Technique groups were added into the comparison, in addition to differences in wFQI, significant differences were found in N_n and Mean C between Scrapes with the lowest and the Mixed-Complete group, with the highest (Figure 8).

NATIVE SPECIES RICHNESS:



NON-NATIVE RELATIVE COVER:

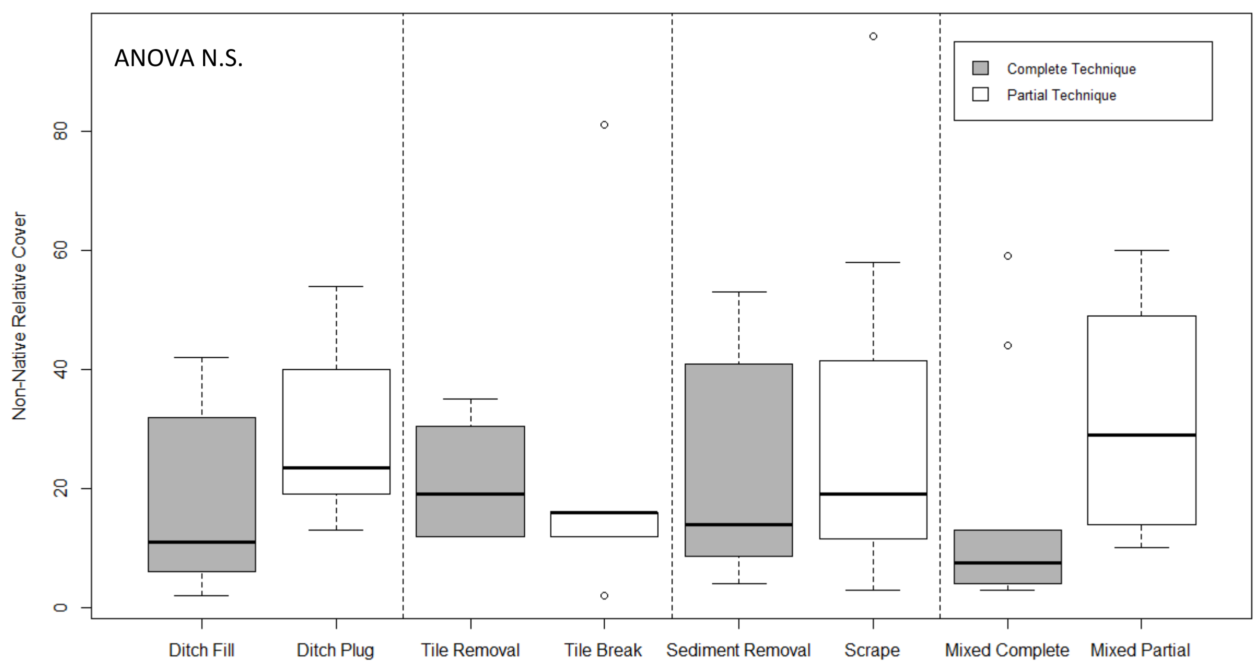
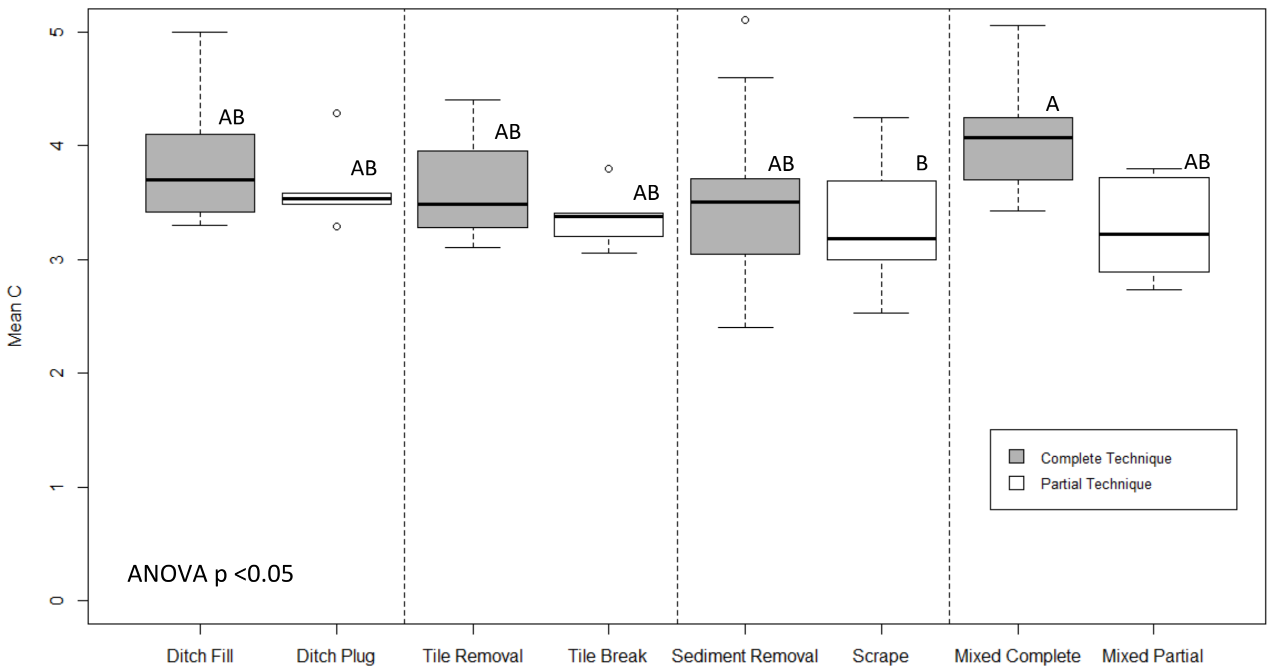


Figure 8 (page 1). Boxplots of floristic quality metrics by restoration technique. For each boxplot the top and bottom of the box represent the 75% quantile and the 25% quantile respectively, the line in the box is the median value, the whiskers represent the highest and lowest values, with outliers represented as dots.

MEAN C:



WEIGHTED MEAN C (*w*C):

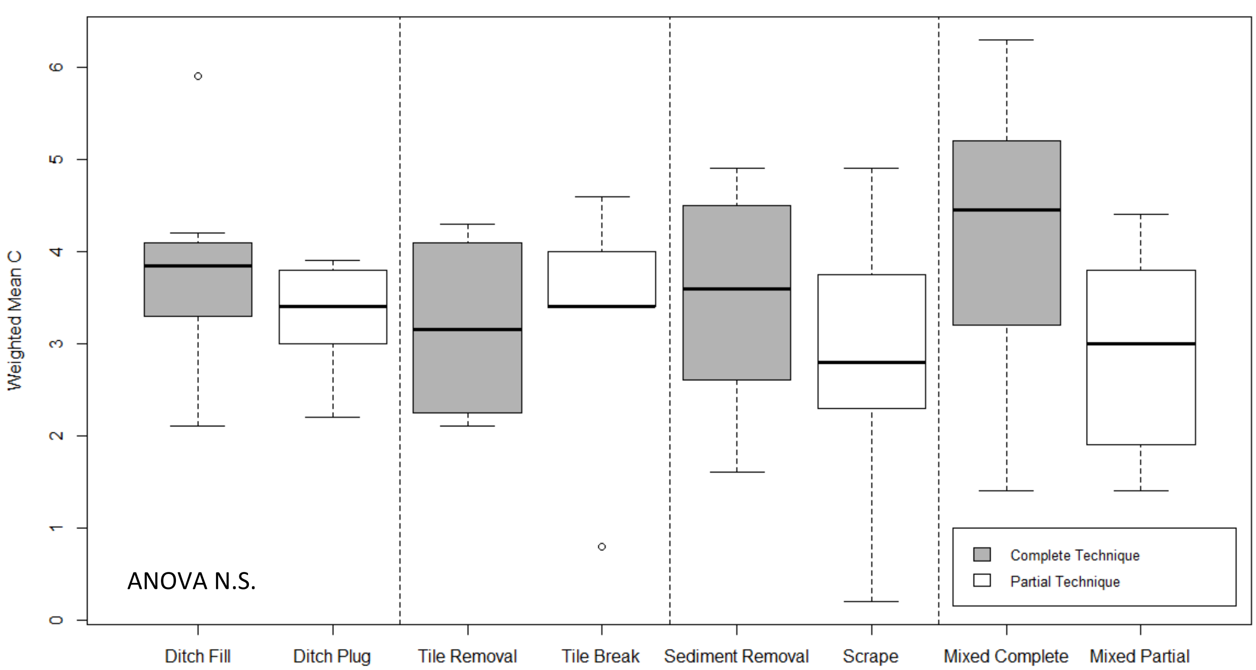
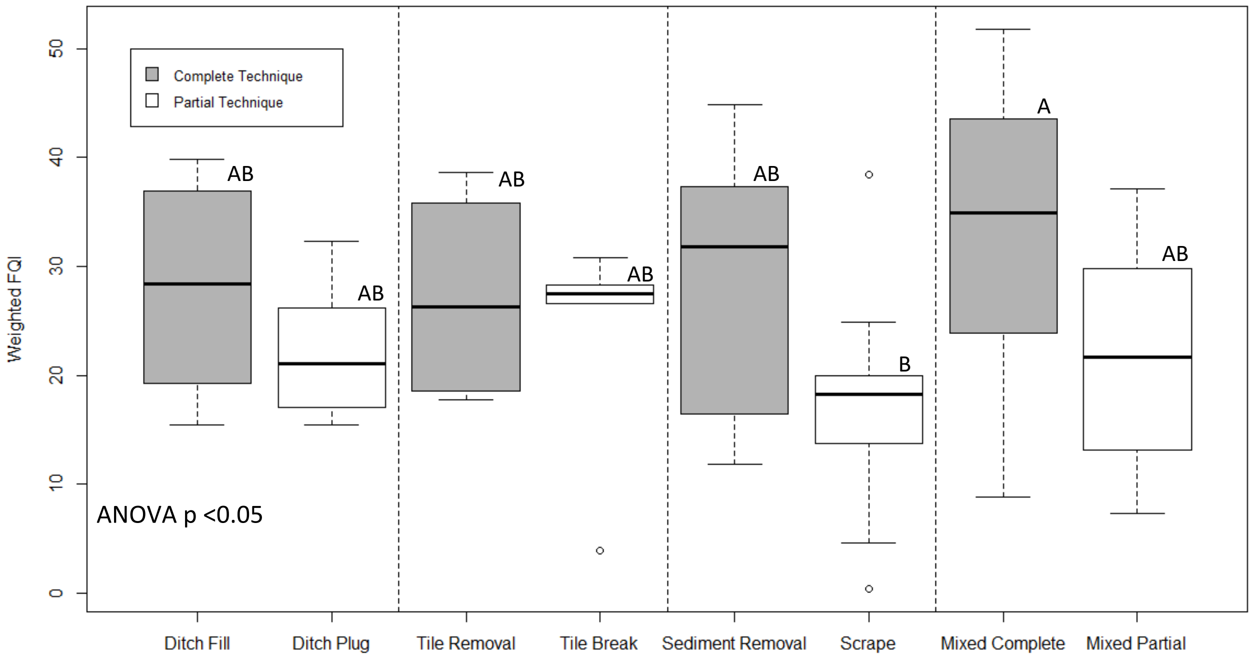


Figure 8 (page 2). Results of testing for significant differences between technique pairs, across all 6 single technique groups and across all 8 groups are summarized in Tables 6 and 8. ANOVA p-values across 8 groups are shown.

Weighted FQI (*w*FQI):



Average Wetland Indicator Score:

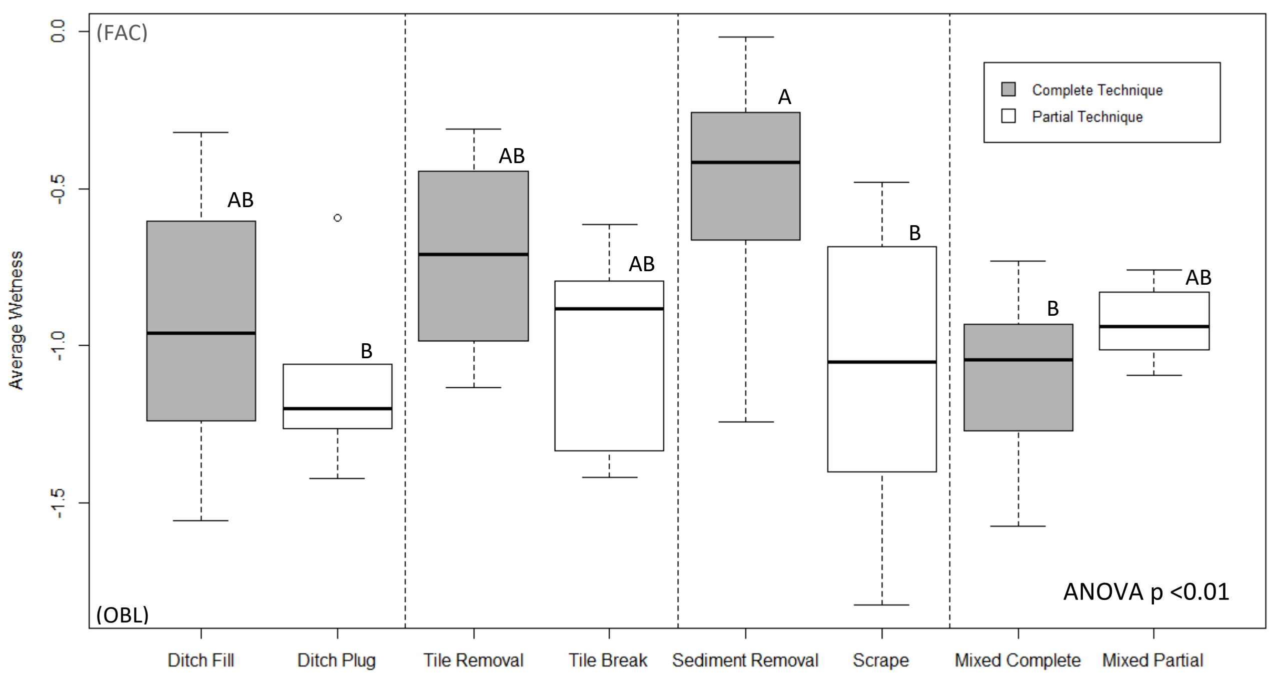


Figure 8 (page 3). Group pairs with significant differences ($p \leq 0.05$) in post-hoc tests are indicated with different letters.

ASSESSMENT AREA SIZE:

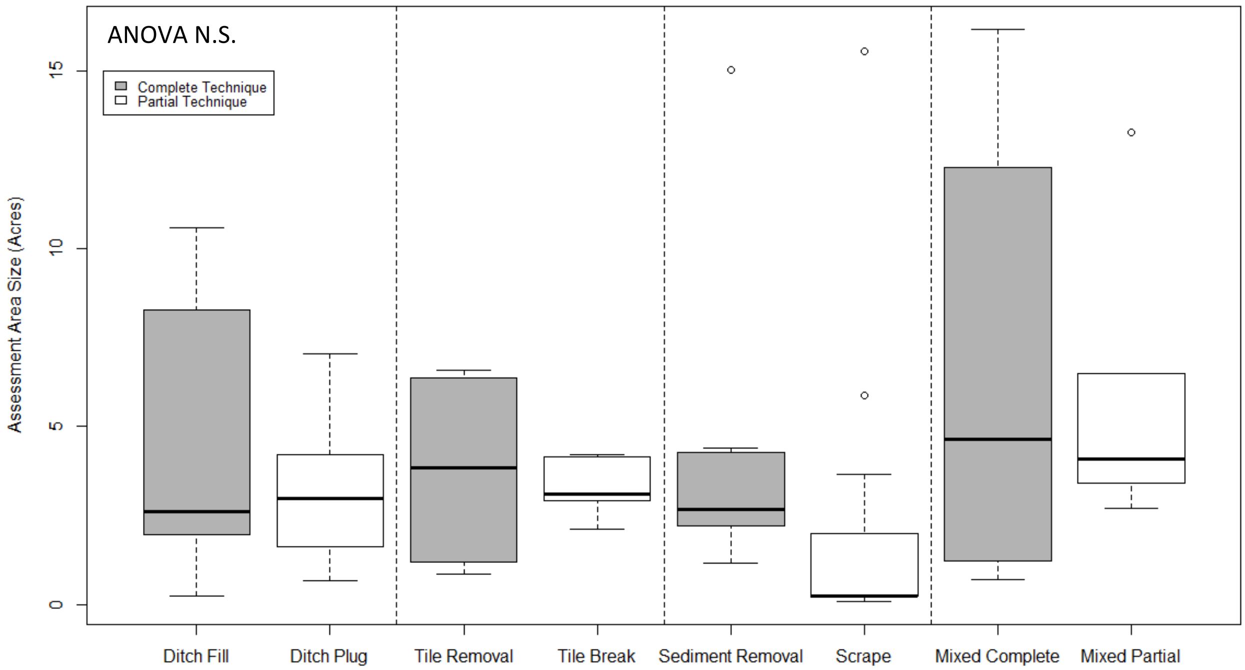


Figure 8 (page 4). Boxplots of floristic quality metrics by restoration technique. For each boxplot the top and bottom of the box represent the 75% quantile and the 25% quantile respectively, the line in the box is the median value, the whiskers represent the highest and lowest values, with outliers represented as dots.

5.2.5 Complete vs Partial Hydrological Restoration:

T-tests between all Complete Techniques (n = 33) and all Partial Techniques (n =35) showed significantly higher floristic quality as measured by N_n, non-native cover, mean C, $w\overline{C}$, and *w*FQI (Figure 9). Average wetland indicator score was significantly higher (drier) in the Complete Techniques group.

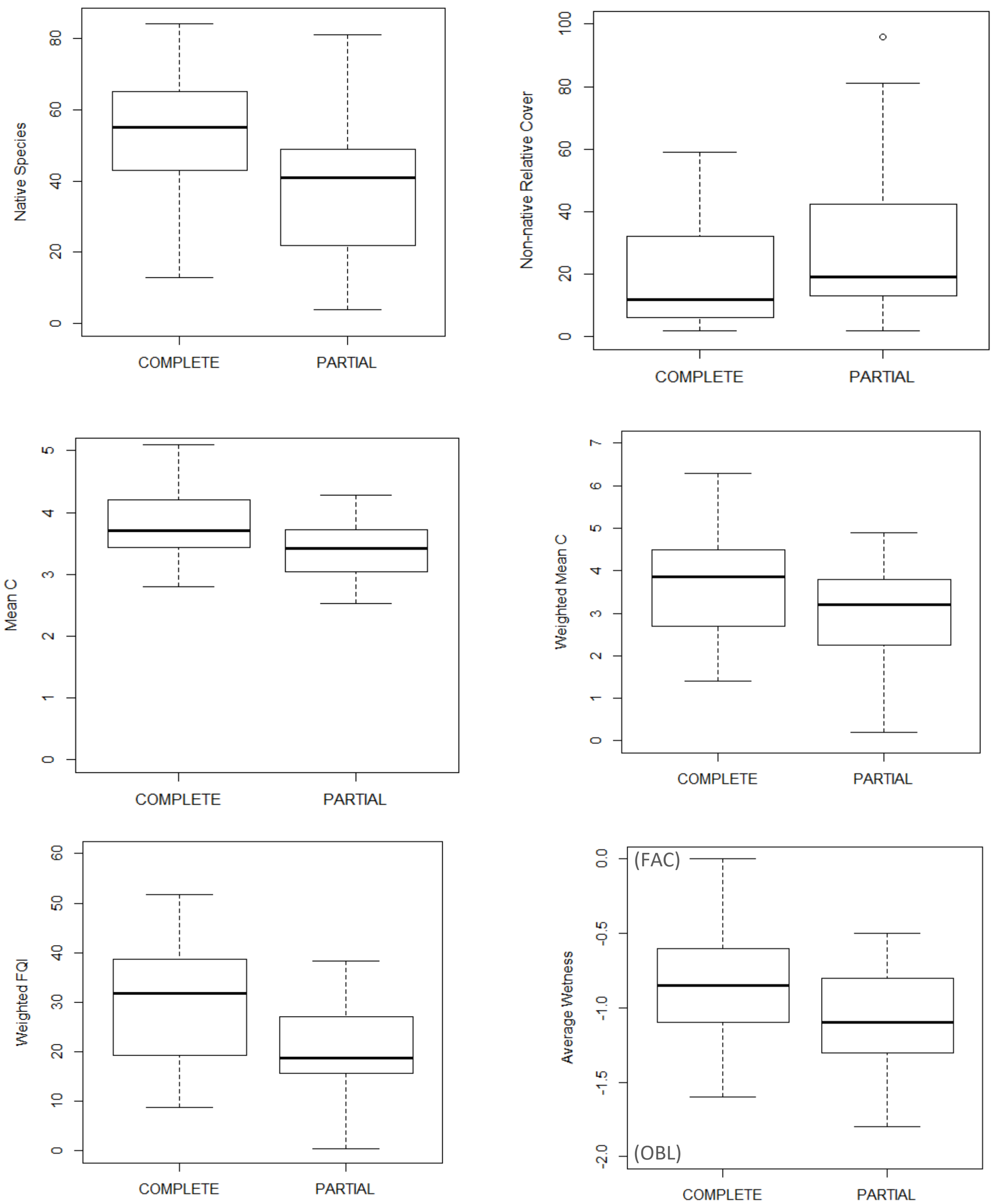


Figure 9. Boxplots of floristic quality metrics by restoration technique group. The complete group includes ditch fill, tile removal, and sediment removal techniques and the partial group includes ditch plug, tile break, and scrapes. Significant differences were found in all comparisons. See Tables 5 and 7 for tabular data and the results of significance testing.

<u>Final condition results in complete vs partial technique groups:</u>

When condition categories were assigned based on DNR's Wetland Floristic Quality Benchmarks for wC scores (Appendix B), few differences were found between complete and partial hydrologic restoration groups (Figure 10). However, complete techniques resulted in more restored wetlands in the "fair" or "good" category (64%) than wetlands restored using partial techniques (63%) (Figure 11).

Figure 10. Percentage of restored wetland assessment areas (AAs) falling within each of five wetland condition tiers using preliminary benchmarks based on wC for two technique groups: those that used complete hydrological restoration techniques and those that used partial techniques. No significant differences were found in condition tier frequency using Fisher's Exact Tests or T-tests with numeric tiers for any technique comparisons.

Figure 11. Condition results for complete vs incomplete restorations divided into two condition groups: "Fair/Good" and "Poor/Very Poor"

5.3 Additional Factors

Individual effects of maintenance, pre-restoration drainage, soil type, community group, and organization type on measures of floristic quality varied by treatment type and are detailed below (Tables 6 and 7, Appendix D for graphs).

Pre-restoration Drainage: (Fully-Drained or Partially-Drained)

Significant differences were found between restorations that were fully-drained vs. partially drained before restoration began. Fully-drained wetlands had significantly higher non-native cover (26.1 vs 13.6; $p < 0.01$); and significantly lower $\bar{C}$ (3.5 vs 4.1; $p<0.01$); $w\bar{C}$ (3.1 vs 4.3; $p<0.01$); and *w*FQI (22.6 vs 32.8; $p<0.01$). No significant differences were found in N_n, wetland indicator scores, or by wetland condition tier. However, 19% more AAs in the partially-drained category fell in the “Fair/Good” category. See Appendix D for boxplots of floristic quality variables and condition category results for the two groups.

Active Maintenance (Yes or No):

Significant differences were found between the two maintenance groups in N_n, with mean N_n of 36.1 in the no maintenance group and mean N_n of 59.9 in the actively maintained group ($p<0.001$). Significant differences were also found in non-native relative cover, (28.7% vs 17.4%; $p < 0.05$); $w\bar{C}$ (3.1 vs 3.7; $p < 0.05$); and wFQI (19.6 vs 30.8; $p<0.001$). No differences were found in mean C or wetland condition tiers between un-maintained and maintained restorations.

Soil Type (Fine-grained, Coarse-grained, or Organic)

Only one variable differed according to soil type: an ANOVA was significant for differences in mean C ($p < 0.001$. Fine-grained (silty or clayey) soils had the lowest mean C (C =3.4) compared to organic soils (C = 4.1). Mean C in sandy soils was in-between (C = 3.8).

General Community Type (Meadow, Prairie, Marsh, Shrub, or Forest):

ANOVA found significant differences in N_n ($p < 0.01$); $w\bar{C}$ ($p < 0.05$), wFQI ($p < 0.01$). No differences were found in in non-native relative cover or wetland condition tiers. Tukey post-hoc tests found differences between Prairie, Marsh, and Shrub communities in N_n, with Prairie having the highest N_n (58.3) and Marsh the lowest (32.3) average native species richness. See Appendix D for boxplots of floristic quality results for the five groups.

Restoration Organization (Non-Profit, Compensatory Mitigation, Wildlife Habitat, and Wetland Reserve Program).

ANOVA found significant differences in N_n ($p < 0.001$); mean C ($p < 0.05$); and *w*FQI ($p<0.01$) between organizational groups. Non-profit restorations had the highest mean N_n (58.4) and wildlife habitat projects the lowest (31.1). Non-profit restorations also had the highest mean C scores (avg. = 3.8) while wetland reserve program restorations had the lowest (3.2). *w*FQI was highest in compensatory mitigation projects with a mean of 28.0 and lowest in wildlife habitat projects (avg. *w*FQI = 17.5). See Appendix D for boxplots of floristic quality results for the four groups. Condition results were similar across organization type, with results ranging from “Very Poor” to “Good” in restorations from all organizations. However, restorations from mitigation sites and non-profit groups had a greater likelihood of “Fair/Good” restorations than either WRP or wildlife habitat restorations (Appendix D).

Comparison	N	Native Spp	Non-Native Rel Cover	Mean C	wC	wFQI	Ave Wet Ind.
Partially-Drained	14	55.2 ± 5.3	19.7 ± 4.91	3.9 ± 0.17*	3.9 ± 0.34*	30.1 ± 2.95*	-1.0 ± 0.11
Fully Drained	54	44.9 ± 2.8	26.2 ± 2.79	3.5 ± 0.07	3.1 ± 0.15	22.5 ± 1.38	-0.9 ± 0.05
Maintained	34	59.2 ± 3.3***	18.2 ± 3.65	3.7 ± 0.10	3.6 ± 0.19*	30.1 ± 1.87***	-0.8 ± 0.07
Not Maintained	39	35.6 ± 2.6	30.4 ± 3.58**	3.5 ± 0.10	3.0 ± 0 0.20	19.2 ± 1.42	-1.0 ± 0.07
Organic Soils	17	44.4 ± 5.3	29.4 ± 6.3	4.1 ± 0.2A	3.5 ± 0.44	24.6 ± 3.66	-1.1 ± 0.07
Sandy Soils	11	57.8 ± 4.4	20.5 ± 5.52	3.9 ± 0.21A	3.5 ± 0.48	28.7 ± 4.25	-1.0 ± 0.11
Silt/Clay Soils	45	47.0 ± 3.9	26.3 ± 3.37	3.3 ± 0.07B	3.1 ± 0.18	23.5 ± 1.71	-0.8 ± 0.07
Meadows	25	47.2 ± 3.5AB	23.1 ± 4.1	3.85 ± 0.13	3.64 ± 0.26	26.5 ± 2.22	-1.2 ±0.04B
Prairies	24	58.3 ± 4.2A	23.1 ± 3.3	3.45 ± 0.10	3.23 ± 0.20	27.1 ± 2.12	-0.6 ±0.05A
Marshes	11	32.3 ± 7.2B	35.4 ±8.5	3.39 ± 0.16	2.85 ± 0.49	17.2 ± 3.44	-1.3 ± 0.09B
Shrubs	10	35.6 ± 3.6B	19.6 ± 4.5	3.40 ± 0.16	2.80 ± 0.11	17.7 ± 0.89	-0.7 ± 0.09A
Forests	2	49.0 ± 11AB	3.0 ± 1.0	3.78 ± 0.40	5.25 ± 1.05	39.4 ± 12.4	-1.0 ± 0.02AB
Wildlife Habitat	18	32.2 ± 3.0B	31 ± 5.34	3.4 ± 0.10B	2.9 ± 0.23	17.5 ± 1.88B	-1.1 ± 0.07B
Compensatory Mitigation	22	50.9 ± 3.1A	18.9 ± 4.12	3.6 ± 0.12AB	3.6 ± 0.26	28.0 ± 2.31A	-1.0 ± 0.08AB
Non-Profit	24	58.4 ± 4.9A	24.8 ± 3.59	3.8 ± 0.14A	3.4 ± 0.24	27.6 ± 2.33A	-0.7 ± 0.09A
Wetland Reserve Program	6	36.0 ± 4.1B	26.3 ± 9.48	3.15 ± 0.12B	2.9 ± 0.49	18.6 ± 3.14AB	-1.0 ± 0.07AB

* p < 0.05 ** p < 0.01 *** p < 0.001

Table 6. Mean values ±SE for floristic quality variables for the factors of pre-restoration drainage, maintenance, soil type, community group, and organization type. Ave Wet Ind. Corresponds to -2 = OBL, -1 = FACW, 0 = FAC, +1 = FACU. *** p < 0.001; * p < 0.05; ** p < 0.01. Comparisons with significant differences are shaded. Letters indicate significantly different groups from ANOVA testing.

	Comparison	Site n	n	Native species richness	Non-Native Cover	Mean C	wC	wFQI	Wetland Ind. Score	wC Condition
Technique	Ditch Plug vs Ditch Fill	10	15	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	Tile Brk vs Tile Rem	8	9	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.	N.S.
	Scrape vs Sed Rem	16	27	0.023	N.S.	N.S.	N.S.	0.024	0.001	N.S.
	Multiple_Complete vs Multiple_Partial	11	16	N.S.	N.S.	0.007	N.S.	N.S.	N.S.	N.S.
	All Single Techniques (6 Groups)	29	51	0.055	N.S.	N.S.	N.S.	0.047	0.016	N.S.
	Single plus Multiple (8 Groups)	34	68	0.034	N.S.	0.030	N.S.	0.022	0.005	N.S.
	Ditch and Tile Only (Complete vs Partial)	18	29	0.08	N.S.	0.06	N.S.	N.S.	N.S.	N.S.
	Ditch vs Tile vs Scrape vs Sed Rem	30	52	0.031	N.S.	N.S.	N.S.	0.024	0.002	N.S.
	Tech: Complete vs Partial	34	68	0.001	0.042	0.002	0.012	**<0.001**	0.020	N.S.
Other	Pre-Rest. Drainage: Fully Dr. vs Partially Dr.	34	68	N.S.	N.S.	0.005	0.005	0.006	N.S.	N.S.
	Maintenance: Yes vs No	34	68	**<0.001**	0.018	N.S.	0.035	**<0.001**	0.019	N.S.
	Soil Type: (3 Groups)	34	68	N.S.	N.S.	**<0.001**	N.S.	N.S.	N.S.	N.S.
	Community Group (5 Groups)	34	68	0.002	N.S.	0.054	0.03	0.005	**<0.001**	N.S.
	Organization (4 Groups)	34	68	**<.001**	N.S.	0.023	N.S.	0.002	0.021	N.S.

Table 7: Results of significance testing of floristic quality variables (native species richness, non-native relative cover, mean C-value, weighted mean C-value, weighted floristic quality index (wFQI), mean wetland indicator score, and mean condition tier, between groups using Welch's t-tests for two groups and ANOVA for three or more groups. wC Condition was tested as both numerical (Good = 2, Fair = 3, etc.) and categorical data using Fisher's Exact test. N.S. indicates differences were insignificant (P > 0.10). Significant differences are indicated with the p-value of the difference in means. P-value was bolded when significance was equal or less than 0.001.

5.4 LINEAR MIXED EFFECTS MODELS: THE EFFECTS OF TECHNIQUE, PRE-RESTORATION DRAINAGE, MAINTENANCE, SOIL TYPE, AND COMMUNITY ON FLORISTIC QUALITY VARIABLES

Mixed effects models using five fixed effects explained from 11.6% to 41.6% of the variation in floristic quality variables. The explained variance was highest for wFQI and Mean C and lowest for non-native relative cover. Technique completeness had only small and insignificant effects on all variables except Mean C where it had a significant, medium-sized effect. See Appendix E for results of preliminary mixed effects models. The effect of site, or assessment areas sharing the same site, explained from 0% (non-native cover and wC) to 29.2% (native species richness) of the variance. Final models, with insignificant effects removed and effect interactions included, are described below.

<u>Factors Influencing Native Species Richness</u>

The strongest predictors of native species richness were active maintenance (ß = 17.8, $p < 0.01$) and community type. Compared to the default community (Meadow), Marsh community was negatively correlated with species richness with medium effect size (ß = -16.7, $p<0.05$); and Prairie had a small positive effect (ß = 10.2, $p < 0.1$). In the final model, active maintenance increased N_n by a coefficient of 26.6 (ß = 26.6; $p < 0.001$; Table 10). Active maintenance was found to be significantly less effective in shrub communities compared to meadow communities for N_n. (ß = -25.4; $p <0.05$; Table 8). Preliminary linear mixed effects model results are shown in Appendix E.

Table 8. Final mixed-effects model summaries for $\mathbf{N_n}$, for the effects of active maintenance, and community group. N.S. indicates the factor was not significant in preliminary testing and was not included in the model. ß refers to the parameter estimate of the explanatory variable in the model, the t-value is the ratio of the estimate divided by the standard error. *** P< 0.001, ** P< 0.01, * P<0.05, and P<0.1

	Native Species Richness			
	ß	*Effect size*	*t-value*	
Technique Completeness	N.S.			
Active Maintenance	**26.6**	**LARGE**	**3.74**	***
Incomplete Drainage	N.S.			
Soil (Sandy)	N.S.			
Soil (Organic)	N.S.			
Community (Marsh)	**-16.7**	**MEDIUM**	**-2.36**	*
Community (Forest)	-12.8	MEDIUM	-1.24	
Community (Shrub)	1.23	V. SMALL	0.18	
Community (Prairie)	**10.23**	**SMALL**	**1.79**	.
<u>Significant Interactions:</u>				
Act. Maint & Comm. (Shrub)	**-25.37**	**LARGE**	**-2.32**	*
Fixed Effects R-Squared	41.8%			
Random (Site) R-squared	26.3%			

Factors influencing Non-Native Cover

Pre-restoration drainage had the strongest effect on non-native cover, however even this was small and statistically insignificant. No factors measured in this study appeared to have a significant effect on non-native relative cover in a mixed effect model. The three factors selected for inclusion in the model based on previous testing, technique, maintenance, and pre-restoration drainage all had small and insignificant effects and together explained only 11.6% of the variation in non-native cover in this dataset.

Table 9. Final mixed-effects model summaries **for non-native cover** for the effects of technique, active maintenance, and pre-restoration drainage. N.S. indicates the factor was not significant in preliminary testing using T-Tests or ANOVA and was not included in the model. ß refers to the parameter estimate of the explanatory variable in the model, the t-value is the ratio of the estimate divided by the standard error. *** P< 0.001, ** P< 0.01, * P<0.05, and P<0.1.

	Non-native Cover			
	ß	*Effect size*	*t-value*	
Technique Completeness	-4.3	SMALL	-0.08	
Active Maintenance	-7.43	SMALL	-1.38	
Incomplete Drainage	-8.45	SMALL	-1.37	
Soil (Sandy)	N.S.			
Soil (Organic)	N.S.			
Community (Prairie)	N.S.			
Community (Marsh)	N.S.			
Community (Shrub)	N.S.			
Community (Forest)	N.S.			
Fixed Effects R-Squared	11.6%			
Random Effects (Site) R-squared	0.0%			

Factors influencing mean C

In preliminary models, soil type had the largest effect on Mean C, followed by pre-restoration drainage and technique. However, when the model was pared down and interactions were included, pre-restoration drainage had the largest effect (ß = 0.67, p <0.05) and secondarily the interaction of complete techniques on sandy soil (ß = 0.51, p = 0.1).

Table 10. Final mixed-effects model summaries for **mean C** for the effects of technique, pre-restoration drainage, and soil type. N.S. indicates the factor was not significant in preliminary testing and was not included in the model. ß refers to the parameter estimate of the explanatory variable in the model, the t-value is the ratio of the estimate divided by the standard error. *** P< 0.001, ** P< 0.01, * P<0.05, and, P<0.1, The fixed effects explained (44.9%) of the variation in Mean C, more than any other floristic quality variable.

	Mean C			
	ß	Effect size	*t-value*	
Technique Completeness	0.17	SMALL	1.04	
Active Maintenance	N.S.			
Incomplete Drainage	**0.67**	**LARGE**	**2.36**	*
Soil (Sandy)	0.11	V. SMALL	0.49	
Soil (Organic)	0.35	MEDIUM	1.54	
Community (Marsh)	N.S.			
Community (Forest)	N.S.			
Community (Shrub)	N.S.			
Community (Prairie)	N.S.			
Significant Interactions:				
Tech & Sandy Soil	**0.51**	**LARGE**	**1.67**	.
Fixed Effects R-Squared	44.9%			
Random R-squared	10.5%			

Factors influencing weighted mean C ($w\bar{C}$):

Pre-restoration drainage and community type were found to be significant factors influencing $w\bar{C}$ in preliminary models. When the model was pared down and interactions were included, only pre-restoration drainage (partially-drained condition) remained as a large and significant positive effect (ß = 1.5; p<0.01) as well as a large negative effect from shrub communities on restorations starting from partially-drained conditions.

Table 11. Final mixed-effects model summaries for $\boldsymbol{w\bar{C}}$ for the effects of complete technique, active maintenance, pre-restoration drainage, soil type, and community group. N.S. indicates the factor was not significant in preliminary testing using T-Tests or ANOVA and was not included in the model. *ß* refers to the parameter estimate of the explanatory variable in the model, the t-value is the ratio of the estimate divided by the standard error. *** P< 0.001, ** P< 0.01, * P<0.05, and "."P<0.1,

	$w\bar{C}$			
	ß	*Effect size*	*t-value*	
Technique Completeness	N.S.			
Active Maintenance	N.S.			
Incomplete Drainage	**1.49**	**LARGE**	**3.14**	**
Soil (Sandy)	N.S.			
Soil (Organic)	N.S.			
Community (Marsh)	-0.43	SMALL	-0.90	
Community (Forest)	1.04	LARGE	0.92	
Community (Shrub)	-0.33	SMALL	-0.69	
Community (Prairie)	0.12	V. SMALL	0.34	
Significant Interactions:				
Incomplete Drainage & Comm. (Shrub)	**-1.67**	**LARGE**	**-1.7**	**.**
Fixed Effects R-Squared	27.5%			
Random R-squared	0.0%			

Factors influencing weighted FQI (*w*FQI):

The strongest effects on *w*FQI were due to community type; both marsh and shrub communities had lower *w*FQI scores compared to meadows. Active maintenance had a medium-strength positive effect on *w*FQI scores (ß = 7.1; p <0.05) and pre-restoration drainage had a small and marginally significant effect on *w*FQI scores (ß = 5.6; p <0.1). No interactions between factors were found to have significant effects on *w*FQI.

Table 12. Final mixed-effects model summaries for *w*FQI for the effects of technique, active maintenance, pre-restoration drainage, soil type, and community group. N.S. indicates the factor was not significant in preliminary testing using T-Tests or ANOVA and was not included in the model. *** P< 0.001, ** P< 0.01, * P<0.05, and "." P<0.1, ß refers to the parameter estimate of the explanatory variable in the model, the t-value is the ratio of the estimate divided by the standard error.

***w*FQI**				
	ß	*Effect size*	*t-value*	
Technique Completeness	3.57	SMALL	1.25	
Active Maintenance	**7.05**	**MEDIUM**	**2.37**	*
Incomplete Drainage	**5.56**	**SMALL**	**1.79**	.
Soil (Sandy)	N.S.			
Soil (Organic)	N.S.			
Community (Prairie)	0.78	V. SMALL	0.27	
Community (Marsh)	**-7.21**	**MEDIUM**	**-2.04**	*
Community (Shrub)	**-8.04**	**MEDIUM**	**-2.40**	*
Community (Forest)	4.81	SMALL	0.74	
Fixed Effects R-Squared	41.6%			
Random Effects (Site) R-squared	8.2%			

6 Discussion

<u>Overall wetland condition in restorations</u>

This study is one of the first applications of Wisconsin DNR's newly-developed statewide benchmarks for wetland condition based on floristic quality. These results, with restored wetlands falling within a range of conditions from "very poor" to "good" and nearly half in "fair" condition, differs from other studies which found lower over-all condition and a narrower range. For instance, a recent study of randomly selected restorations in the Glacial Habitat Restoration Area (GHRA) in southeastern Wisconsin found all restored wetlands to be in "poor" or "very poor" condition (Schultz 2019). And a study in southern Minnesota mitigation banks (Strojny 2019) found 40% of restorations to be in "Fair" condition and 60% to be in "Poor" condition using condition benchmarks with four tiers (Exceptional, Good, Fair, Poor).

The population of restorations in this study were not intended as a representative sample of wetland restorations, instead, selection of sites was based on the use of specific techniques of interest. It is likely that site selection methods biased the sampling toward the higher end of the spectrum of wetland condition in restorations for two reasons. First, common techniques such as berms, impoundments, and water control structures were avoided because these techniques are already discouraged by regulators of compensatory mitigation projects due to potential long-term structural failure, and a preference for vegetated rather than open-water wetlands (WDNR 2013). Additionally, their presence on a site was thought likely to interfere with detecting differences among the techniques of interest. Assuming these techniques are in fact associated with low floristic quality, avoiding them would raise the average quality of wetlands in the study. Second, site selection relied on word-of-mouth recommendations in many cases, which may have consciously or unconsciously biased the selection in favor of more "successful" or floristically notable restorations.

Overall, the scope of the sampling of restored wetlands was broad and captured a wider range of outcomes than other similar studies. Restorations selected for this study varied in hydrogeomorphic type and came from all four major Omernik level III ecoregions as well as crossing the state line into Illinois. Wetlands also came from different agencies, each with its own restoration goals, from the a half-acre creation of waterfowl habitat to a hundred-acre restoration of pre-settlement plant communities.

The finding that no restorations resulted in an "Excellent" condition wetland or even came close, despite this study having a broad scope from an above-average population of restorations, confirms the value and irreplaceability of "Excellent" condition natural wetlands still existing in Wisconsin. The absence of restored wetlands in the highest condition tier(s) is supported by the study of mitigation banks in Minnesota and the GHRA and was also a result of a previous DNR study of wetland restorations in SE Wisconsin (Wilcox 2009) using benchmarks for unweighted $\bar{C}$ and FQI.

<u>Seven restorations in "Good" condition:</u>

The result of 10% of restorations matching natural wetlands in "Good" condition is high in comparison with other studies. The seven wetland restorations in this study that met the $w\bar{C}$ standard of "good" for their community type were restored using different techniques; some had a maintained plant community and others did not, some began on fully drained soils and some on partially drained soils, and they were of different soil types. The following are some of the circumstances that stood out about these restorations:

1. **Minimally-drained soils with no plowing history and fully-restored hydrology**.
   - Two sites, one from Summerton Bog SNA and one from Beaver Brook mitigation site, a former cranberry farm, were still recognizable as sedge meadows before ditches were filled and dikes or subsurface drainage were removed. Historical images from before restoration show that the sedge meadow at Summerton Bog was mowed and possibly grazed prior to restoration but not plowed. And at Beaver Brook, cranberry cultivation took place around the remnant sedge meadow but not within it. This area may never have been drained, though its hydrology was impacted by the adjacent system of dikes and ditches. These wetlands had organic peat or mucky peat soils.

2. **Calcareous soils or groundwater combined with surface modification**.
   - Two scrapes in the GHRA fell in the "good" condition category for an emergent marsh. These were dominated by common spikerush (*Eleocharis palustris*) with a C-value of 6, on alkaline silty clay loam soil. The calcareous substrate is the likely explanation of the dominance of conservative species on these scrapes. However, other scrapes on the same site with similar soils were dominated by hybrid cat-tail, reed canary grass, or sandbar willow. It is unclear what combination of factors led to these areas escaping invasion and these two scrapes were some of the youngest restorations in the study at only 4 years old.

   - Another example was from Campton Hills, Illinois, where sediment removal in a springy area created areas of limited plant growth due to the combination of calcareous groundwater and removal of topsoil**.** The lowest areas (over-excavated according to site managers) resulted in a southern sedge meadow with calcareous fen elements, however this area was only in "fair" condition compared to southern sedge meadow benchmarks. The surrounding drier areas were dominated by wet-mesic prairie species but had enough conservative elements to put it in the "good" condition tier. The combination of removal of sediment and a continuous flow of calcareous groundwater both effectively reduce nutrient levels, favoring more conservative species.

3. **Community classification affected condition tier assignment**
   - A restoration in a former cranberry bed also resulted in a sedge meadow in "good" condition, however, this was not a remnant sedge meadow and it did not easily fall into the natural community definition. Dominants were *Glyceria canadensis* and *Scirpus cyperinus,* not typical sedge meadow dominants- and many bog species were present in low abundance. The high condition rating could be interpreted as a mis-categorization of a disturbed open bog or black spruce/tamarack swamp. Had it been categorized as one of these acidic communities it would have fallen in "fair" or, more likely, "poor" condition tier.

- A southern hardwood swamp restoration in a groundwater-fed valley in the Driftless region combined good conditions for floristic quality with benchmarks for a community that tends to have lower average $w\bar{C}$. Again, this could be interpreted as a mis-categorization of community. Had trees not been planted it would be a sedge meadow in fair condition and if it had been categorized as a northern hardwood swamp, which tend to be groundwater fed, the result also would have been "fair" condition. However, this was also a very well-designed and managed site. The combination of groundwater dominance, filling ditches, diverting surface water inputs to a settling basin, and successful tree establishment were also key factors.

In short, achieving a restoration in "good" condition did not seem to be the guaranteed result of specific practices that could be repeated on other sites but tended to be associated with unique site chemistry combined with a favorable community classification, or sites that had an uninterrupted history of saturated soils with minimal plowing. There is little evidence from this study that natural wetlands in "Good" condition can be reliably recreated via restoration.

<u>Six Restorations in "Very Poor" Condition:</u>

Restorations with the poorest condition outcome spanned organization type, technique, soil type, and initial conditions with little in common except for dominance by invasive species: reed canary grass (*Phalaris arundinacea*) in four of the six sites, and non-native cat-tail (*Typha angustifolia*) on one site. Weighted mean C ranged from 0.2 to 2.1. Relative non-native cover ranged from 42% to 96% on these sites.

The exception was a shrub-carr from a former cranberry farm in the Northern Lakes and Forests ecoregion which was dominated by native but fairly generalist species. This community was dominated by Bebb's willow (*Salix bebbiana*) and sandbar willow (*S. interior*), with a $w\bar{C}$ of 3.2 and only 12% relative non-native cover, demonstrating that the bar is quite a bit higher in the northern region where overall wetland quality is higher than in the southern ecoregions.

Only two sites in this category were undergoing active maintenance, and these happened to be the two shrub-dominated wetlands. This suggests that the active maintenance taking place at these sites was not directed at the shrub layer.

<u>"Poor" condition results:</u>

Restorations in the "Poor" category were also dominated by reed canary grass or non-native cat-tail in 17 out of 26 restorations (65%). An additional five AAs in the "Poor" category were invaded by the native shrub species sandbar willow (*Salix interior*). Weighted $\bar{C}$ ranged from 1.1 in a *Typha* X *glauca*-dominated scrape in the Southeastern Till Plains to 6.3 in a restored black spruce/tamarack swamp in the Northern Lakes and Forests ecoregion. Relative non-native cover ranged from 4% to 79% in this category.

The difference between an invasive-dominated wetland that receives a "Poor" rather than a "Very Poor" rating can lie in the presence of just a handful more conservative species at 1% cover. Because the lowest cover value given to a species is 1% (rather than 0.1% or 0.001%) in DNR's timed-meander protocol, trace species detected in the survey will have a slightly exaggerated impact on mean C and $w\overline{C}$ scores, especially noticeable when the dominants have a C-value of 0.

One site in the "Poor" category had the highest $w\overline{C}$ score in the study ($w\overline{C}$ = 6.3). This was a black spruce/tamarack swamp restoration from a cranberry production area in the Northern Lakes and Forests ecoregion which clearly had the highest dominance by conservative species in the study. However, compared to natural black spruce/tamarack swamps it only met the "poor" benchmark. This suggests that practitioners restoring communities with many conservative species that may take longer to establish, like black spruce swamp or open bog, may find it difficult to achieve the same condition tiers in the same time frame as other communities. Since benchmarks were set for communities that were defined based on a minimum cover of trees or shrubs, it might be advisable to use herbaceous community benchmarks for forested wetlands until they achieve the cutoff of a minimum of 50% tree cover in addition to the target community benchmarks.

"Fair" condition results:

"Fair" was the most common condition result in this study, occurring in 34 restored wetlands. It is also the condition tier with the widest range of allowable $w\overline{C}$ values (see state-wide benchmarks in Appendix B), with values from this study ranging from 2.4 in a sandbar willow (*Salix interior*) -dominated shrub swamp on a seepage slope, to 4.9 in a tussock sedge (*Carex stricta*) -dominated sediment removal project in the Central Corn Belt Plains. Relative cover of non-native species ranged from 2% to 40%. Most of the restorations that fell in this category were dominated by native species, with only 9% listing a non-native as the species with the highest cover.

"Fair" appears achievable for a substantial proportion of restorations at least for emergent marsh, southern sedge meadow, northern sedge meadow, shrub-carr, and southern hardwood swamp. This result has implications for setting vegetation performance standards for mitigation and as a guidepost for voluntary restorations.

Complete techniques resulted in higher floristic quality

In this study the use of complete techniques was associated with the following measured benefits over the use of partial hydrologic restoration techniques:

a. More species-rich plant communities (Ave. N_n = 56.0 vs 38.3)
b. More conservative plant species (Ave. wC = 3.8 vs 3.0)
c. Reduced relative cover by non-native species (18.7% vs 27.8%)
d. More AAs falling in the "Fair/Good" condition category (64% vs 54%)
e. More soil organic matter (18% OM vs 11.2%) and frequency of organic soils (28% vs 12%)

However, it is likely that several combined, correlated factors rather than just technique alone led to the higher floristic quality scores.

1. Restorations that used complete techniques were more likely to attempt restoration of highly conservative or species-rich communities. In this study, this includes black spruce/tamarack swamp, northern sedge meadow, wet-mesic prairie, and southern hardwood swamp. These restorations had the effect of raising average species richness and average conservatism in the complete techniques

group. This contrasted with restorations that had a goal of open water and emergent marsh, which tend to be less diverse. (See Appendix D for a comparison of communities in scrapes vs sediment removal restorations as an example).

2. Restorations that used complete techniques also were more likely to actively maintain the plant community post-restoration (69% vs 21%). This is related again to the initial goals of the projects. When the goal is a diverse wetland plant community rather than open water, projects are more likely to be prepared to invest more in the maintenance of healthy plant communities. In this study, active maintenance was associated with greater species richness, reduced non-native cover, and higher wC and wFQI.

3. The size of the restored assessment areas was slightly larger (mean size = 4.9 acres vs 3.0 acres) in restorations using complete techniques which is likely to have impacted both native species richness and wFQI results. Scrapes in particular, stood out as having smaller average wetland community size. This is an expected result since complete techniques should have a larger area of impact. Our methods of determining the size of assessment areas surveyed using timed-meander needs to become more standardized before this can be verified, however.

Technique completeness by itself, when the effects of maintenance, initial conditions, and community are isolated, only had a small and insignificant effect on non-native cover, wFQI, and $\overline{\text{C}}$. Only in association with sandy soils was technique found to have a large effect though marginally significant. If meaningful, this suggests that technique completeness may matter more in low-nutrient environments, and perhaps that eutrophication is having an over-riding effect on the plants in wetland restorations. However, more data points are needed to draw any firm conclusions.

Native species richness, non-native cover, $\overline{\text{C}}$, and *w*FQI were all found to be more strongly affected by factors other than technique except for non-native cover which had no significant explanatory variable in this dataset.

At least two other studies also found few differences among different restoration techniques: Schultz *et al.* (2019) found no differences in condition in a comparison of scrapes, scrapes plus ditch modification, or scrapes plus water control structure. This study was also restricted to a smaller geographic area and included a narrower range of techniques. Also, a meta-analysis of 628 restored or created wetlands found no differences in biotic assemblage trajectory or biogeochemical functioning between flow re-establishment techniques and surface modification techniques to restore hydrology (Moreno-Mateos *et al.* 2015). This study was not looking at the completeness of hydrological restoration but nevertheless found little difference in the trajectory of restorations between two broad categories of technique.

Condition outcomes were slightly better with the use of complete techniques but no significant differences were found:

Floristic quality is a valuable function of wetlands taken on its own, however, condition is intended to measure overall ecological integrity, at least to the extent that vascular plants intersect ecological health. Condition is essentially relative floristic quality, or floristic quality relative to the highest and lowest values found in each community type.

In this study few differences were found in condition outcomes between complete and incomplete technique groups: Both groups had outcomes ranging from "good" to "very poor" with "fair" being the most common condition result. However, dividing the results between the top tiers and the bottom tiers found that restorations in the complete group were more likely to be in "good" or "fair" condition (64%) than the partial techniques group (54%). Possible reasons for the lack of strong differences in condition scores include:

1. Insufficient sample sizes given the considerable number of variables affecting wetland restoration outcomes. Furthermore, assigning a condition category reduces a continuous range of scores into only five categories making differences difficult to detect unless effect sizes or sample sizes are large.
2. Assigning condition tiers eliminates the differences in floristic quality between communities: a restoration of a black spruce swamp or open bog with abundant conservative species is given the same value as the restoration of an emergent marsh which has few. This may explain in large part the discrepancy between the perceived view and the condition results of this study. Restorations that used complete techniques had as their goal the restoration of communities with more conservative species than those that used incomplete techniques; however, the relative condition of these communities was similar. (See Appendix D for comparison of community types in scrapes versus sediment removal as an example). In addition, some highly-conservative communities may take longer to achieve higher conditions scores than common types such as emergent marsh and wet meadow.
3. Condition scores are intended to measure ecological health. For wetlands, lingering alterations due to past land-use may be a common, over-riding factor impacting the plant community in restorations of all types. There is evidence for this in the data from this study, with initial conditions having the strongest effect in linear mixed models on both Mean C and wC. (discussed further below). Eutrophication may be acting as a similar overriding common stressor to wetland restorations of all types, at least in southern WI. This was not measured in this study, but evidence of elevated phosphorus associated with lower Mean C has been demonstrated in Wisconsin wetlands by Marti & Bernthal (2019).

Initial conditions had the strongest effect on floristic quality in the study

This study found that pre-restoration drainage, i.e. whether soils were fully or partially-drained prior to restoration, had the strongest effect of any other variable measured on $\bar{C}$ and $w\bar{C}$, the metrics used as the basis of condition assessment. In other words, restorations that met the definition of a wetland before restoration began, were able to host more conservative species after hydrology was restored than those that were fully-drained.

We expect that fully-drained wetlands were subjected to a many-fold increase in disturbance factors compared to their partially-drained neighbors. The greater degree of drainage itself being only the beginning of years of tillage, fertilizing, and harvesting that the unsuccessfully-drained areas were spared most years. Although this factor is measured as either full or partial drainage, a continuum probably exists with both soil and hydrologic alteration increasing with the extent to which soils were successfully drained.

The finding that pre-restoration disturbance has a larger effect than restoration technique was also found in a meta-analysis of 628 restored wetlands in which wetlands with an agricultural history had reduced biogeochemical functioning compared to those impacted by mining or hydrological alteration alone, but few differences were found that were attributable to technique (Moreno-Mateos *et al*. 2015).

<u>Active maintenance resulted in higher floristic quality and native species richness</u>
Active maintenance had a large and significant positive effect ($ß = 26.6$, $p < 0.001$) on native species richness in the linear mixed effects model. It also had a medium-sized effect ($ß = 7.1$, $p < 0.05$) on *w*FQI. Interestingly, it was not found to have a significant effect on non-native species cover. A possible explanation is that not all non-native species are targets for maintenance, for instance, non-native or hybrid cattails or aggressive sand-bar willow may be considered acceptable in some projects and maintenance efforts primarily target species such as reed canary grass. This explanation is supported by the linear mixed effects model, which found that maintenance had the biggest impact on meadow communities and the least effect on shrub communities in improving species richness.

<u>Restored wetlands in this study had significantly less soil organic matter than natural wetlands.</u>
Many studies have documented lower soil organic matter in restored and/or created wetlands in comparison with natural wetlands including Bishel-Machung *et al.* (1996) and Campbell *et al.* (2002) in Pennsylvania; Stolt *et al.*(2000) in Virginia; and Bruland & Richardson (2005, 2006) in North Carolina. Explanations for the low organic matter in restorations given in these studies are 1) decomposition of organic matter after drainage and land-use (Bruland 2006); 2) removal of the organic-rich top layer due to excavation during the restoration process (Bruland 2006); and 3) increased export of organic materials by drainage systems that create surface water connections to streams and other wetlands where none existed previously (Zilverberg *et al.* 2018).

A fourth factor may be site-selection bias towards drier-end wetlands that occurs when starting wetland restorations on lands in former agricultural production. Fully-drained farmland is likely to have existed on areas of the landscape that were easiest to drain and therefore drier to begin with and less likely to have hosted the consistently saturated conditions required for organic matter accumulation. In addition, because drier-end wetlands are less flood prone they are also likely to have experienced more years of tillage than wetter areas of the landscape which would contribute to more loss of organic matter and soil structure than the adjacent wetter areas on the landscape.

In this study, restorations starting in partially-drained soils had on average 17.5% more organic matter than those begun on fully-drained soils probably due to all of the factors previously mentioned: Fully-drained wetlands are likely to have had 1) less organic matter to begin with, and 2) a greater rate of loss due increased frequency of plowing and harvest of organic materials. Yet former farm fields seem to be the most common start point for restoration in Wisconsin.

For compensatory mitigation projects wetland acreage gain is the goal (rather than function or condition) and this can bias site selection towards finding large areas of successfully drained farmland that can be re-wetted. Under current compensatory mitigation guidelines (WDNR 2013) restorations that result in the conversion of non-wetland to wetland are given the highest credit, normally one credit for each acre restored, while restoration from partially-drained wetlands are given less. But scrapes, which are not often associated with mitigation projects were also much more likely to have been created on fully-drained mineral soils, indicating that acreage gain is not the only reason for the bias toward fully-drained agricultural areas as the start point for restoration.

Another factor contributing to low organic matter is simply the long time it takes to accumulate again after its loss. The wetlands in this study ranged in age from 4 to 22 years since restoration but there was no sign that organic matter content was higher in the older restorations. Several studies have also found no change in OM in restoration soils over time when looking at restorations less than 8 years old (Bishel-Machung *et al.* 1996; Shaffer 1999). However, a study of permanently-inundated *Typha* marshes in New York, with some restored more than 50 years ago, showed an increase in OM after 35 years although levels remained less than 50% of that found in natural wetlands even after 55 years (Ballantine 2009). Recovery of lost organic matter in restored wetlands is thought to to take decades or centuries, depending on the degree of loss (Ballantine & Schneider 2009). And a meta-analysis of seven studies that measured OM in restored wetlands found that average levels were 62% of reference levels 20-30 years after restoration (Moreno-Mateos et al. 2012).

<u>Low organic matter on restoration sites may indicate low biogeochemical functioning:</u>

Organic matter (OM) content significantly impacts other soil properties (Bishel-Machung 1996) and functions such as denitrification, contaminant removal capacity, and carbon sequestration (Mitsch & Gosselink 2012; Ballantine & Schneider 2009). Low OM is also associated with higher bulk density; lower cation exchange capacity (CEC); and lower water holding capacity (Stolt *et al.* 2000, Mitsch & Gosselink 2012).

OM also serves as a substrate for microbes, which mediate many of the biochemical processes that we value in wetlands (Mitch & Gosselink 2012). For instance, Vepraskas *et al.* (1995) suggested that a minimum organic content of 3% is required for the formation of iron depletions by microbes. In this study 15.7% of sampled soils had organic content less than 3%.

If organic matter content is considered a proxy for biogeochemical functioning, this suggests that many restored wetlands are providing services (e.g. denitrification, sequestration, and contaminant removal) at lower levels than natural wetlands. One researcher estimated that biogeochemical function remained lower in restored wetlands even 100 years after restoration due to lower carbon storage (Moreno-Mateos et al. 2012).

Cranberry farm restorations had higher floristic quality outcomes (but not higher condition results)

Although only two cranberry farm restorations were surveyed, these wetlands had considerably higher floristic quality results (in $\bar{C}$, $w\bar{C}$, and *w*FQI) than other restorations. Both cranberry restorations combined the techniques of filling ditches and removing dikes and were placed in the "Mixed - Complete" technique group. These sites had every factor that would be expected to increase floristic quality: they began on relatively un-drained, unplowed soils, the plant communities were actively maintained, and the techniques used to restore them had the potential to completely restore hydrology by back-filling ditches and removing the dikes formerly used to control water levels. They were also all found in the Northern Lakes and Forests ecoregion where water quality tends to be higher due to overall reduced agricultural impacts.

However, in terms of wetland condition, open bog and black spruce/tamarack swamp restorations, even beginning on cranberry farms, are still unlikely to achieve even a "fair" rating, arguing for even higher levels of protection of natural examples of these highly conservative communities.

Scrapes had the lowest floristic quality averages

Scrapes, or restorations that combined scrapes with tile breaks or ditch plugs, had the lowest average floristic quality scores for all variables measured. This was particularly apparent and statistically significant in native species richness and *w*FQI. In terms of final condition outcome, 71% of the AA's associated with scrapes in this study were in "poor" or "very poor" condition, a higher percentage than any other technique except for tile breaks which had similar condition results.

The results from this study suggest that both lack of post-restoration maintenance and small AA size are related to the lower native species richness and *w*FQI found in scrapes. Scrapes had low maintenance rates, with only 7% being actively maintained. Scrapes also had the smallest average AA size of any technique (1.9 ± .94 acres). Species richness generally tends to increase with area and the small size of communities associated with scrapes may have been a factor in the low scores. Scrapes might be expected to impact smaller areas overall than other techniques, but another contributing factor is that the area they impacted tended to create multiple communities: an open-water area surrounded by a marsh or meadow, and a shrub-carr where sand-bar willow had invaded.

Other possible reasons for the lower floristic quality outcomes associated with scrapes include:

1. The soil disturbance associated with excavation created conditions favorable to invasive cat-tail and sandbar willow. Both species are early colonizers of disturbed areas.

2. Ditch and tile systems may still be functioning if scrapes are the only technique used to restore drained farmland.

3. Scrapes that intercept and collect surface water, especially in a eutrophic landscape, will favor invasives more than those that intercept the groundwater table, which tends to have less nutrient-rich water.

Scrapes appear to meet the need for deeper water where the hydrology of the landscape does not naturally support it, judging by the low organic matter content of the soils from these sites in general.

Interestingly, of the scrapes in this study, only two had a “fair” outcome and these also happened to be the only scrapes excavated in organic soils.

As previously mentioned, two scrapes achieved the “good” condition tier; both had calcium-rich soils and were dominated by spikerush (*Eleocharis palustris*). While unique soil chemistry may explain these particular outcomes, such results are also a reminder that scrapes can share many of the benefits of sediment removal: removal of the disturbed, nutrient-rich upper layers of the soil can reveal better soil conditions for native plants underneath.

<u>Open water/submergent marsh areas have no condition results but appear to be fairly comparable to natural shallow lakes.</u>

Scrapes created a significant area of open water, or submergent marsh communities in 27% of restorations, more than any other technique. Due to a lack of developed protocols and condition benchmarks, this study was unable to include the submergent marsh communities encountered. Results from another study that did survey submergent marsh plants in scrapes found high raw floristic quality scores (Schultz 2019). However, aquatic plants tend to be biased toward higher C values than the rest of the flora on average (Paul Skawinski, pers. comm.) Benchmarks for condition are needed to enable their use in condition assessments.

Informal observations of the aquatic plant species found in restored submergent marshes match species found in an aquatic macrophyte community called “Submersed Cosmopolitan” in a recent survey of lakes across Wisconsin (Poinsatte *et al.* 2018). Common species in this community are *Ceratophyllum demersum* (coontail), *Potamogeton pusillus* (slender pondweed*)*, *Elodea canadensis (*common waterweed*)*, and *Lemna minor* (lesser duckweed). This community is found in hard-water lakes with high nutrient availability across Wisconsin, especially in the southern half, and the only community found in impoundments or reservoirs. This community had lower floristic quality scores, as measured by FQI, than the other four communities (Floating-leaf glade, Isoetid meadow, Mixed Characid, and Moss-dominated). Despite showing signs of belonging to a community with lower floristic quality than some other macrophyte communities, there is no sign that submergent marshes in scrapes were invaded by non-natives or were of significantly lower quality than natural communities.

<u>Restoration objectives explain much of the variation in outcomes</u>

Both compensatory mitigation and non-profit restorations resulted in better floristic quality outcomes than Wetland Reserve Program (WRP) and wildlife habitat restorations in this study (Appendix D). Non-profit restorations showed the highest average species richness and $\bar{C}$ of all groups but restorations from mitigation banks were not significantly lower. WRP restorations appeared similar to wildlife habitat restorations in most measures but our sample size was low for this group so our results may not be fully representative of these restorations.

Compensatory mitigation sites had the lowest mean relative non-native cover of all groups, as might be expected given the requirements to meet performance standards that exist for this group and therefore higher investment in maintenance. Compensatory mitigation sites also resulted in more “fair” or “good” condition wetlands than other groups, though few statistically significant differences in condition tiers were found between groups.

Overall the differences in floristic quality across this study are best explained by differences in objectives, with non-profit and compensatory mitigation putting more emphasis on restoring wetland plant communities than wildlife habitat restorations which are mainly focused on creating areas of open water and perhaps not investing as much in the surrounding wetland areas. Compensatory mitigation policy in Wisconsin actively discourages the creation of ponds and open-water habitats as compensation and the results here suggest that this policy has raised the floristic quality of their restorations.

"Past experience with compensatory mitigation projects in Wisconsin and elsewhere in the United States has shown that creation of small ponds with a ring of emergent vegetation has had a poor track record in terms of species diversity, nuisance species invasions, and water quality problems. The use of scrapes has also been problematic in Wisconsin; when scrapes are dug too deep, they often result in creation of an unvegetated pond. Typically, an area that is found to hold water year-round and is not vegetated will not be given credit. (WDNR 2013)."

However, non-profit and compensatory sites may be avoiding the restoration of wetter-end plant communities, judging from the significantly drier over-all wetland indicator scores measured on these sites. Restorations with the objective of creating deeper water or standing water communities are disadvantaged because such communities are by nature less diverse than drier-end wetlands, more prone to invasive species, and are not well suited to the historically drier areas (i.e. wetlands converted to agriculture) that are most commonly available for restoration. However, deeper water areas are valuable communities to restore due to their many valuable biogeochemical functions such as carbon sequestration, filtration, nutrient transformation, and flood storage capacity. We hope that in the future methods can be developed that allow for restoration of these valuable wetlands in ways that do not compromise floristic quality.

<u>Caveats of this study:</u>

1) The tradeoff of having a dataset that is broad in scope is that very few variables were controlled, and the number of replicates was low for any given set of factors. This makes hypothesis testing, which was one of the motivations for this study, difficult. It was difficult to find wetland restoration sites that used a single technique, and the use of multiple techniques in a wide array of combinations were frequent. For instance, although the study targeted only six techniques, we found 12 different combinations of techniques (Table 2) with few replicates. Sample sizes for tile modifications were particularly low and as a result, little can be said about the consequences of breaking rather than completely removing subsurface drain tile lines.
2) The study did not make any direct measurement of the completeness of hydrological restoration, relying instead on the assumed potential of technique categories.
3) The study did not identify the set goals or expectations of any given restoration effort. Specifically, not all wetland restoration efforts have a primary goal of achieving high floristic quality.
4) We did not measure factors currently impacting hydrology at each site which may have differed significantly between sites.

5) Several factors that may be important to wetland restoration outcomes were not measured in this study:
   a) The effects of eutrophication: Excess nutrients were probably a significant factor impacting the success of restorations in this study. Total nitrogen and total phosphorus were measured but results are not shown because we have not yet found a reliable method to distinguish excess nutrients from nutrients bound up with organic matter. Future work will use the data collected from this study to do further exploration.
   b) The effects of site grading, which was common and would be expected to have an impact on soil compaction, and thus could potentially negatively impact floristic quality.
   c) Variation in plant introduction techniques (e.g., seeding, planting plugs, or letting the seed bank come in naturally) could potentially affect later floristic quality.

SUMMARY OF FINDINGS:

1. **Site history may be the most important factor determining final condition outcome.** Incompletely drained areas with reduced disturbance history provide the best chance of restoring wetlands that host conservative species or wetlands with high organic matter from the start. There is little evidence that restoration of wetlands in "good" and "excellent" condition are consistently achievable from sites with severe soil and hydrological alterations.

2. **Maintenance in the form of invasive species control and/or prescribed burning had a strong and significant effect on species richness and wFQI.** Vegetative maintenance was most often reported by restorations completed by non-profit groups and as part of mitigation banks but was uncommon in wildlife habitat and Wetland Reserve Program restorations.

3. **Complete restoration techniques maximize a site's floristic quality and condition outcome.** Higher floristic quality outcomes, especially the presence of more conservative plant species as measured by Mean C, were achieved using complete techniques such as:
   a. backfilling or disabling drainage structures (ditches and tile);
   b. removing accumulated sediment when present; and
   c. avoiding use of impounding structures and/or removing existing impoundment structures.

4. **"Fair" condition is an achievable goal for wetland restorations that have a starting condition of full-drainage, at least for southern sedge meadow, wet-mesic prairie, emergent marsh, and southern hardwood swamp restorations.** "Good" condition may be possible under certain acidic or calcareous conditions or when starting with a wetland with intact saturated soils. However, there was no evidence from this study that open bog or black spruce swamp could achieve more than a "poor" condition tier, even starting from the favorable conditions of a cranberry farm.

5. **Restored wetlands from this study have significantly reduced organic matter in their soils in comparison to natural wetlands**. This may have implications on the potential of these wetlands to perform many biogeochemical functions such as filtration, water retention, and nutrient sequestration.

7 CONCLUSIONS

This study measured floristic quality and wetland condition on wetlands restored using different hydrologic restoration techniques from a broad range of projects across Wisconsin. Condition outcomes ranged from “Very Poor” to “Good”, with “Fair” being the most frequent result. No restorations were in “Excellent” condition. We found that floristic quality, including species richness, native cover, $\overline{C}$, $w\overline{C}$, and wFQI were higher in projects that used complete hydrologic restoration techniques. There were multiple factors contributing to higher levels of floristic quality in restorations that used complete techniques, including higher maintenance rates, richer species assemblages, drier-end target plant communities, and larger community sizes. Active maintenance had the highest effect on native species richness and wFQI while pre-restoration drainage conditions were found to be the strongest factor affecting $\overline{C}$ and $w\overline{C}$. Results from soil testing found significantly reduced amounts of soil carbon storage in restored wetlands compared to natural wetlands which has implications on biogeochemical functioning. Selecting restoration sites with low disturbance history, utilizing techniques that remove hydrological alterations as completely as possible, and active maintenance of plant communities all have the potential to improve condition and floristic quality results in wetland restorations.

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APPENDIX A: WISCONSIN DNR NATURAL COMMUNITY KEY

Wisconsin Department of Natural Resources

Natural Heritage Conservation

Key to Wetland Natural Communities

Introduction

This key is designed for use with natural communities with minimal anthropogenic disturbance, although ruderal communities based in part on the U.S. National Vegetation Classification have been included for completeness. Semi-disturbed natural sites as well as sites undergoing ecological restoration may fall somewhere between a weedy, ruderal type and a least-disturbed natural community and may be difficult to classify. If utilizing this key in the field, avoid transition areas and keep in mind that sites change over time through succession and disturbance. For example, tree or shrub encroachment or disturbances such as catastrophic fire, pest and disease outbreaks, windthrow, or beaver flooding may leave a site in an intermediate state as it recovers from disturbance or transitions from one community type to another. As with any key, users are encouraged to choose the statement in the couplet that best fits the community observed in the field, even if it does not match all aspects of the description.

This key is not intended to be used alone to definitively classify natural communities. Once you have worked a through the key, you are encouraged to read the additional descriptions provided on the WDNR Natural Heritage Inventory natural community webpages available online at dnr.wi.gov, keyword “natural communities”. Links to the community webpages are included in the key below. For each natural community type, online information includes a general overview, photos, associated rare plants and animals, and the print-ready 2 to 4-page detailed description featuring the distribution, abundance, environmental setting, ecological processes, community composition and structure, and conservation and management considerations excepted from Chapter 7 of the Ecological Landscapes of Wisconsin (dnr.wi.gov, keyword "ecological landscapes").

1a. Wetland dominated by non-native vegetation; associated native species indicative of disturbance (ruderal communities).

2a. Wetlands with at least 25% cover of trees or shrubs (ruderal forested and shrub wetlands).

3a. Forested with at least 25% canopy of trees, usually dominated by non-native tree willows [e.g., crack willow (*Salix* X *fragilis*), etc.] or weedy natives such as boxelder. Shrub layer strongly dominated by non-native species such as non-native bush honeysuckles (*Lonicera* spp.), common buckthorn (*Rhamnus cathartica*), glossy buckthorn (*Frangula alnus*), and multiflora rose (*Rosa multiflora*); herbaceous layer also usually dominated by non-natives such as reed canary grass (*Phalaris arundinacea*), garlic mustard (*Alliaria petiolata*), creeping Charlie (*Glechoma hederacea)*, dame's rocket (*Hesperis matronalis*), and moneywort (*Lysimachia nummularia*). Generalist native tree species may be co-dominant in the canopy, especially green ash or red maple .... **Ruderal Flooded and Swamp Forest**

3b. Dominated by non-native shrubs (<25% tree cover) such as non-native bush honeysuckles, common buckthorn, or glossy buckthorn, sometimes co-dominated by aggressive native shrubs such as dogwoods (*Cornus* spp.), sandbar willow (*Salix interior*), etc. Ground layer typically strongly dominated by reed canary grass, or occasionally bare ground where shrubs are very dense.. **Ruderal Shrub Swamp**

2b. Wetlands with trees and tall shrubs (>5 feet tall) less than 25% cover (ruderal marshes and meadows).

4a. Dominated by non-native reeds and cat-tails such as common reed (*Phragmites australis* ssp. *australis*), invasive or hybrid cattail species (e.g. *Typha angustifolia*, *T.* X *glauca*), or reed manna grass (*Glyceria maxima*). Non-native forbs may also be dominant, such as purple loosestrife (*Lythrum salicaria*). .... **Ruderal Marsh**

4b. Dominated by non-native grasses such as reed canary grass (*Phalaris arundinacea*) and redtop (*Agrostis gigantea*), or by weedy native forbs such as giant ragweed (*Ambrosia trifida*), stinging nettle (*Urtica dioica*), Canada goldenrod (*Solidago canadensis*), blunt spike-rush (*Eleocharis obtusa*), etc. .... **Ruderal Wet Meadow**

1b. Wetland dominated by native vegetation (Wisconsin Natural Heritage Inventory natural communities).

5a. Very small (usually one acre or less) kettle depressions in forested landscapes on moraines or interlobate regions, with standing water in spring, usually drying by late summer... **Ephemeral Pond**

5b. Larger wetlands, or if small, occurring in a variety of other landscapes and hydrologic setting combinations.

6a. Forested or tall shrub-dominated wetlands. Mature trees contributing greater than 25% overall canopy cover or tall shrubs (> 5 feet) contributing more than 50% canopy cover.

7a. FORESTED WETLANDS. Dominated by mature trees contributing greater than 25% overall canopy cover.

8a. Community occurring adjacent to Great Lakes shorelines on alternating series of narrow, sandy, upland ridges and low swales. Ridges may be open or shrub-dominated closest to the shoreline, and further from the shore are forested with pines, oaks, white spruce, balsam fir, and paper birch. Swales may contain open water, sedge meadow, alder, or be forested with black ash, tamarack, or northern white-cedar ... **Great Lakes Ridge and Swale**

8b. Community occurring adjacent to Great Lakes shorelines or not, but landforms and topography otherwise.

9a. Conifers common to dominant throughout canopy layer.

10a. Canopy strongly dominated by northern white-cedar or white pine. Tamarack and black spruce may be present but are minor canopy components and are not dominant across large areas.

11a. Canopy dominated by white pine, subcanopy dominated by red maple. Groundlayer often dominated by cinnamon fern (*Osmunda cinnamomea*), bristly dewberry (*Rubus hispidus*), and long sedge (*Carex folliculata*). Located mainly in Central Sand Plains ecological landscape on an ancient glacial lakebed. Soils usually acid sands with a thin layer of organic material. .... **White Pine-Red Maple Swamp**

11b. Canopy dominated by northern white-cedar, sometimes co-dominant with black ash, balsam fir, tamarack, or black spruce. Groundlayer often contains sedges (such as *Carex disperma* and *C. trisperma*) and forbs such as fringed polygala (*Polygala pauciflora*), naked miterwort (*Mitella nuda*), twinflower (*Linnaea borealis*), creeping snowberry (*Gaultheria hispidula*), and Sphagnum and other mosses. Located mainly in northern (occasionally in southeastern) Wisconsin in areas with mineral-enriched groundwater, often on outwash plains and ground moraines. Soils usually minerotrophic, at least where in contact with groundwater...**Northern Wet-mesic Forest**

10b. Canopy strongly dominated by black spruce or tamarack. Cedar and white pine absent to sparse.

12a. Located mainly south of Wisconsin's climatic tension zone. Dominated by tamarack, may be co-dominated by American elm, black ash, red maple, or yellow birch; black spruce absent to sparse. Poison sumac often common in tall shrub layer. Soils usually minerotrophic............... **Southern Tamarack Swamp**

12b. Located mainly north of Wisconsin's climatic tension zone or in the Central Sand Plains Ecological Landscape. Canopy dominated by black spruce or tamarack; most associates above (American elm, red maple, yellow birch) absent or sparse, though black ash may be present. Poison sumac absent to sparse. Soils usually strongly acid to weakly minerotrophic. [Formerly, all northern coniferous wetlands dominated by tamarack or black spruce were termed Northern Wet Forest. While this type is retained to cross-walk legacy data, it has been effectively retired and is now split into the following communities.]

13a. Canopy dominated by black spruce or co-dominant with tamarack. Tall shrub layer (> 5 feet) usually sparse (< 5% total cover, usually much less). Sphagnum moss abundant, often forming a nearly continuous carpet. Soils typically strongly acid. ....**Black Spruce Swamp**

13b. Canopy dominated by tamarack, black ash sometimes co-dominant. Tall shrubs common (> 5% total cover, usually much greater) dominated by species such as speckled alder (*Alnus incana*), mountain holly (*Ilex mucronata*), winterberry (*Ilex verticillata*), black chokeberry (*Aronia melanocarpa*), and bog birch (*Betula pumila*). Sphagnum moss occasional on hummocks, usually discontinuous. Soils moderately acid to weakly minerotrophic .... **Northern Tamarack Swamp**

9b. Conifers absent, or, if present, less dominant than hardwoods (may be locally co-dominant in hardwood swamps).

14a. Occurring in floodplains of 3rd order or greater streams and rivers. Dominant overstory species include silver maple, green ash, black willow, cottonwood, river birch, basswood, swamp white oak, bur oak, bitternut hickory, and hackberry (boxelder may be dominant in disturbed stands). Where organic soil accumulates in areas such as groundwater seepages, backswamps, and meander scars, tree species may include black ash, yellow birch, red maple, and conifers (tamarack, northern white-cedar, white pine, and hemlock), especially in northern Wisconsin..**Floodplain Forest**

14b. Occurring along headwater streams (1st and 2nd orders), seeps, and on poorly drained glacial outwash, lakeplain, and/or depressions in moraines or ice-contact topography.

15a. Occurring along seepage areas with active spring discharges in hardwood forests, usually at the head of ravines or at the base of steep bluffs. Found primarily in Driftless Area coulees, end moraines, and clay ravines... **Forested Seep**

15b. Occurring along headwater streams, basins in outwash plains, lakeplains, or depressions in moraines and ice-contact topography.

16a. Canopy dominated by black ash, often with red maple, yellow birch, or American elm. Conifers such as balsam fir and northern white-cedar may be locally common. Green ash and silver maple usually uncommon. Specked alder common. Groundlayer often dominated by species typical of saturated swamps such as marsh marigold (*Caltha palustris*), swamp raspberry (*Rubus pubescens*), orange jewelweed (*Impatiens capensis*), purple-stemmed aster (*Symphyotrichum puniceum*), lake sedge (*Carex lacustris*), blue-joint grass (*Calamagrostis canadensis*); many also include groundwater-loving species like bristle-stalked sedge (*Carex leptalea*), American golden saxifrage (*Chrysosplenium americanum*), and swamp saxifrage (*Micranthes pensylvanica*). Soils are mucks or mucky sands, usually constantly saturated with a relatively stable water table. Occurring along lakes, streams, or poorly drained basins.

.... **Northern Hardwood Swamp**

16b. Canopy dominated by silver maple, red maple (or the hybrid *Acer* X *freemanii*), and green ash. Associate species may include swamp white oak, bur oak, basswood, and American elm, and may be dominant in stands impacted by emerald ash borer. Black ash may be present but is usually not dominant. Speckled alder uncommon or absent. Groundlayer often dominated by species typical of floodplain forests such as Virginia wild-rye (*Elymus virginicus*), white grass (*Leersia virginica*), common wood-reed (*Cinna arundinacea*), wood nettle (*Laportea canadensis*), false nettle (*Boehmeria cylindrica*), and Ontario aster (*Symphyotrichum ontarionis*). Soils are predominantly mineral rather than muck, with a water table that fluctuates seasonally (wet in the spring, drying below the soil surface by late summer). Occurring in insular basins on low-lying portions of till plains and on lakeplains. Not restricted to southern Wisconsin; the name rather refers to swamps more commonly found in the southern Midwest.. **Southern Hardwood Swamp**

7b. SHRUB-DOMINATED WETLANDS. Mature trees contributing 25% or less to overall canopy cover. Tall shrubs (> 5 feet) dominant, contributing greater than 50% overall canopy cover.

17a. Occurring in southeastern Wisconsin. Tamarack common, forming a semi-open canopy (may be locally greater than 25% cover, but usually not over entire wetland). Poison sumac usually common, along with ericaceous shrubs (e.g., leatherleaf, bog rosemary, and bog laurel). Soils watery muck to firm peat, usually minerotrophic.

.... **Bog Relict**

17b. Occurring elsewhere, or, if in southeastern Wisconsin, tamarack absent or sparse. Shrubs and soils various.

18a. Shrub layer dominated by speckled alder, with alder contributing to half or more of the shrub canopy cover relative to all other shrubs combined. Occurring mainly in central and northern Wisconsin, rare in southern Wisconsin and Driftless Region. Soils acidic to minerotrophic. ....**Alder Thicket**

18b. Shrub layer dominated by a greater diversity of shrubs, often at least 4 or 5 species that are co-dominant. Alder usually present, even common, but contributes less than half of the relative shrub cover. Other common shrub species may include willows (*Salix* spp.), dogwoods (*Cornus* spp.), meadowsweet (*Spiraea alba*), bog birch (*Betula pumila*), nannyberry (*Viburnum lentago*), winterberry (*Ilex verticillata*), poison sumac (*Toxicodendron vernix*), etc. Occurring statewide. Soils acidic to minerotrophic. .... **Shrub-carr**

6b. OPEN (NON-FORESTED) WETLANDS. Mature trees absent or contributing 25% or less overall canopy cover. Tall shrubs (> 5 feet) contributing to 50% or less canopy cover.

19a. Standing water greater than 6 inches deep usually present in growing season (most marshes).

20a. Vegetation dominated by submergent or floating-leaved aquatic vegetation. Emergent vegetation (1.5-3 feet above surface of water) sparse with the exception of American lotus-lily (*Nelumbo lutea*).

21a. Vegetation dominated by near-continuous (>50%) cover of rooted floating leaved vegetation (i.e., not counting free-floating duckweeds) or American lotus-lily (*Nelumbo lutea*).

22a. Vegetation dominated by American lotus-lily. Occurring along margins of large rivers, especially the Mississippi, Lower Wolf and Winnebago Pool lakes. ....**American Lotus-lily Marsh**

22b. Vegetation dominated by other species, usually with large round leaves such as white water-lily (*Nymphaea variegata*), bull-head pond-lily (*Nuphar variegata*), or water-shield (*Brasenia schreberi*). Other aquatic macrophytes with long, narrow floating leaves may also be present such as long-leaf pondweed (*Potamogeton nodosus*) and floating-leaf bur-reed (*Sparganium fluctuans*). Occurring in lakes, ponds, or occasionally margins of rivers. ....**Floating-leaved Marsh**

21b. Vegetation dominated by submergent aquatics. Rooted, floating leaved aquatic macrophytes (i.e., not counting free-floating duckweeds) less than 50% cover.

23a. Vegetation dominated by rosette-forming aquatic macrophytes such as seven-angled pipe-wort (*Eriocaulon aquaticum*), yellow hedge-hyssop (*Gratiola aurea*), aquatic lobelia (*Lobelia dortmanna*), dwarf water-milfoil (*Myriophyllum tenellum*), brown-fruited rush (*Juncus pelocarpus*), and quillworts (*Isoetes* spp). Occurring in clear, deep, circumneutral lakes with extremely soft water in northern Wisconsin. Bottom materials usually sand or occasionally gravel. ....**Oligotrophic Marsh**

23b. Vegetation dominated by a wide variety of common aquatic macrophytes, including pondweeds (*Potamogeton* spp.), waterweeds (*Elodea* spp.), coon's-tails (*Ceratophyllum* spp.), slender naiad (*Najas flexilis*), eel-grass (*Vallisneria americana*), water-milfoils (*Myriophyllum* spp.) and bladderworts (*Utricularia* spp.). Occurring in a wide variety of lake types and water chemistries. Bottom materials usually muck or silt but may also include sand and gravel. ....**Submergent Marsh**

20b. Vegetation dominated by emergent vegetation, usually 1.5 – 3+ feet above the surface of the water by mid- to late summer.

24a. Occurring along the margins of sand-bottomed seepage lakes and ponds on glacial lakebeds (especially Glacial Lake Wisconsin) and outwash plains in south central Wisconsin. Vegetation exhibiting strong zonation with sedges (*Carex* spp.) and bulrush (*Scirpus* spp.) dominant in the emergent zone, aquatic macrophytes (e.g., water-shield, etc.), in deeper water, and with medium-statured grasses, sedges, and forbs disjunct from the Atlantic Coastal Plain in shallow water and along the shore, especially *Fimbristylis*, *Fuirena*, *Lipocarpha*, *Rhynchospora*, *Scleria*, brown-fruited rush (*Juncus pelocarpus*), milkworts (*Polygala cruciata* and *P. sanguinea*), tooth-cup (*Rotala ramosior*), meadow-beauty (*Rhexia virginica*), lance- leaved violet (*Viola lanceolata*), and yellow-eyed grass (*Xyris torta*). .... **Coastal Plain Marsh** (high water phase)

24b. Occurring in a wide variety of hydrologic settings including inland lakes, Great Lakes, and along rivers Vegetation dominated by cat-tail, wild rice, bulrushes, or other species, not strongly zonal, lacking Coastal Plain disjuncts.

21a. Vegetation dominated by northern wild rice (*Zizania palustris*) or southern wild rice (*Zizania aquatica*). ....

....**Wild Rice Marsh**

21b. Vegetation dominated by species such as cat-tails (*Typha latifolia*), giant reed (*Phragmites australis var. americana*), bulrushes (*Schoenoplectus* spp.), river bulrush (*Bolboschoenus fluviatilis*), lake sedge (*Carex lacustris*), bur-reeds (*Sparganium* spp.), water-plantains (*Alisma* spp.), common spike-rush (*Eleocharis palustris*) and occasionally cut grass (*Leersia oryzoides*); wild rice may also present locally but is not dominant across large areas. Non-native cat-tail (*Typha angustifolia*, *T.* X *glauca*) and giant reed (*Phragmites australis* var. *australis*) may be occasional to locally common; if dominant, please see Ruderal Marsh (couplet 4a). .... **Emergent Marsh**

19b. Standing water absent or less than 6 inches deep throughout community in growing season, though water may be deeper in local pools (peatlands, fens, wetland prairies, sedge meadows, and coastal plain marsh, in part).

26a. Community structure characterized by a repeated, alternating pattern of low peat rises (strings) and hollows (flarks), especially evident on aerial photos. Strings may support scattered and stunted black spruce, tamarack, northern white-cedar, low shrubs including bog birch, shrubby cinquefoil, bog rosemary (*Andromeda glaucophylla*), leatherleaf (*Chamaedaphne calyculata*), and sedges (*Carex oligosperma, C. limosa, C. lasiocarpa*). The alternating flarks are often inundated and may support many sedges of bogs and fens, along with ericads, sundews (*Drosera* spp.), orchids, arrow-grasses (*Triglochin* spp.), and calciphilic shrubs such as bog birch and shrubby cinquefoil (*Dasiphora fruticosa*). Soils are deep peat and slightly acid to circumneutral. Extremely rare in Wisconsin, known from only a handful of sites. ....**Patterned Peatland**

26b. Community structure lacks repeating pattern of low peat rises and alternating hollows.

27a. Ground layer dominated by a continuous carpet of sphagnum mosses, or sphagnum mosses locally dominant on scattered low peat mounds.

28a. Tree canopy cover typically 10 to 25%, consisting of scattered and stunted black spruce and tamarack. Occurring in central and northern Wisconsin. Soils strongly acidic deep peat. .... **Muskeg**

28b. Trees absent or occurring in localized areas with overall canopy cover typically less than 10%.

29a. Vegetation surface uneven and dominated by pronounced hummocks (often 2 feet or more in height) with intervening hollows; hummocks dominated by ericaceous shrubs such as leatherleaf, bog rosemary, Labrador tea, and bog laurel (*Kalmia polifolia*). Soil very strongly acidic, deep fibric peat. Occurring primarily in central and northern Wisconsin, usually in the center of large peatland basins or occasionally on firm peat above a lake margin, always where the rooting zone is elevated above the influence of minerotrophic groundwater.. **Open Bog**

29b. Vegetation surface more even or with widely scattered low hummocks (usually less than 2 feet high). Soils strongly acidic to weakly minerotrophic. Occurring in broad depressions on lakeplains and outwash plains or along the margins of lakes, usually in contact with groundwater or surface water.

30a. Vegetation dominated by few-seed sedge (*Carex oligosperma*) and/or wiregrass sedge (*C. lasiocarpa*). Common shrubs are leatherleaf, bog rosemary and occasionally bog birch, plus stunted tamarack and black spruce. Other indicator species include mud sedge (*Carex limosa*), pitcher-plant (*Sarracenia purpurea*), round-leaved sundew (*Drosera rotundifolia*), pod grass (*Scheuchzeria palustris*), bogbean (*Menyanthes trifoliata*) and the pink-flowered orchids (*Calopogon tuberosus*, *Pogonia ophioglossoides* and *Arethusa bulbosa*). Usually occurring north (rarely south) of the climatic tension zone in kettle depressions and on level areas or shallow depressions of glacial outwash and lakeplains, often on the margins of "bog" lakes with a floating or grounded mat of peat and sedge rhizomes. ....**Poor Fen**

30b. Vegetation dominated by common yellow lake sedge (*Carex utriculata*), few-seed sedge (*Carex oligosperma*), wiregrass sedge (*C. lasiocarpa*), and bluejoint grass (*Calamagrostis canadensis*); wool grass (*Scirpus cyperinus*) occasional. Small tamarack and white pine scattered. Common shrubs are hardhack (*Spiraea tomentosa*), bristly dewberry (*Rubus hispidus*), leatherleaf, black chokeberry (*Aronia melanocarpa*), Kalm's St. John's-wort (*Hypericum kalmianum*) and sometimes bog birch (*Betula pumila*). Indicator forbs include swamp-candles (*Lysimachia terrestris*) and bog goldenrod (*Solidago uliginosa*). Occurring almost exclusively in the Central Sand Plains on the lakebed of Glacial Lake Wisconsin. .... **Central Poor Fen**

27b. Ground layer dominated by sedges, rushes, grasses, and/or forbs; sphagnum mosses absent or local.

31a. Soils loam to silty clay loam, usually at soil surface.

32a. Dominated by big bluestem, little bluestem, and Indian grass, with prairie dropseed, bluejoint grass, cordgrass, and tussock sedge locally common. Prairie forbs such as prairie blazing-star (*Liatris pycnostachya*), prairie phlox (*Phlox pilosa*), prairie coneflower (*Ratibida pinnata*), prairie dock (*Silphium terebinthinaceum*), and Culver's-root (*Veronicastrum virginicum*) much more common than marsh forbs (see 32b)... **Wet-mesic Prairie**

32b. Dominated by cordgrass and occasionally bluejoint grass and tussock sedge. Marsh forbs such as Joe-Pye-weed (*Eutrochium maculatum*), boneset (*Eupatorium perfoliatum*), common water hemlock (*Cicuta maculata*), swamp milkweed (*Asclepias incarnata*), and water smartweed (*Persicaria amphibia*) more common than prairie forbs (see 32a), or both marsh and prairie forbs about equally common..**Wet Prairie**

31b. Soils sand, peat, or muck (including mucky mineral); if heavier mineral soils at surface, soils saturated.

33a. Occurring along the shorelines of Lake Michigan and Superior, or in estuarine complexes near the Great Lakes, with hydrology influenced at least indirectly by Great Lakes water levels.

34a. Located in coastal embayments, often behind a barrier sandspit or near the mouth of estuarine rivers. Vegetation usually a floating mat dominated by wiregrass sedge (*Carex lasiocarpa*), twig-rush (*Cladium mariscoides*), sweet gale (*Myrica gale*), and buckbean (*Menyanthes trifoliata*).....**Great Lakes Shore Fen**

34b. Located in depressions in open dunes or between dune ridges. Soils moist or submerged sand (sometimes covered by a thin layer of muck or marl). Water level sometimes deepening to several feet in center of depression. Species various, but often include Baltic rush (*Juncus balticus*), silverweed (*Potentilla anserina*), seven-angled pipewort (*Eriocaulon aquaticum*), golden-seeded spike-rush (*Eleocharis elliptica*), and sedges (e.g., *Carex aquatilis*, *C. lasiocarpa*, *C. oligosperma*, *C. viridula*).

.... **Interdunal Wetland**

33b. Occurring elsewhere, or, if near the Great Lakes, hydrology not influenced by Great Lakes water levels.

35a. Occurring in shallow sandy depressions or on perimeters (or rarely entire shallow basins) of softwater seepage lakes with drying shores and other isolated depressions characterized by large water table fluctuations (both seasonally and from year to year). Soils sand or peaty sand.

36a. Occurring along the margins of sand-bottomed seepage lakes and ponds on glacial lakebeds (especially Glacial Lake Wisconsin in the Central Sand Plains) as well as on sandy outwash plains.

Vegetation usually exhibiting strong zonation with an aquatic zone, shorted-statured emergent zone, and drier upland zone.

37a. Vegetation includes species disjunct from the Atlantic Coastal Plain, including *Fuirena*, *Lipocarpha*, *Rhynchospora*, *Scleria*, brown-fruit rush (*Juncus pelocarpus*), milkworts (*Polygala cruciata* and *P. sanguinea*), tooth-cup (*Rotala ramosior*), meadow-beauty (*Rhexia virginica*), and yellow-eyed grass (*Xyris torta*); may also contain species listed below (see 37b). .... **Coastal Plain Marsh**

37b. Vegetation lacks Coastal Plain specialists (see 37a), dominated by graminoids such as Arctic rush (*Juncus arcticus*), narrow-panicle rush (*J. brevicaudatus*), Smith's bulrush (*Schoenoplectus smithii*), little green sedge (*Carex viridula*), yellow sedge (*C. flava*), broom sedge (*C. scoparia*), clustered beak-rush (*Rhynchospora capitellata*), and containing forbs such as silver-weed (*Argentina anserina*), brook lobelia (*Lobelia kalmii*), purple false foxglove (*Agalinis purpurea*), common false foxglove (*A. tenuifolia*), and northern St. John's-wort (*Hypericum boreale*). .... **Inland Beach**

36b. Occurring in moist sandy depressions with a high water table, but with little to no standing water; not associated with seepage lakes. Vegetation zonation weak, usually a mixture of species of coastal plain marsh as well as sedge meadow, oak barrens, and/or pine barrens. .... **Moist Sandy Meadow**

35b. Occurring in depressions in glacial lakeplains and outwash plains, abandoned glacial lakebeds, stream corridors, and margins of lakes. Soils usually organic at surface or if mineral at or near surface, soil texture usually clay loam to sandy clay loam (silt loam on degraded sites), rarely sand.

38a. Dominated by sedges, particularly tussock sedge (*Carex stricta*), wiregrass sedge (*C. lasiocarpa*), and/or lake sedge (*C. lacustris*), with bluejoint grass occasionally co-dominant. Sedge and bluejoint grass tussocks, if present, often tall (> 6 inches). Soils peat or muck, acid to neutral. Wet sedge meadow species such as water smartweed, great water dock (*Rumex britannica*), broad-leaved arrowhead (*Sagittaria latifolia*), marsh skullcap (*Scutellaria galericulata*), and wool grass (*Scirpus cyperinus*) more prevalent than fen specialists (see 38b), which are usually sparse.[1]

39a. Located in northern Wisconsin, north of the climatic tension zone. Vegetation dominated by sedges (*Carex stricta*, *C. lacustris*, *C. lasiocarpa*, *C. oligosperma*, *C. utriculata*) and bluejoint grass. Species such as leatherleaf, marsh cinquefoil (*Comarum palustre*), northern blue flag (*Iris versicolor*), and bog willow (*Salix pedicellaris*) more prevalent than those listed below (see 39b). Soils are neutral to strongly acidic, shallow to deep peat. Frequently invaded by speckled alder with tamarack and/or cedar on the margin .... **Northern Sedge Meadow**

39b. Located in southern Wisconsin, mostly south of the climatic tension zone. Vegetation dominated by tussock sedge, lake sedge, and sometimes by wiregrass sedge. Species such as Joe-Pye-weed, jewelweed (*Impatiens capensis*), sensitive fern (*Onoclea sensibilis*), giant goldenrod (*Solidago gigantea*), glossy-leaved aster (*Symphyotrichum firmum*), and tall meadowrue (*Thalictrum dasycarpum*) more prevalent than species listed above (see 39a). Soils are typically neutral to mildly alkaline peat. Frequently invaded by dogwoods and willows (e.g., *Salix bebbiana*, *S. discolor*); alder absent to sparse .... **Southern Sedge Meadow**

38b. Dominance usually shared by sedges, grasses, rushes, bulrushes, and forbs (in boreal rich fens, Carex lasiocarpa may be dominant). Sedge tussocks, if present, usually short (< 6 inches). Soils neutral to moderately alkaline deep peat or marl. Vegetation strongly influenced by surface and subsurface groundwater seepage. Fen specialists such as sedges (*Carex buxbaumii*, C. *leptalea*, *C. limosa*, *C. livida*, *C. sterilis*), Kalm's lobelia (*Lobelia kalmii*), bog goldenrod (*Solidago uliginosa*), pitcher-plant (*Sarracenia purpurea*), beak-rushes (*Rhynchospora alba* and *R. capillacea*), bog arrowgrass

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[1] Some wetland restorations may key here, especially where conducted on former agricultural land, but may not match the descriptions of naturally-occurring sedge meadow communities. For an alternate categorization of these sites, please see the U.S. National Vegetation Classification description for Sedge species - Canada Bluejoint Midwest Wet Meadow Alliance.

(*Triglochin maritimum*), twig-rush (*Cladium mariscoides*), golden-seeded spike-rush (*Eleocharis elliptica*), shrubby cinquefoil (*Dasiphora fruticosa*), and alder-leaved buckthorn (*Rhamnus alnifolia*) more prevalent than sedge meadow/marsh specialists (see 38a), which are usually sparse.

40a. Located in northern Wisconsin, often adjacent to lakes or cedar swamps. Northern shrubs and stunted trees present such as bog rosemary, leatherleaf, sweet gale, northern white-cedar, tamarack, and black spruce. .... **Boreal Rich Fen**

40b. Located in southern Wisconsin or occasionally in central Wisconsin, primarily in interlobate regions. Species of prairies and calcareous southern wetlands present such as big bluestem, little bluestem, whorled loosestrife (*Lysimachia quadriflora*), cowbane (*Oxypolis rigidior*), swamp lousewort (*Pedicularis lanceolata*), Virginia mountain-mint (*Pycnanthemum virginianum*), Riddell's goldenrod (*Solidago riddellii*), and poison sumac (*Toxicodendron vernix*). ....**Calcareous Fen**

APPENDIX B: PRELIMINARY CONDITION BENCHMARKS FOR $w\bar{C}$

INTERPRETING Mean Coefficient of Conservatism Results: $\bar{C}$ and $w\bar{C}$

Preliminary suggested benchmarks for weighted mean C ($w\bar{C}$) and unweighted mean C ($\bar{C}$) are available below. Weighted mean C ($w\bar{C}$) benchmarks should be used whenever possible, but unweighted C benchmarks ($\bar{C}$) can be used in cases where $w\bar{C}$ benchmarks for community don't exist or for plant data without abundance estimates for each species.

BENCHMARKS FOR **WEIGHTED MEAN C ($w\bar{C}$)**

Preliminary **Weighted Mean C ($w\bar{C}$)** Condition Benchmarks for **Northern Lakes and Forests** Ecoregion Wetlands based on Overall Disturbance Scores.

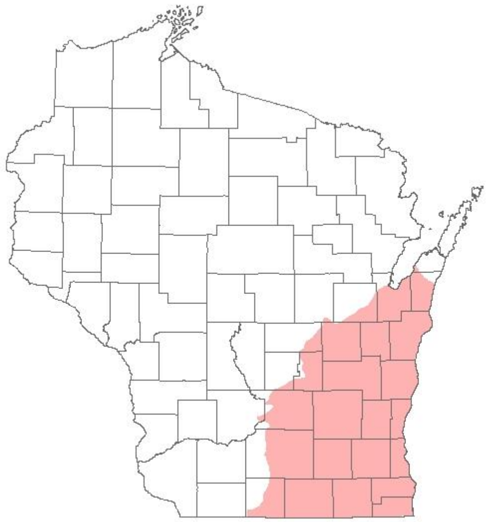
		Condition Category				
		Least Disturbed			Most Disturbed	
	Natural Community:	Excellent	Good	Fair	Poor	Very Poor
Emergent	Emergent Marsh	> 7.1	5.2 - 7.1	2.8 - 5.1	0.7-2.7	< 0.7
	Northern Sedge Meadow	> 7.1	5.2 - 7.1	3.5 - 5.1	< 3.5	
Shrub-Scrub	Shrub Carr	> 5.1			3.9-5.1	< 3.9
	Alder Thicket	> 5.3	4.5 - 5.3	4.1 - 4.4	3.8-4.0	< 3.8
	Open Bog	> 8.9	8.0 - 8.9	< 8.0		
	Muskeg	> 8.5	7.9 - 8.5	< 7.9		
Forested	Black Spruce/ Tamarack Swamp	> 7.9	7.4 - 7.9	6.7 - 7.3	5.7-6.6	< 5.7
	Cedar Swamp (NWMF)	> 7.4	6.9 - 7.4	< 6.9		
	Northern Hardwood Swamp	> 6.2	5.7 - 6.2	3.9 - 5.6	2.5-3.8	< 2.5

Source: Hlina, P., NP Danz, K. Beaster, D. Anderson S. Hagedorn. 2015. Northern Lakes and Forests Inland Wetland Surveys: Relationship between Floristic Quality Assessment and Anthropogenic Stressors. Technical Report 2015-2. Lake Superior Research Institute, University of Wisconsin-Superior, Superior, WI.

Preliminary **Weighted Mean C ($w\bar{C}$)** Condition Benchmarks for **North Central Hardwood Forest** and **Western Corn Belt Plains** Wetlands based on Overall Disturbance Scores.

		Condition Category:				
		Least Disturbed			Most Disturbed	
	Natural Community:	Excellent	Good	Fair	Poor	Very Poor
Emergent	Emergent Marsh	> 6.6	5.2 - 6.6	3.1 - 5.1	0.8 - 3.0	< 0.8
	Southern Sedge Meadow	> 6.0	5.0 - 6.0	2.7 - 4.9	1.9 - 2.6	< 1.9
	Northern Sedge Meadow	> 7.0	5.9 - 7.0	2.8 - 5.8	1.4 - 2.7	< 1.4
Shrub	Shrub Carr	> 5.7	4.9 - 5.7	2.0 - 4.8	1.6 - 1.9	< 1.6
Forested	Northern Hardwood Swamp	> 6.1	5.0 - 6.1	2.7 - 4.9	2.5 - 2.6	< 2.5
	Cedar Swamp (NWMF)	> 7.1		6.8 - 7.1	< 6.8	
	Northern Tamarack Swamp	> 7.1	6.7 - 7.1	5.7 - 6.6	4.5 - 5.6	< 4.5

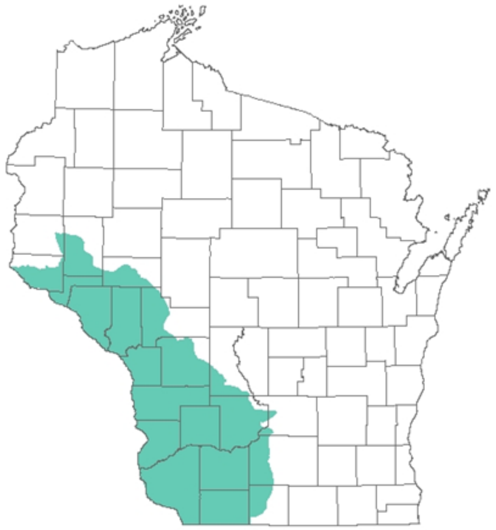
Source: Marti, A.M. and T.W. Bernthal. 2019. Provisional wetland floristic quality benchmarks for wetland monitoring and assessment in Wisconsin. Final Report to US EPA Region V, Grants # CD00E01576 and #CD00E02075. Wisconsin Department of Natural Resources. Unpublished manuscript.



Preliminary **Weighted Mean C (w$\bar{C}$)** Condition Benchmarks for **Southeast WI Till Plains** and **Central Corn Belt Plains** Wetlands based on Overall Disturbance Scores.

	Natural Community:	**Condition Category:** Least Disturbed				Most Disturbed
		Excellent	Good	Fair	Poor	Very Poor
Emergent	Emergent Marsh	> 5.7	4.1 - 5.7	2.1 - 4.0	1.0 - 2.0	< 1.0
	Southern Sedge Meadow	> 6.3	5.6 - 6.3	3.8 - 5.5	1.0 - 3.7	< 1.0
	Wet-Mesic Prairie	> 5.5	4.6 - 5.5	3.1 - 4.5	1.9 - 3.0	< 1.9
	Calcareous Fen	> 7.0	6.2 - 7.0	3.6 - 6.1	2.2 - 3.5	< 2.2
Shrub	Shrub-Carr	> 5.1	4.7 - 5.1	3.2 - 4.6	2.3 - 3.1	< 2.3
Forested	Northern Hardwood Swamp	> 6.2	5.4 - 6.2	3.6 - 5.3	3.4 - 3.5	< 3.4
	Southern Hardwood Swamp	> 4.7	4.0 - 4.7	2.9 - 3.9	2.0 - 2.8	< 2.0
	Cedar Swamp (NWMF)	> 6.5	6.5	5.8 - 6.4	5.3 - 5.7	< 5.3
	Floodplain Forest	> 4.0	3.4 - 4.0	2.3 - 3.3	2.2	< 2.2

Source: Marti, A.M. and T.W. Bernthal. 2019. Provisional wetland floristic quality benchmarks for wetland monitoring and assessment in Wisconsin. Final Report to US EPA Region V, Grants # CD00E01576 and #CD00E02075. Wisconsin Department of Natural Resources. Unpublished manuscript.



Preliminary **Weighted Mean C (wC̄)** Condition Benchmarks for **Driftless Area** Ecoregion Wetlands based on Overall Disturbance Scores.

		Condition Category:				
		Least Disturbed			Most Disturbed	
	Natural Community:	Excellent	Good	Fair	Poor	Very Poor
Emergent	Emergent Marsh	> 5.2	4.8 - 5.2	3.4 - 4.7	1.7 - 3.3	< 1.7
	Southern Sedge Meadow	> 5.9	5.0 - 5.9	1.6 - 5.1	1.1 - 1.5	< 1.1
Shrub	Shrub-Carr	> 5.5	4.4 - 5.5	2.6 - 4.4	1.8 - 2.5	< 1.8
	Alder Thicket	> 4.9	4.5- 4.9	3.8 - 4.4	3.1 - 3.7	< 3.1
Forested	Floodplain Forest	> 4.4	3.5 - 4.4	2.7 - 3.4	2.2 - 2.6	< 2.2

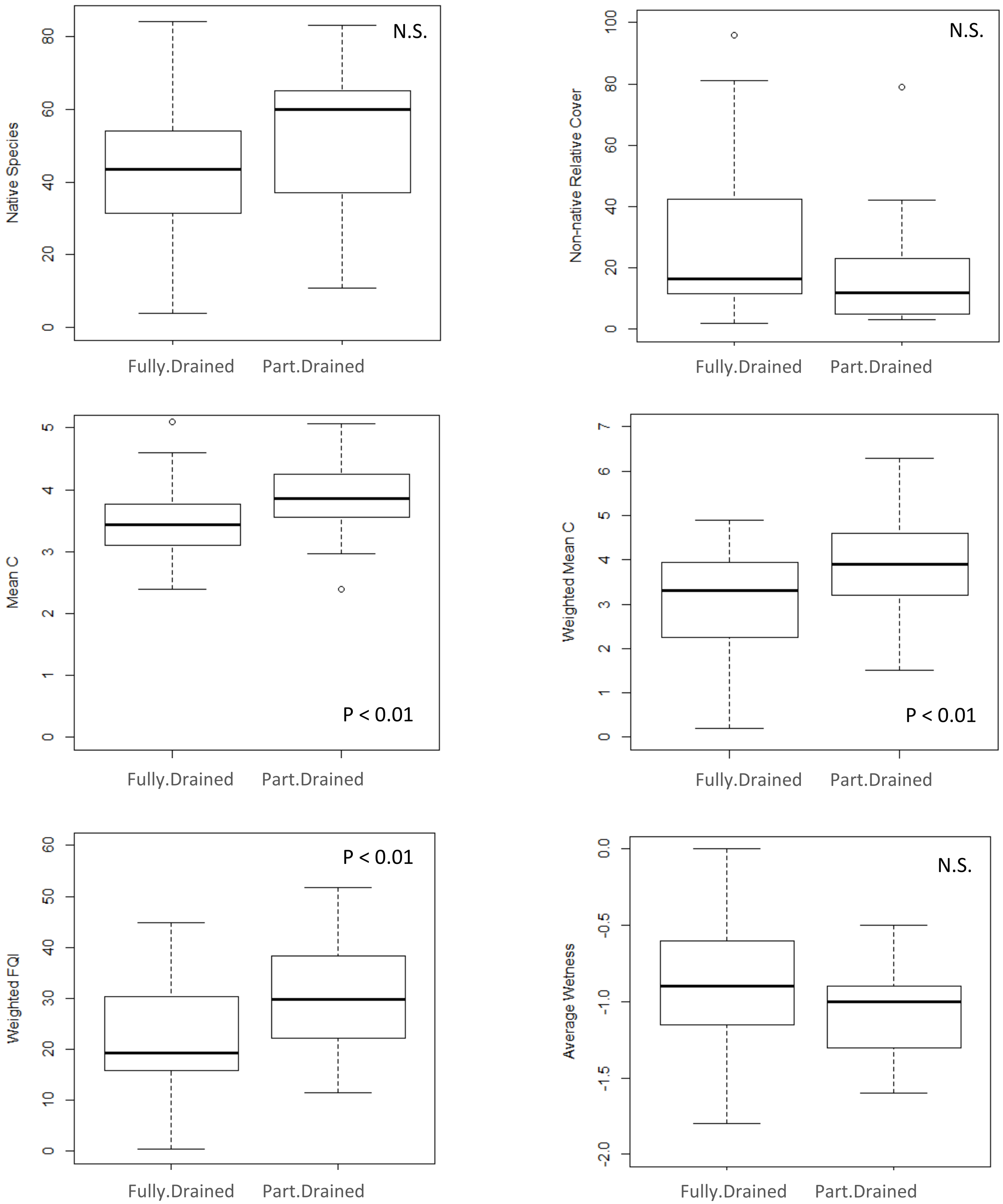
Source: Marti, A.M. and T.W. Bernthal. 2019. Provisional wetland floristic quality benchmarks for wetland monitoring and assessment in Wisconsin. Final Report to US EPA Region V, Grants # CD00E01576 and #CD00E02075. Wisconsin Department of Natural Resources. Unpublished manuscript.

APPENDIX C: SITE RESULTS

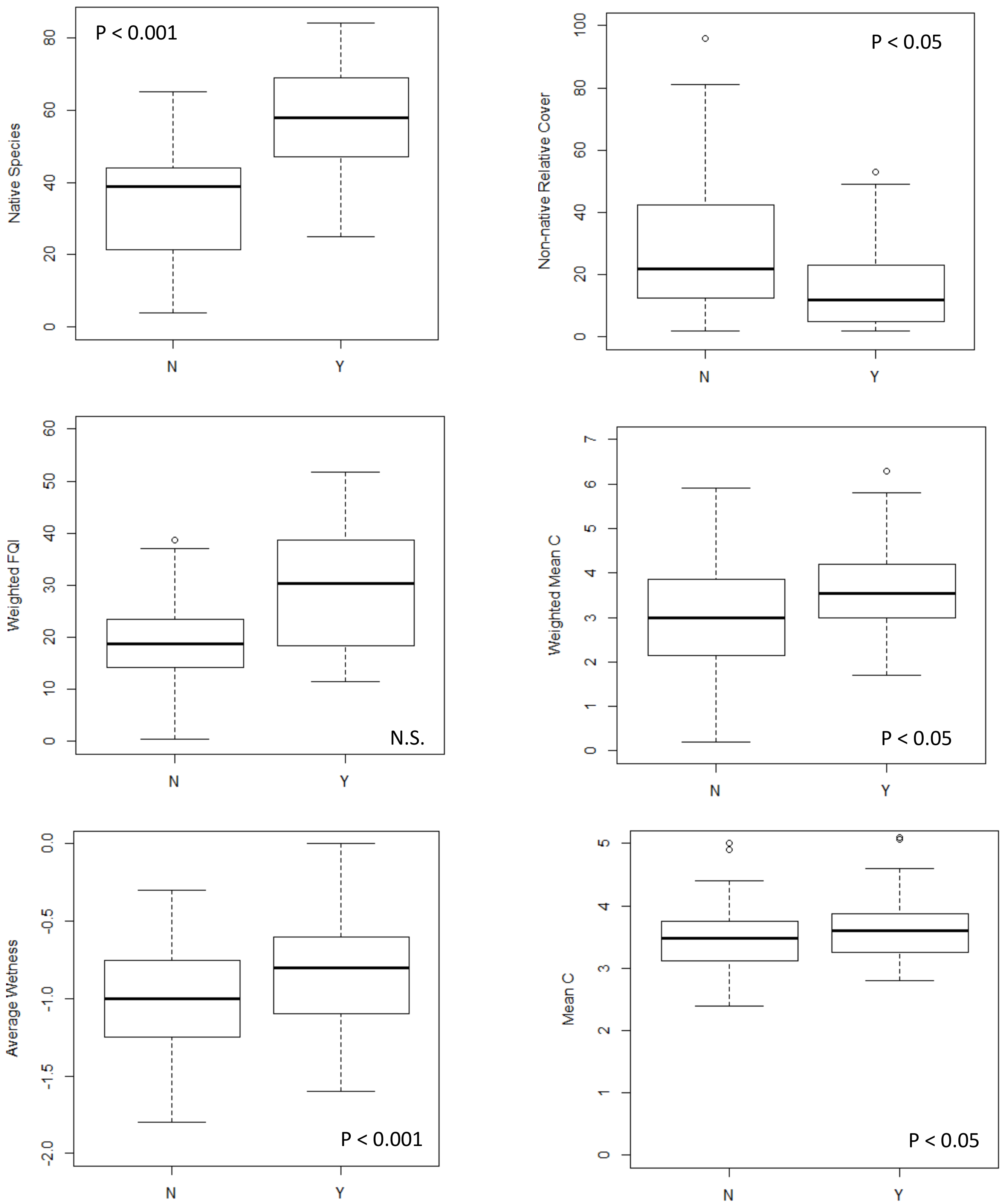
SITE-LEVEL WETLAND CONDITION RESULTS USING WEIGHTED AVERAGES TO COMBINE INDIVIDUAL AA RESULTS.

Restoration Site Name	Restoration Organization Type	Restoration Age (yrs)	Communities Surveyed	Hydrologic Restoration Technique(s)	Avg. Condition Tier Score	Avg. Condition
Ashley Furniture Mitigation Bank	Compensatory Mitigation	10	2	Ditch Fill, Sediment Removal	3	Fair
Beaver Brook WisDOT Mitigation	Compensatory Mitigation	7	4	Ditch Fill, Dike Removal	3	Fair
Brooklyn Wildlife Area	Wildlife Habitat	6	1	Tile Break	5	Very Poor
Dane Co. Cherokee Marsh	Compensatory Mitigation	11	2	Sediment Removal	3	Fair
Dane Co. Starkweather Creek	Compensatory Mitigation	13	1	Sediment Removal	4	Poor
Drost WRP	Wetland Reserve Program	5	1	Tile Break, Scrape	4	Poor
East Troy Sod WRP	Wetland Reserve Program	4	2	Tile Break, Scrape, Berm	4	Poor
Faville Grove Ledge Lowland	Non-Profit	13	2	Ditch Fill	3	Fair
Faville Grove Snake Marsh	Non-Profit	10	1	Scrape	3	Fair
Faville Grove Tillotson Prairie	Non-Profit	17	1	Ditch Fill	3	Fair
Faville Grove Tillotson Floodplain	Non-Profit	15	1	Ditch Fill	4	Poor
GHRA- Spirit Enterprises	Wildlife Habitat	11	8	Scrape, Berm	3	Fair
GHRA- Stoppleworth	Wildlife Habitat	7	1	Scrape, Berm	3	Fair
Goose Pond Hopkins Rd. Prairie	Non-Profit	15	1	Sediment Removal	4	Poor
Goose Pond Lapinski-Kitze Prairie	Non-Profit	12	1	Sediment Removal	4	Poor
Goose Pond Sue Ames Prairie	Non-Profit	20	1	Sediment Removal	4	Poor
Headwaters	Compensatory Mitigation	11	1	Tile Removal	3	Fair
Heritage Crossing	Compensatory Mitigation	8	1	Tile Removal	4	Poor
Hickory Knolls - Carol's Wetland	Non-Profit	22	2	Sediment Removal	3	Fair
Jackson Marsh Wildlife Area	Wildlife Habitat	9	1	Scrape, Berm	3	Fair
Kettle Moraine SF Mukwonago Unit	Wildlife Habitat	7	1	Ditch Plug	3	Fair
Kettle Moraine SF Northern Unit	Wildlife Habitat	6	1	Scrape	3	Fair
Knights Creek WisDOT Mitigation	Compensatory Mitigation	15	1	Ditch Plug, Tile Break	3	Fair
Lodi Marsh Mitigation Bank	Compensatory Mitigation	18	3	Tile Break, Sediment Removal, Stream Re-meander	4	Poor
Loon Lake Wildlife Area North	Wildlife Habitat	4	3	Ditch Plug, Tile Break, Scrape	4	Poor
Loon Lake Wildlife Area South	Wildlife Habitat	5	1	Berm	3	Fair
Lost Creek	Compensatory Mitigation	7	3	Ditch Fill, Tile Break, Scrape	3	Fair
McDonald WRP	Wetland Reserve Program	10	3	Ditch Plug, Scrape	3	Fair
Mequon Nature Preserve	Non-Profit	12	2	Tile Break, Berm	3	Fair
Moses Creek WisDOT Mitigation	Compensatory Mitigation	6	1	Scrape	4	Poor
Mueller/Shea Prairie	Non-Profit	4	2	Sediment Removal, Tile Removal	3	Fair
Neptune	Compensatory Mitigation	14	3	Ditch Plug, Tile Break, Scrape	3	Fair
Pecatonica 2006	Non-Profit	11	1	Sediment Removal, Scrape	3	Fair
Pecatonica 2008	Non-Profit	9	1	Sediment Removal	3	Fair
Pheasant Branch Conservancy	Non-Profit	13	1	Ditch Fill	3	Fair
Summerton Bog SNA	Non-Profit	12	7	Ditch Fill, Tile Removal, Sediment Removal	3	Fair
Tom Lawin Wildlife Area	Wildlife Habitat	11	1	Ditch Plug	4	Poor
Upper Chippewa Mitigation Bank	Compensatory Mitigation	11	1	Ditch Fill, Dike Removal	2	Good
Walkerwin Mitigation Bank	Compensatory Mitigation	20	1	Ditch Fill, Ditch Plug, Berm	3	Fair

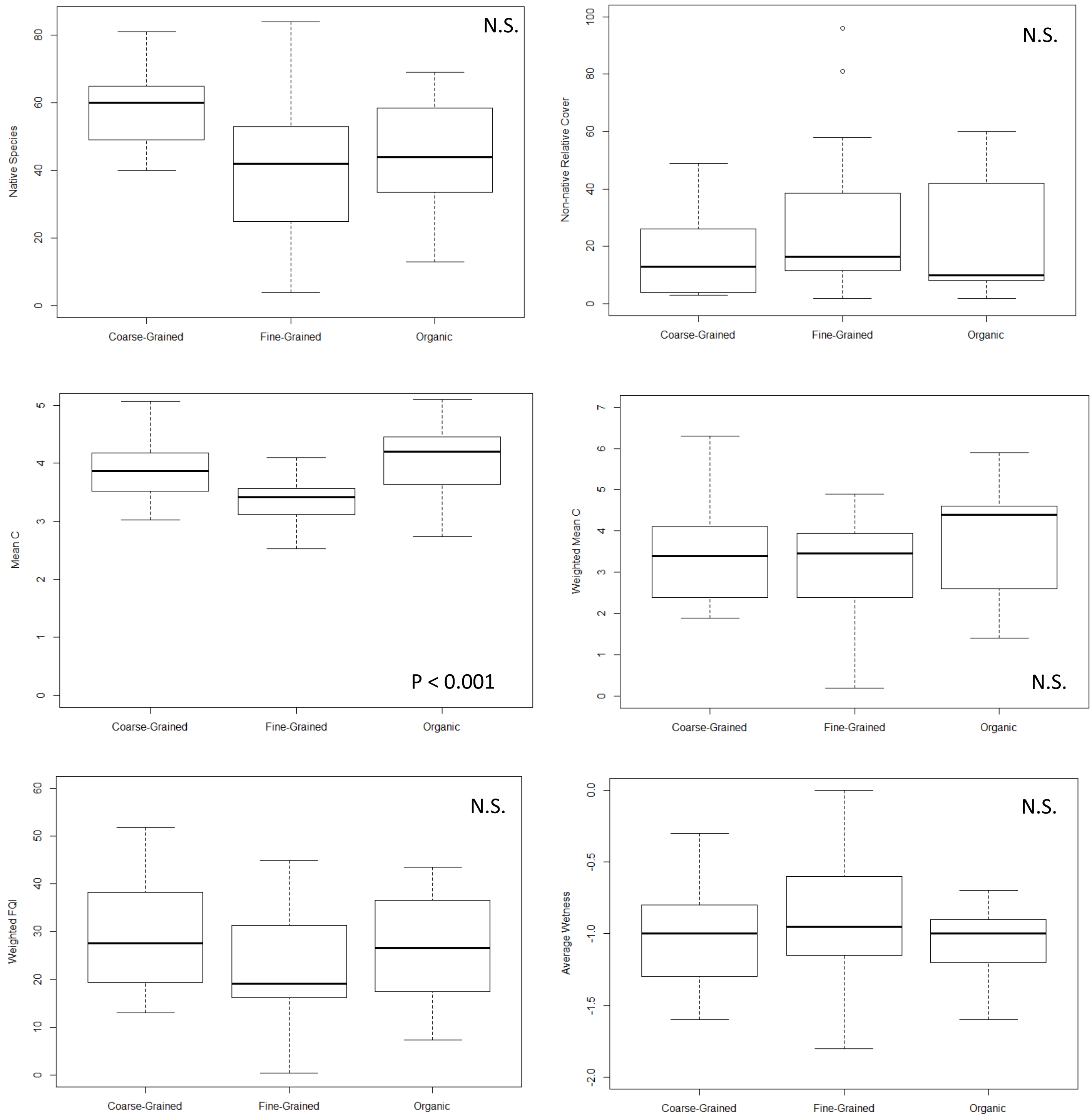
Appendix D: Additional Comparisons



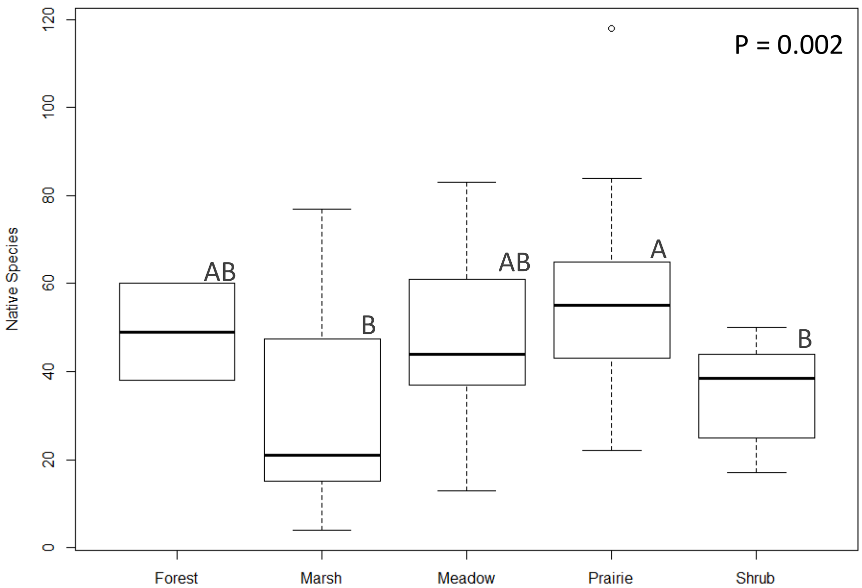
Boxplots of floristic quality metrics by **initial conditions**- fully drained (n = 54) or partially drained (n = 14). For each boxplot the top and bottom of the box represent the 75% quantile and the 25% quantile respectively, the line in the box is the median value, the whiskers represent the highest and lowest values, with outliers represented as dots. Average Wetness = Average Wetland Indicator Score: 0 = FAC, -1 = FACW, and -2 = OBL.

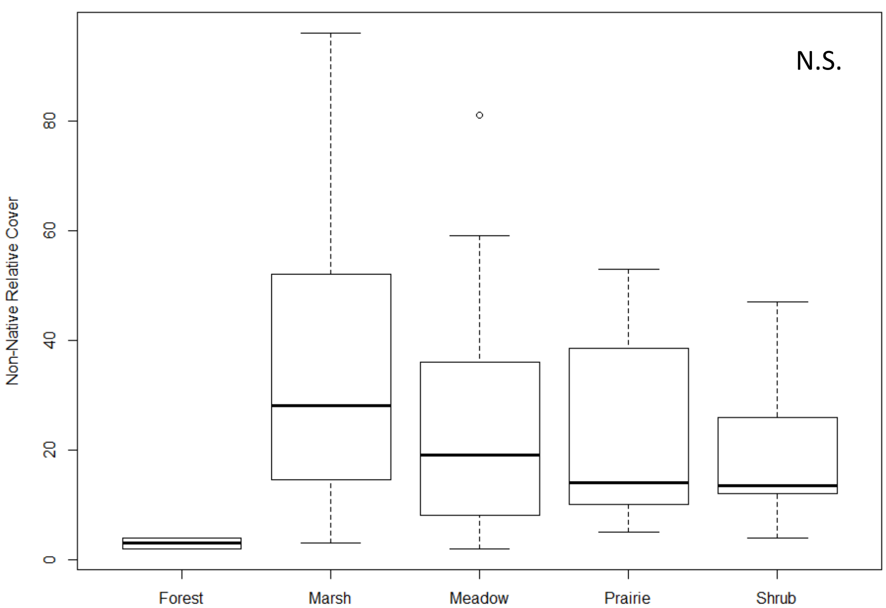


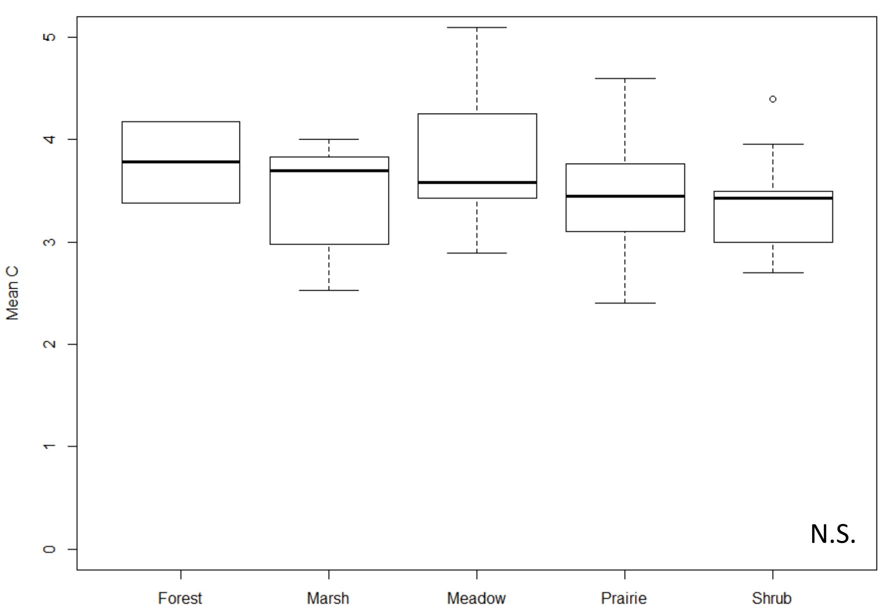
Boxplots of floristic quality results for restored wetlands grouped by the presence (Yes; n = 34) or absence (No; n = 49) of **active maintenance activities**. For each boxplot the top and bottom of the box represent the 75% quantile and the 25% quantile respectively, the line in the box is the median value, the whiskers extend to the highest and lowest values, with outliers represented as dots. Average Wetness = Average Wetland Indicator Score: 0 = FAC, -1 = FACW, and -2 = OBL.



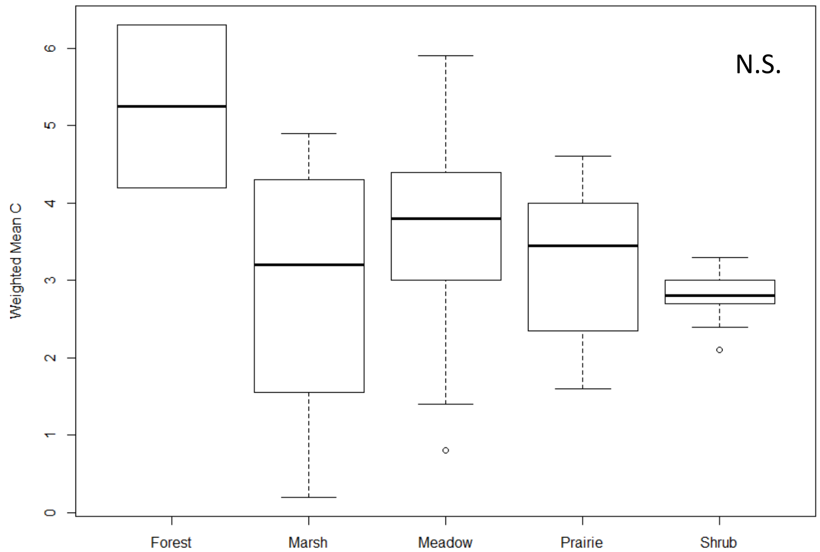
Boxplots of floristic quality metrics by **soil type**. Coarse-Grained = sandy (n = 11); Fine-Grained = silty or clayey (n = 45); and Organic = mucky or peaty soils (n = 17). For each boxplot the top and bottom of the box represent the 75% quantile and the 25% quantile respectively, the line in the box is the median value, the whiskers extend to the highest and lowest values, with outliers represented as dots. Average Wetness = Average Wetland Indicator Score: 0 = FAC, -1 = FACW, and -2 = OBL.

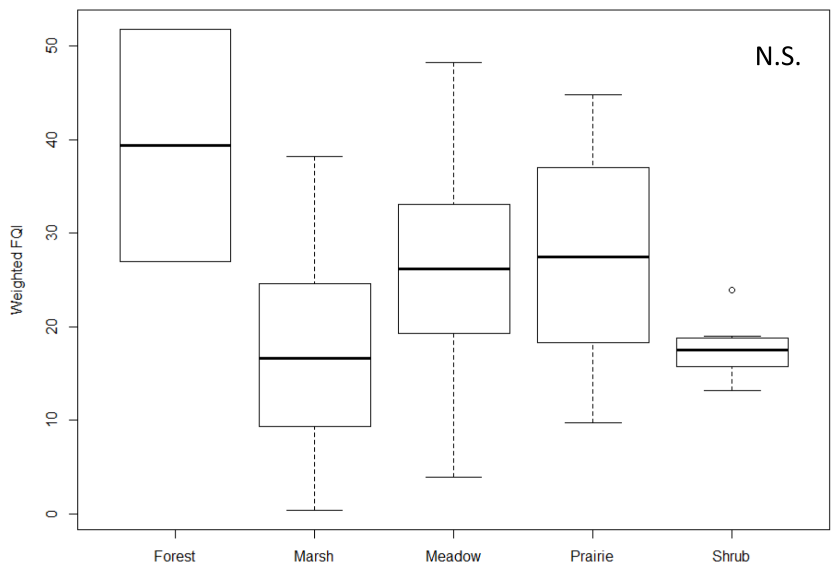


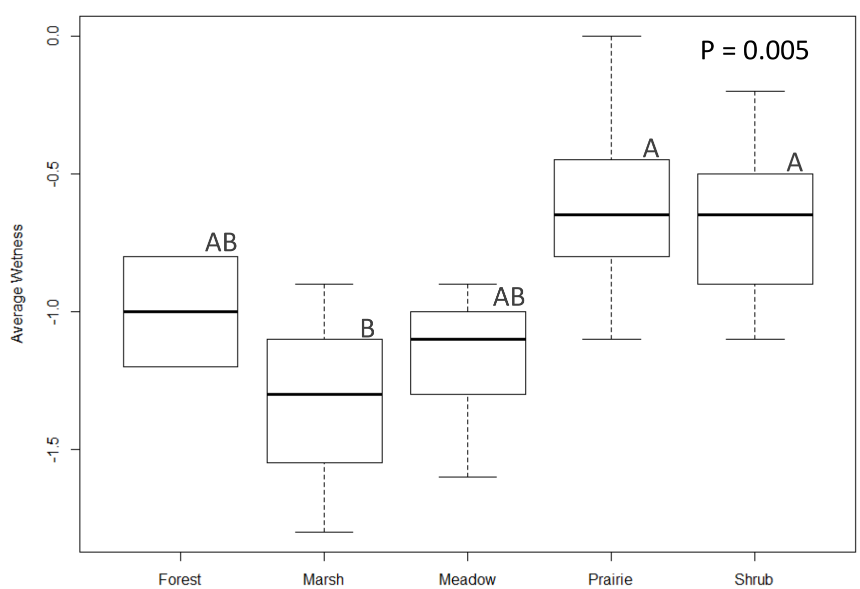




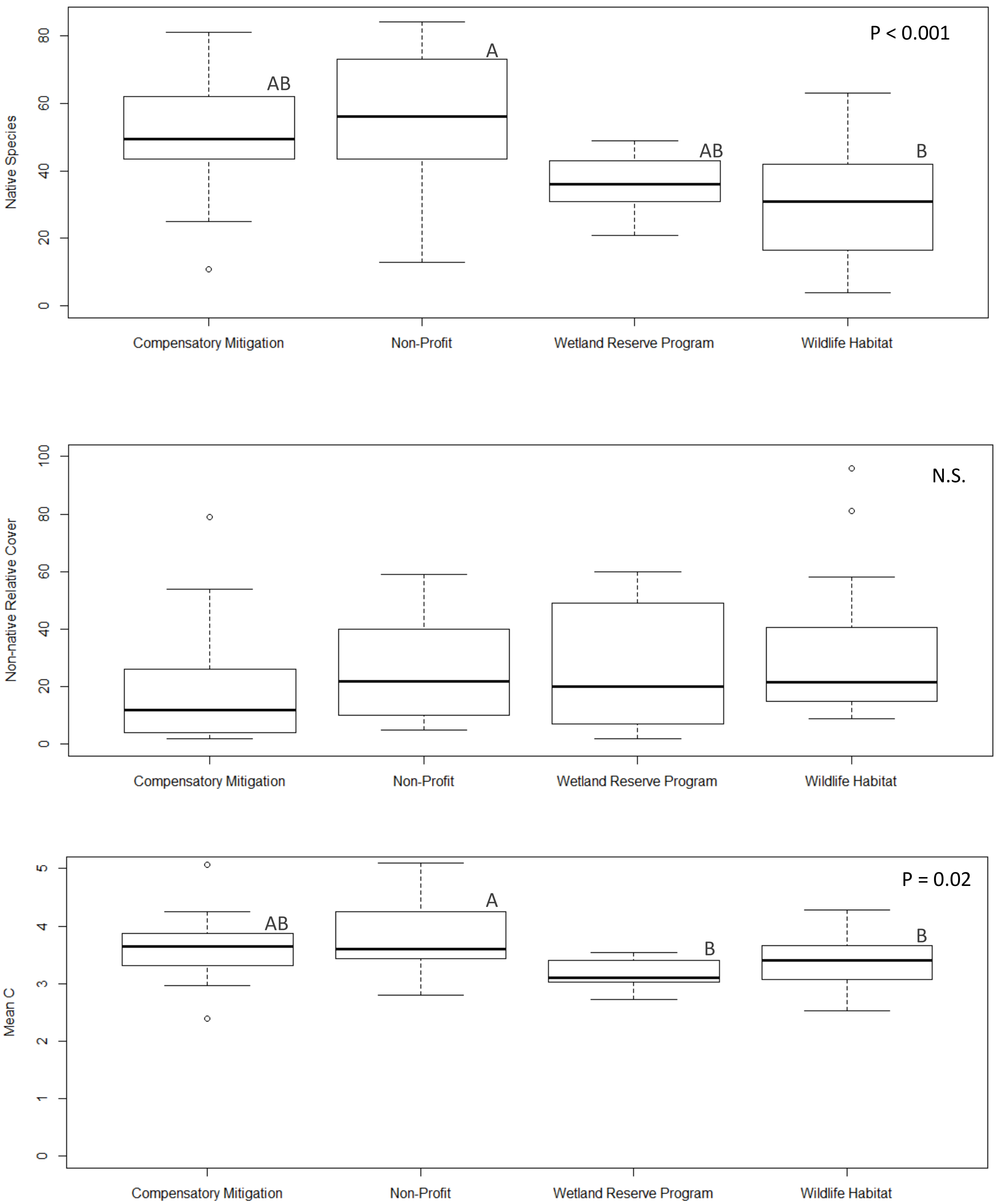
Boxplots of floristic quality metrics by **general community type**. See Tables 5 and 7 for tabular data and the results of significance testing.



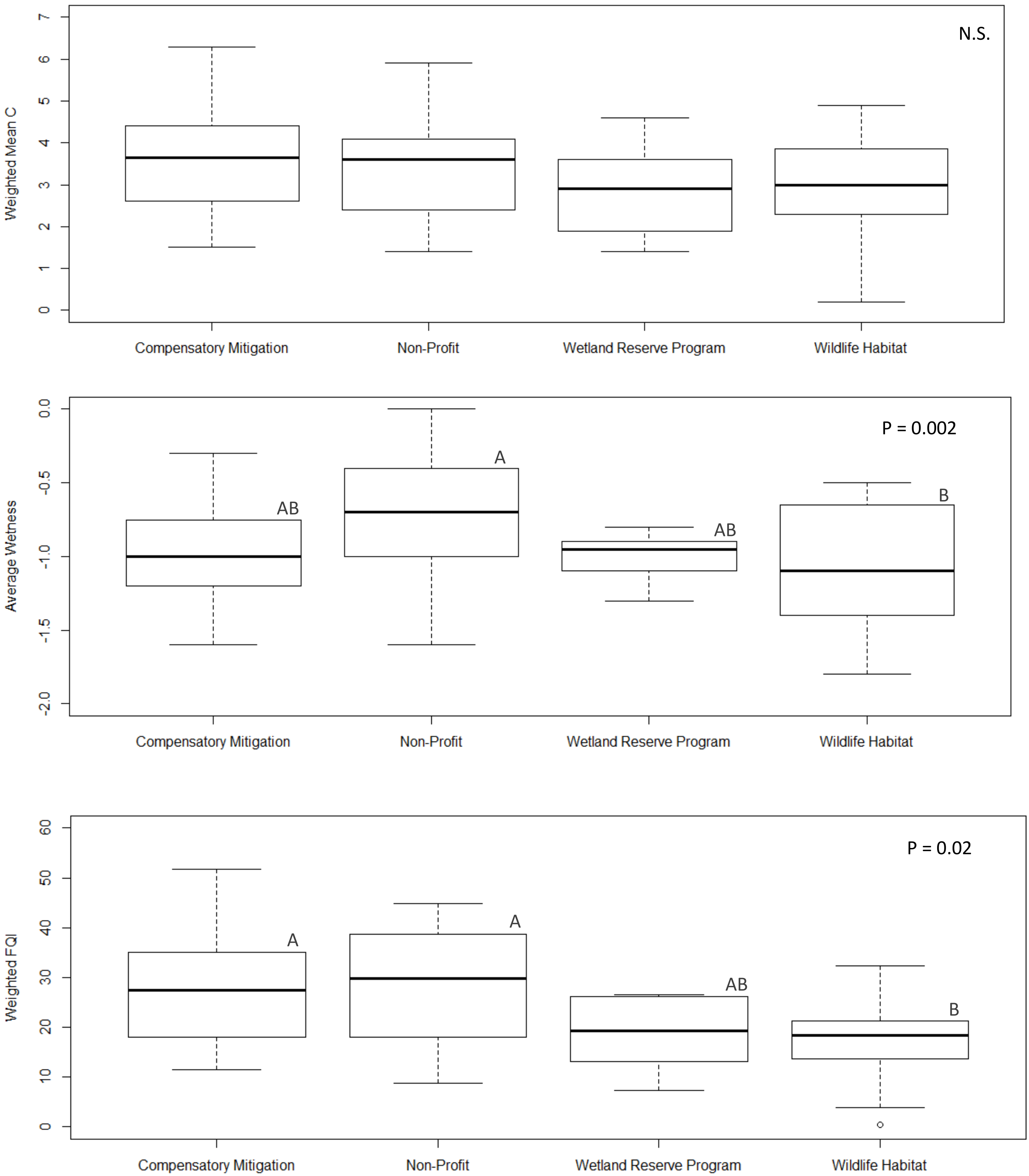




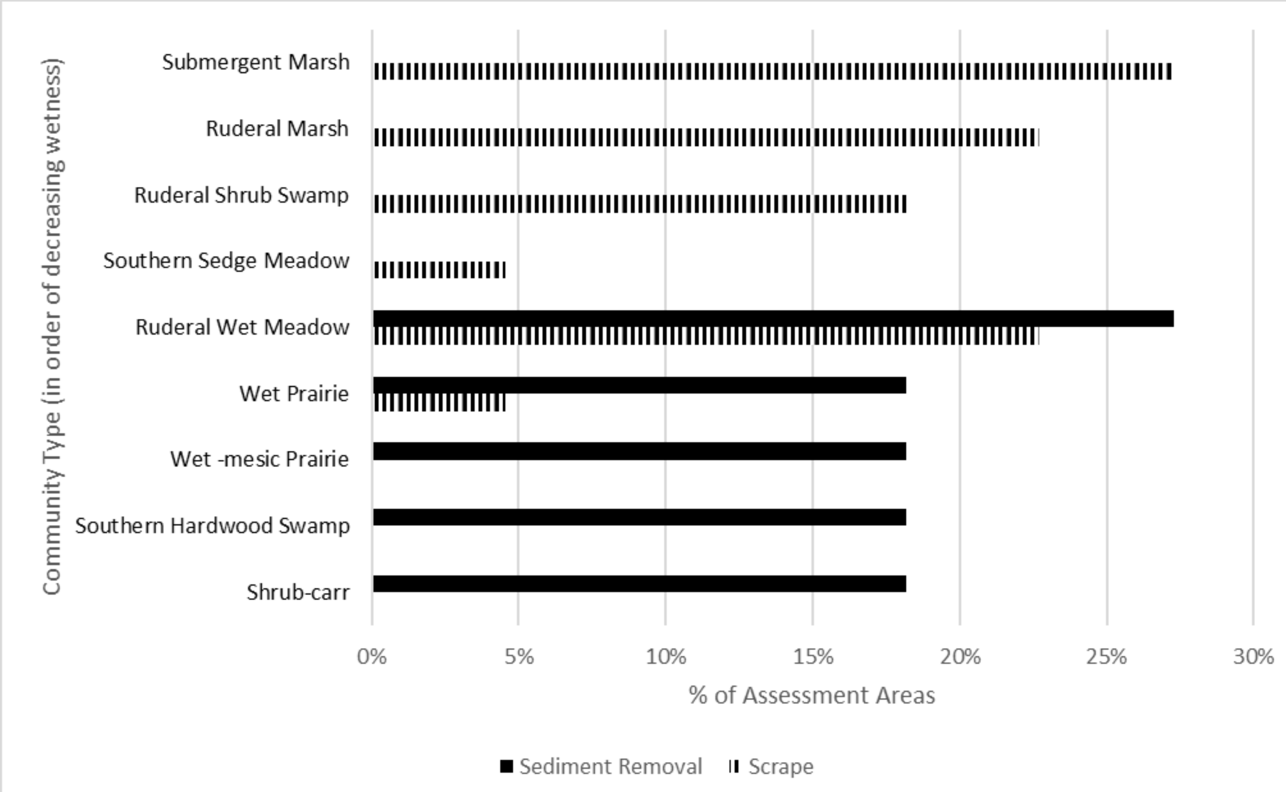
Boxplots of floristic quality metrics by **general community type**. Average Wetness = Average Wetland Indicator Score: 0 = FAC, -1 = FACW, and -2 = OBL. See Tables 5 and 7 for tabular data and the results of significance testing.



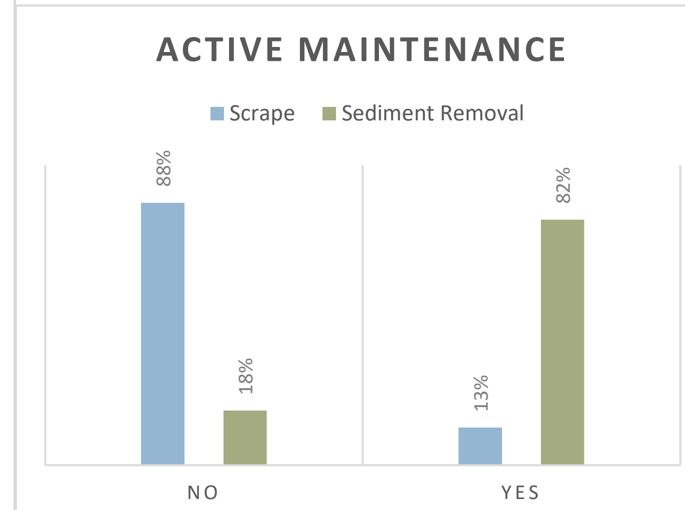
Boxplots of floristic quality metrics by **organization type**. For each boxplot the top and bottom of the box represent the 75% quantile and the 25% quantile respectively, the line in the box is the median value, the whiskers extend to the highest and lowest values, with outliers represented as dots. See Tables 5 and 7 for tabular data and the results of significance testing.

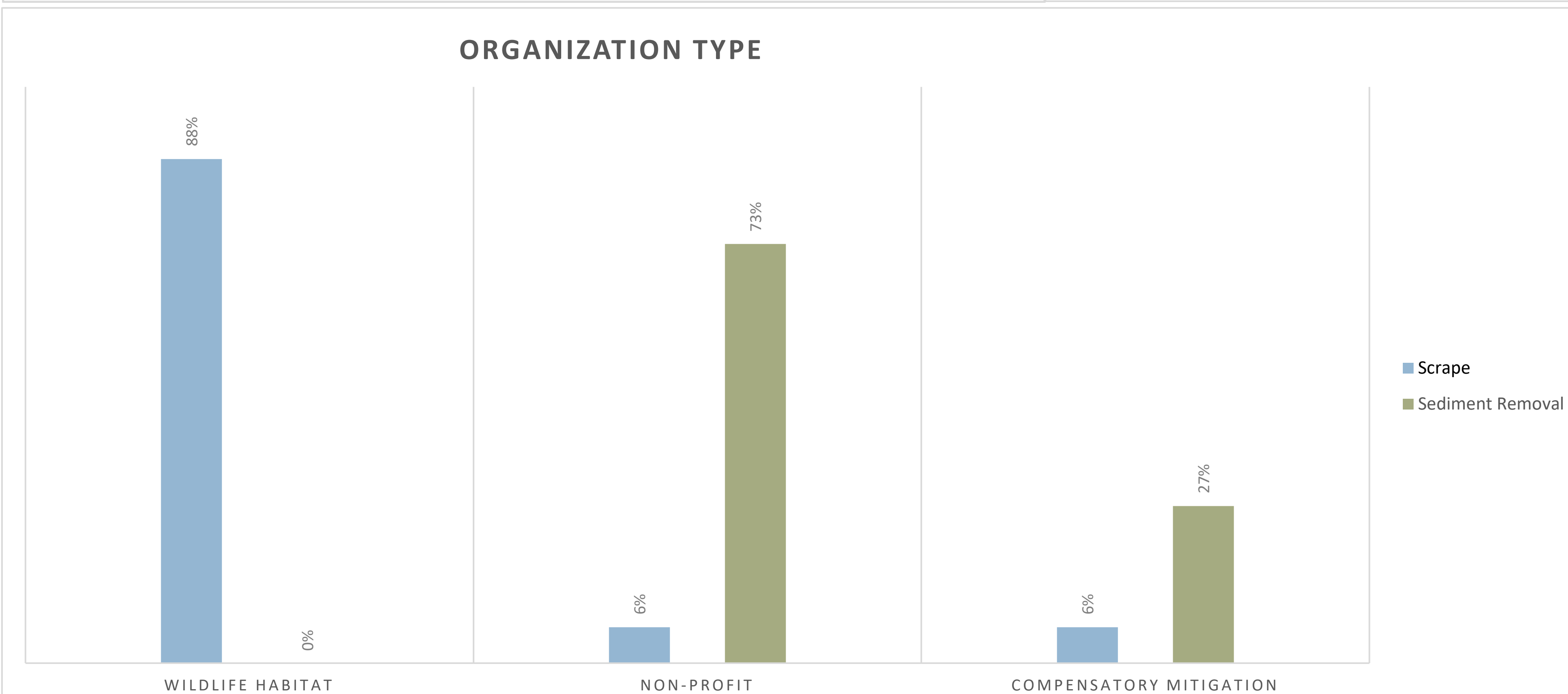


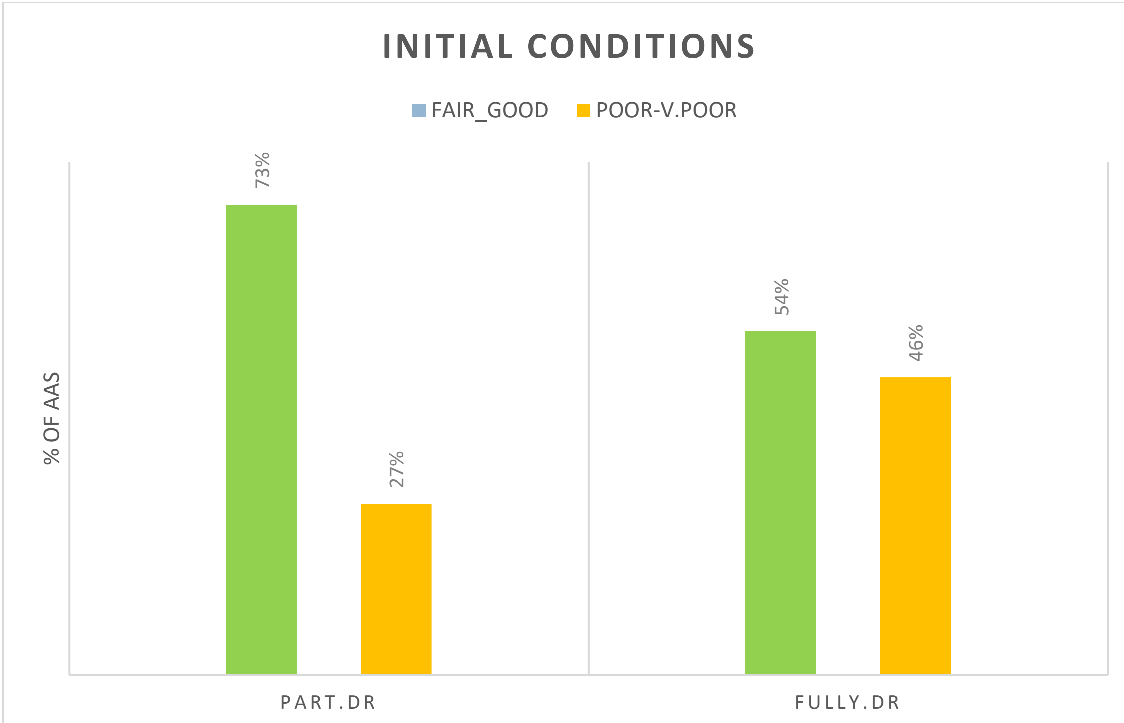
Boxplots of floristic quality metrics by organization type. For each boxplot the top and bottom of the box represent the 75% quantile and the 25% quantile respectively, the line in the box is the median value, the whiskers extend to the highest and lowest values, with outliers represented as dots. See Tables 5 and 7 for tabular data and the results of significance testing.

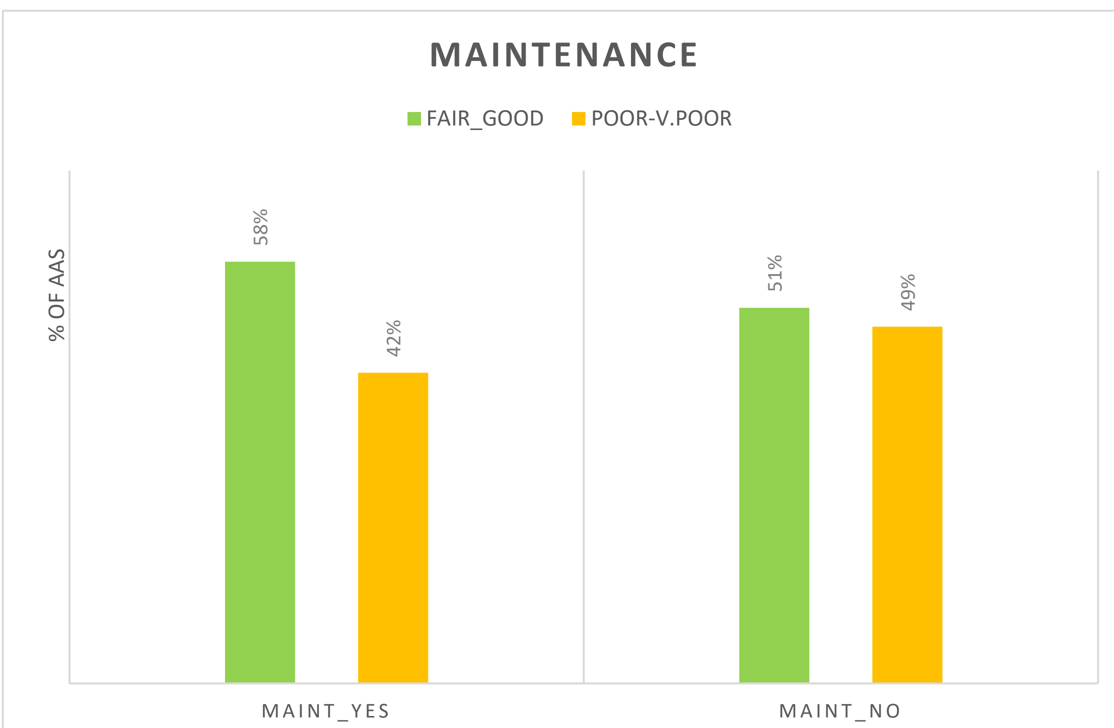


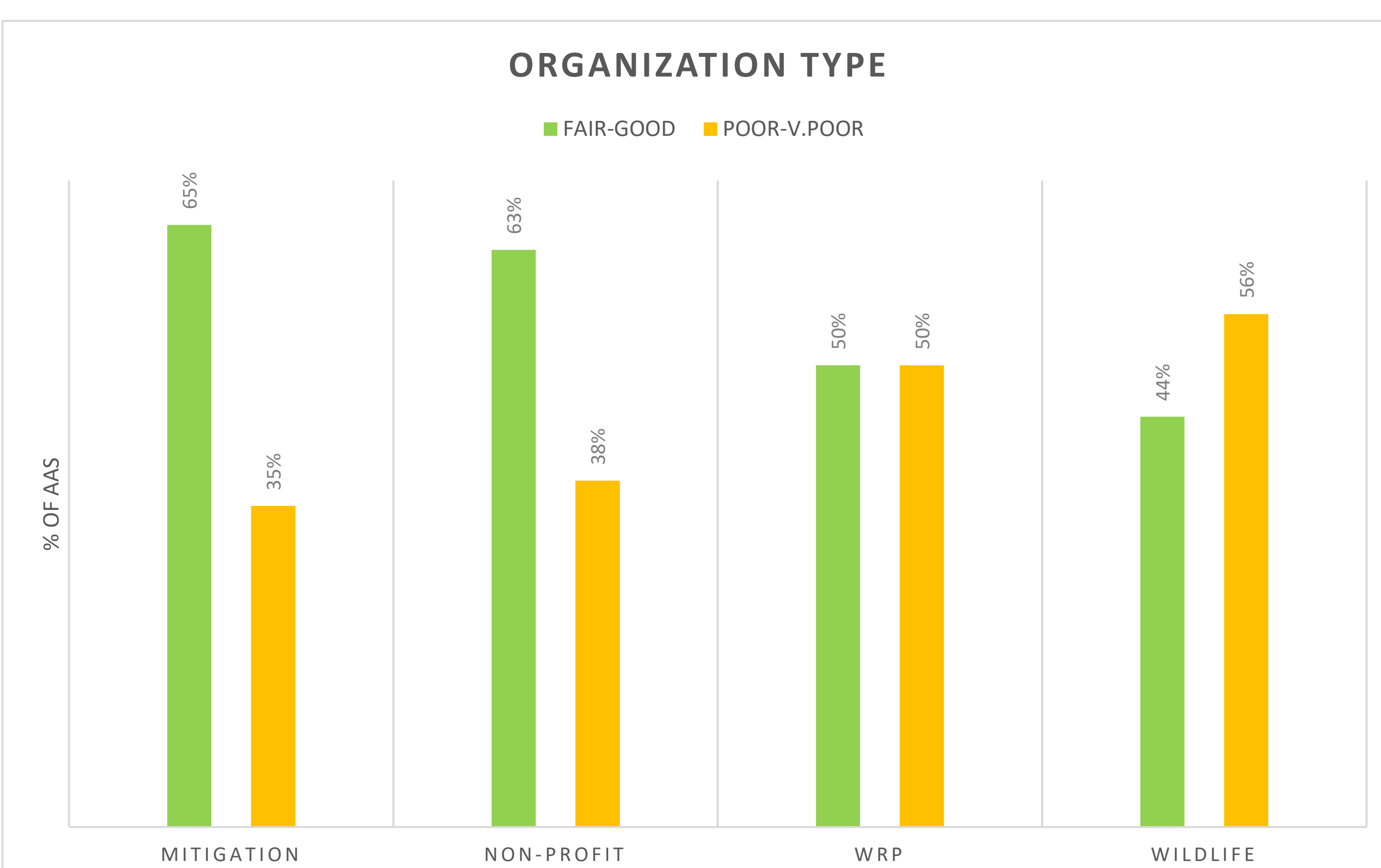
Comparisons between restorations that used Sediment Removal vs those that used Scrapes in communities restored, % of sites with active maintenance, and organization type.











Condition results with four condition tiers reduced to two: “Fair-Good” and “Poor-Very Poor” for initial condition, maintenance, and organization type. Statistically significant differences were not found between any groups in condition outcomes.

Appendix E: Preliminary Linear Mixed Effects Model Results

Mixed-effects model summaries for native species richness, non-native cover, mean C, weighted mean C (wC), and weighted FQI (wFQI) for the effects of technique, active maintenance, pre-restoration drainage, soil type, and community group. The default levels were "partial" for technique; "no" for active maintenance; "fully-drained" for pre-restoration drainage; "silt/clay" for soil type; and "meadow" for community group. N.S. indicates the factor was not significant in preliminary testing using T-Tests or ANOVA and was not included in the model. *** P< 0.001, ** P< 0.01, * P<0.05, and P<0.1, *ß* refers to the parameter estimate of the explanatory variable in the model, the *t-value* is the ratio of the estimate divided by the standard error.

	Native Species Richness				Non-native Cover				Mean C				wC				wFQI			
	ß	*Effect size*	*t-value*		*ß*	*Effect size*	*t-value*		*ß*	*Effect size*	*t-value*		*ß*	*Effect size*	*t-value*		*ß*	*Effect size*	*t-value*	
Technique Completeness	5.7	SMALL	1.02		-4.3	SMALL	-0.08		**0.29**	**MEDIUM**	**2.20**	*	0.28	SMALL	0.84		3.57	SMALL	1.25	
Active Maintenance	**17.8**	**LARGE**	**2.88**	**	-7.43	SMALL	-1.38		N.S.				0.26	SMALL	0.79		**7.05**	**MEDIUM**	**2.37**	*
Drainage Completeness	N.S.				-8.45	SMALL	-1.37		**0.37**	**MEDIUM**	**2.49**	*	**0.85**	**MEDIUM**	**2.25**	*	**5.56**	**SMALL**	**1.79**	.
Soil (Sandy)	N.S.				N.S.				**0.38**	**MEDIUM**	**2.33**	*	N.S.				N.S			
Soil (Organic)	N.S.				N.S.				**0.53**	**LARGE**	**3.39**	**	N.S.				N.S			
Community (Prairie)	6.52	SMALL	1.41		N.S.								-0.23	V. SMALL	-0.62		0.78	V. SMALL	0.27	
Community (Marsh)	**-10.43**	**SMALL**	**-1.78**	.	N.S.				N.S.				-0.49	SMALL	-1.13		**-7.21**	**MEDIUM**	**-2.04**	*
Community (Shrub)	-6.38	SMALL	-1.15		N.S.								**-0.77**	**MEDIUM**	**-1.86**	.	**-8.04**	**MEDIUM**	**-2.40**	*
Community (Forest)	-9.7	SMALL	-0.92		N.S.								1.13	LARGE	1.36		**4.81**	SMALL	**0.74**	
Fixed Effects R-Squared	37.3%				11.6%				41.4%				26.3%				41.6%			
Random Effects (Site) R-squared	29.2%				0.0%				16.9%				0.0%				8.2%			