SOIL CHARACTERISTICS BY MITIGATION TYPE AT CEDARS WETLAND COMPENSATORY MITIGATION SITE IN BATTLE GROUND, WA

by

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ABSTRACT

Soil Characteristics by Mitigation Type
at Cedars Wetland Compensatory Mitigation Site
in Battle Ground, WA

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The value of wetlands is immeasurable due to the environmental, social, and economical services provided by these ecosystems. The benefits of wetland biomes are far reaching, and heavily influence factors such as hydrology, water quality and storage, nutrient cycling, wildlife habitat, and carbon sequestration. However, wetlands are often threatened by land development, agricultural practices, population growth, and more. As a result, policies were created to ensure that these ecosystems are protected, and that unavoidable impacts to wetlands are compensated for. The Washington State Department of Transportation (WSDOT) Wetlands Program handles the mitigation of many roadway projects throughout the state to comply with standards set forth by the government to ensure a “no-net-loss” of wetlands. When wetlands are impacted, WSDOT works in various ways to mitigate losses through compensatory mitigation sites. While it is both common and efficient to measure wetland mitigation success based on vegetative indicators, studies have shown that soils tend to have a stronger influence on the functional aspects of wetland ecosystems. This thesis is a case study exploring the relationships between soil nutrient levels and different mitigation types at Cedars Wetland Compensatory Mitigation Site. The goal of this research is to investigate potential differences between restored and preserved wetland soils at this site. Soil samples from the ‘natural’ mitigation type had higher Soil Organic Matter (SOM) content, and lower Nitrate-Nitrogen (NO_3-N), Cation Exchange Capacity (CEC), and Potassium (K) compared to soils from the ‘restored’ mitigation type. Overall, this research sheds light on the soil relationships at Cedars Wetland which can foster important conversations about research and practice moving forward.

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Acknowledgements

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Soils are the building blocks of any healthy ecosystem. It all begins with soils. Soils make plant life possible by providing water, nutrients, oxygen and physical support. Healthy soils are teeming with microorganisms, such as fungi, bacteria and nematodes, as well as insects large and small. For the most part, soil fauna are beneficial, controlling plant pests, breaking down organic material and binding and biodegrading some chemical pollutants. This fauna provides a rich food source for wildlife while soil itself provides places for nests and burrows. Undisturbed soils better infiltrate stormwater, allow for greater plant root development and filter out a greater degree of chemical and organic contaminants. Our native soils were formed from a variety of parent materials derived from volcanic eruptions, glacial processes, and bedrock, weathered in place or a combination of these processes.

–Sound Native Plants, Olympia

1. INTRODUCTION

Wetlands are critical to both local and global ecological health as they provide a wealth of ecosystem functions (NRC, 2001). Despite widespread knowledge of the importance of wetlands, they continue to face ongoing threats from land-use practices, such as development and agriculture. Impacts to wetlands resulting from such practices are often unavoidable. As a result, laws have been created as an attempt to mitigate ecological degradation, requiring developers and agencies to restore and/or create wetlands elsewhere (NRC, 2001). However, wetlands have continued to decline—both in acreage and quality—revealing the potential for wetland mitigation standards to be improved (Turner et al., 2001).

The Washington State Department of Transportation (WSDOT) plays a significant role in compensatory wetland mitigation throughout the state. In compliance with federal, state, and local policies, WSDOT follows strict guidelines to compensate for loss of wetland acreage and function due to roadway development (Ballantine et al., 2011; Schafer and Ossinger, 1990). To uphold the requirements laid out in Section 404 of the U.S. Clean Water Act, WSDOT continuously seeks improvements in their commitment to 'no-net-loss of wetlands' based on adaptive management principles (Ballantine et al., 2011; Schafer and Ossinger, 1990).

WSDOT's current qualitative wetland monitoring protocols focus primarily on vegetation indicators; however, it is expressed throughout the literature that additional attributes of wetland health could contribute to our understanding of wetland restoration ecology (Ballantine et al., 2011; Karlen et al., 1997). The most notable of such attributes is soil health, often determined by levels of soil organic matter (SOM). Wetlands are unique in that they tend to function under anaerobic conditions. This allows for slow decomposition of plant and animal residues, giving wetland soils the capacity to hold a substantial amount of organic matter. Soils with higher levels of SOM are known to promote plant growth, increase water and carbon storage, improve nutrient availability, among many other critical ecosystem services (Tabatabai, M.A., 1996; Dumansky, 1994). Thus, taking a closer look at wetland soils could provide important information about the development of compensatory mitigation sites.

This research explores the relationships between mitigation type and soil quality at the Cedars Wetland Mitigation Site in Battle Ground, Washington. This nearly 43-acre site was established to compensate for both the I-5/Salmon Creek Interchange Project and the SR-502 Corridor Widening Project developed by the Washington State Department of Transportation (WSDOT Wetland Program, 2020). The site is made up of wetland establishment, wetland enhancement, and wetland preservation zones, representing three typical approaches to wetland mitigation (WSDOT Wetland Program, 2020). The primary goal of this research is to identify trends in soil nutrient metrics between created or restored wetland zones and the preserved wetland area of the Cedars Wetland mitigation site. In addition, this study has the potential to shed light on the variability of soil quality based on mitigation type. Nonetheless, this research will provide useful information to WSDOT's Wetland Program that can be used to improve future practices.

This thesis will answer the following questions: Is there a difference in soil nutrient levels between natural and created wetland zones at the Cedars Wetland mitigation site? I hypothesize that the soil samples within the wetland preservation zone (natural wetland) will contain higher levels of Soil Organic Matter (SOM) than the created or restored wetland zones. With SOM being the most critical element to soil quality in wetlands, this outcome would essentially provide evidence that the natural wetland section of the site contains healthier soils. Furthermore, I also predict that there will be differences in other soil nutrient attributes between the natural and created/restored zones. Eight soil nutrients important to wetland ecology will be used in statistical analyses to test this hypothesis: Soil Organic Matter (SOM), Cation Exchange Capacity (CEC), Phosphorus (P1 Weak Bray), Phosphorus (P2 Strong Bray), Nitrate-Nitrogen ($N0_3$-N), Potassium (K), Soil pH, and Sulfur (S). I will also ask whether these soil attributes vary based on both sample location and Cowardin type (e.g., emergent wetland, scrub-shrub wetland, forested wetland, and wetland buffer).

2. LITERATURE REVIEW

2.1 Introduction

The Washington State Department of Transportation (WSDOT) plays a significant role in wetland mitigation throughout the state. In compliance with Section 404 of the Clean Water Act (EPA, 2022) WSDOT follows strict guidelines to protect Washington's wetlands. As of 2023, WSDOT is responsible for 87 different compensatory wetland mitigation projects from the time of site construction to site closeout. These sites comprise of a total of 918 acres of wetland actively managed by WSDOT staff (WSDOT, 2023). Being the largest holder of wetlands in the State of Washington, WSDOT continuously seeks out potential improvements to their Wetlands Program (Bell, 2012).

The following section will discuss the importance of wetlands and their associated functions. Next, I will provide a background of compensatory wetland mitigation as well as current trends in monitoring. The final section will look at the importance of wetland soil health, with a specific focus on soil organic matter (SOM).

2.2 Importance of Wetlands

Wetlands are highly important ecosystems which provide a vast array of valuable ecosystem functions essential to the dynamics of hydrology, water quality, wildlife habitat, vegetative growth, carbon storage, and more (Novitzki et al., 1999). As a result, the benefits of wetland ecosystems reach far beyond the wetland itself. Wetlands have a positive influence on hydrology as they have the capacity to hold large amounts of water, reducing the risk of flooding in nearby upland environments (NRC, 2001). Without these areas for water storage provided by wetlands, local communities, infrastructure, and non-hydrophytic vegetation are put in jeopardy. Furthermore, wetlands are critical to water quality. They maintain a healthy cycle for both the removal and retention of nutrients and sediments by capturing surface runoff as well as processing containments, which provides a natural system for water purification (Novitzki et al., 1999). Not only does this impact healthy drinking water for humans, but these processes also offer the necessary elements of wildlife habitat for a variety of animal species (Novitzki et al., 1999).

In addition to the hydrologic benefits of wetland ecosystems, wetland soils play a significant role as well. These soils not only contribute to nutrient cycling and water infiltration, but healthy wetland soils also promote plant growth. With slow decomposition of plant and animal residues, Soil Organic Matter (SOM) builds up below ground. The high levels of organic material within wetland soils are a major factor in the productivity of vegetation in these ecosystems (EPA, 2008; Xu et al., 2019). In turn, these plants can thrive and provide adequate food resources to wildlife. Wetlands also perform as a massive carbon sink through slow rates of decomposition, which decreases the output of CO2 to the atmosphere (Reddy and DeLaune, 2008; Xu et al., 2019). For all these reasons, as well as those not mentioned above, it is crucial that wetland loss is either avoided or compensated to maintain the wealth of ecosystem values they provide.

2.3 Compensatory Wetland Mitigation & Monitoring

Compensatory wetland mitigation has been used as a solution to prevent wetland loss in circumstances when avoiding or minimizing impact is not possible (Schafer and Ossinger, 1990). This practice dates back to 1972, when Section 404 of the Clean Water Act was enacted, requiring a permit for "…the discharge of dredged and fill material into the waters of the United States, including wetlands." (EPA, 2015). Under Section 404 of the Clean Water Act, permitted projects must either restore, establish, enhance, or preserve wetlands to replace the functions and characteristics lost due to land-use change (EPA, 2022). The Washington State Department of Transportation (WSDOT) has therefore established a five-step mitigation sequence to guide the planning process of projects of potential wetland impact: Avoid, minimize, restore, compensate, and monitor results (Schafer and Ossinger, 1990).

Previous studies have investigated how wetland mitigation practices can be improved, by examining the ways in which their success is evaluated (Kentula, 2000; Race and Fonseca, 1996; Stapanian et al., 2013; Matthews and Endress, 2008; Windham et al., 2004; Hossler et al., 2011; Xu et al., 2019). For example, Kentula (2000) expresses the importance of looking beyond compliance success to incorporate functional and landscape success. This would require putting more emphasis on the functional attributes of wetland health indicators to balance the heavy focus on structural elements (e.g., vegetation metrics) common in such project evaluations (Stapanian et al., 2013). Furthermore, Hossler et al. (2011) explain that current methods in wetland mitigation are not sufficient in meeting no-net-loss requirements of the Clean Water Act due to the absence of nutrient-related metrics in wetland monitoring. If this is the case, it would mean that wetland mitigation is falling short of its purpose, and the loss of wetland ecosystems will continue if adjustments are not made.

Wetland mitigation projects in Washington are evaluated by wetland biologists at WSDOT along a site-specific timeline. Sites are monitored for three to ten years, with each year associated with either qualitative or quantitative methodologies (Horner and Raedeke, 1989). Common practice in wetland mitigation monitoring relies heavily on vegetation metrics to evaluate the success of a mitigation site, reinforced by meeting benchmarks and/or thresholds in specified performance standards (Kentula, 2000). While vegetation is an important indicator of site development, it is possible that such a focus overlooks other significant aspects of wetland health (e.g., soil composition). Establishing and monitoring indicators of ecosystem health is recommended by Bentley et al. (2022) to better understand the effectiveness of wetland restoration. As a result, without sufficient measures to consider all aspects of wetland development, we cannot realistically determine the integrity of the ecosystem.

When sites fail to pass performance standards, it is often difficult to identify the reason. Kentula (2000) offers that a more holistic approach to wetland mitigation monitoring would reveal critical information to better understand site progress and identify necessary actions to reach project goals (p. 199). Because of the importance of proper soil composition to wetland development, it is possible that the culprit lies within the soils. However, without proper measurement, it is impossible to know for sure. In addition, without performance standards for soil properties, soil health tends to receive little attention throughout the mitigation process (Ballantine et al., 2011). Ballantine et al. (2011) speculate that by including soil standards in wetland mitigation monitoring, "…projects will be encouraged to incorporate techniques that have been shown to improve soil properties at similar sites.". Such techniques could potentially increase success in meeting vegetative parameters as well, initiating a feedback loop to improve wetland mitigation from start to finish.

Bergdolt et al. (2005) evaluated compliance of WSDOT wetland mitigation sites and found that only one site out of thirty met all performance standards, while a handful of sites had "significant shortfalls". Furthermore, their analysis showed that, out of 173 total performance standards across all sites, only 96 were met (Bergdolt et al., 2005). Authors hypothesize that factors such as site selection, site design, site maintenance, and permit requirements could explain the deficits (Bergdolt et al., 2005). In this regard, there is a chance that soils could be connected to any or all of the potential reasons stated in their study.

When investigated quantitatively, researchers have found soil organic carbon content to be a significant indicator of overall wetland health (Hossler & Bouchard, 2010; Hossler et al., 2011). Wetland soils generally hold high amounts of soil organic matter, as slow decomposition takes place under the anaerobic conditions typical of wetlands (Ballantine et al., 2011). Sufficient nutrient cycling within wetland ecosystems depends on such characteristics, and without the cycling of nutrients, plants will have a difficult time establishing on the landscape (Ballantine et al., 2011). As stated by Ballantine et al. (2011), Soil Organic Matter is essential to the development of vegetation, as it contains many of the critical soil properties necessary to vegetative growth (p. 1483). In their study, Ballantine et al. (2011) uncover the differences between restored and created wetlands. The results from this research provide evidence supporting the idea of incorporating soil-based criteria into performance standards, alongside vegetative requirements (Ballantine et al., 2011). Similarly, Xu et al. (2019) express that there seems to be a knowledge gap pertaining to patterns of Soil Organic Carbon in restored wetlands (p. 89). Filling this gap could potentially improve overall management practices of wetland mitigation sites. Thus, quantifying Soil Organic Carbon at wetland sites monitored by the Washington State Department of Transportation could provide useful information about site progress and could help illustrate the importance of soil quality in the development of wetland mitigation projects (Hossler & Bouchard, 2010; Stalnaker, 2015).

2.4 Wetland Soils

Most wetland mitigation project plans in the United States tend to base site success primarily on vegetation development, however, it is worth noting that soils are the foundation of all wetland plants. Thus, soil quality is likely to influence the overall development of wetland mitigation sites – in both the ecosystem functions of the wetland and the metrics used to determine success in meeting performance standards. As defined by the U.S. Environmental Protection Agency (U.S. EPA, 2008), soil quality is "…the capacity of the soil to function within ecosystem boundaries and to sustain biological productivity, maintain environmental quality, and promote plant and animal health." (p. 23). Stapanian et al. (2013) elaborate on this idea, stressing that hydric soils are essential to the establishment and survival of wetland vegetation. Furthermore, compensated wetlands are intended to fulfill both wetland characteristics and wetland functions (Bergdolt et al., 2005; Schafer and Ossinger, 1990). Ballantine et al. (2011) explain that wetlands rely on soil processes to satisfy ecosystem functions and thus, criteria for soil should have a place in the goals, design, and construction of compensatory wetland mitigation sites. Therefore, it could be worth exploring the soil composition of WSDOT's wetland mitigation sites alongside annual performance standard results to understand how soil quality relates to overall site success.

A large number of studies have demonstrated that the percentage of Soil Organic Matter (SOM) in restored wetlands is a reliable indicator of soil health (Stapanian et al., 2013; Brown and Norris, 2017; Bentley et al., 2022; Stalnaker, 2015; Karlen et al., 1997; Ballantine et al., 2011; Bruland and Richardson, 2006; Ahn and Jones, 2013; Hossler and Bouchard, 2010; Craft et al., 2003; Windham et al., 2004; Ossinger, 1989). Although there are many other components indicative of wetland soil health (Stapanian et al., 2013; Bentley et al., 2022), limited resources often hinder the ability for agencies to test for all relevant characteristics of healthy hydric soils. Accordingly, testing for SOM content could prove to be a perfect starting point for incorporating soil analysis into WSDOT's quantitative monitoring process.

Microorganisms consume carbon compounds within the soil organic material at a slow rate in wetlands due to the anaerobic and saturated conditions typical of these ecosystems

(Anderson and Davis, 2013; Bell, 2012). This gradual decomposition results in rich organic soils in various stages of decomposition and high amounts of SOM (Ahn and Jones, 2013; Anderson and Davis, 2013; NRC, 2001). The ability of wetland soils to perform essential ecosystem functions, such as water storage and nutrient cycling, is reliant on a sufficient level of SOM content (Ahn and Jones, 2013; Bruland and Richardson, 2006; NRC, 2001). Studies show an increase in SOM when organic soil amendments are used in wetland restoration projects (Ballantine et al., 2011), which has the potential to improve overall success. Monitoring the development of SOM at WSDOT's mitigation sites would therefore provide insight to decision-makers about the effectiveness of the current efforts to improve soil quality and demonstrate if there is a need to alter practices in the future.

Unlike wetland vegetation development, soil processes in restored and created wetlands may take 10 or more years to perform the critical functions found in natural wetlands (Brown and Norris, 2017; Stapanian et al., 2013; Bruland and Richardson, 2006; Ahn and Jones, 2013). This is likely the reason behind the focus on vegetation metrics in compensatory wetland monitoring, as typical mitigation projects are evaluated on timescales of 5-10 years. However, when sites fail to meet vegetative performance standards, it can be difficult to pinpoint the cause behind the lack of vegetation development. Coupling these results with quantitative soil data would give WSDOT a more holistic understanding of why sites are failing to meet standards, and thus, make more informed decisions about ongoing site maintenance. Furthermore, this knowledge would invite conversation about the importance of wetland soil health, which could lead to improvements in construction practices for future mitigation projects.

3. METHODOLOGY

The purpose of this research is to establish an experimental design for evaluating soil health at wetland mitigation sites monitored by the Washington State Department of Transportation's (WSDOT's) Wetlands staff. Additionally, the data collected through this study can be used as baseline conditions to track soil development over time. 21 soil samples were collected at Cedars Wetland over the span of two days, covering all mitigation zones as well as all Cowardin Types. These samples were tested for a variety of soil nutrients at Midwest Laboratories. Soil properties included in analyses include Soil Organic Matter (SOM), Cation Exchange Capacity (CEC), Phosphorus (P1 Weak Bray), Phosphorus (P2 Strong Bray), Nitrate-Nitrogen ($N0_3$), Potassium (K), Soil pH, and Sulfur (S) as indicators of soil function important for wetland ecosystems.

3.1 Site Selection

Monitoring reports from 2019-2022 were used to gather basic information about WSDOT's wetland mitigation sites. Sites that had gone through at least ten years of monitoring were then investigated for additional details surrounding mitigation type, size, and ecological zones. The potential site needed to include the following mitigation types to be considered for this study: Wetland Establishment, Wetland Enhancement, and Wetland Preservation. This narrowed down options to just two wetland mitigation sites: Charles E. Plummer (15 acres) and Cedars Wetland (42.95 acres). Based on recommendations from WSDOT Wetlands staff as well as size considerations, Cedars Wetland was selected for the location of this research.

The Cedars Compensatory Wetland Mitigation Site is in the Salmon Creek watershed located just east of the Hockinson area in Clark County, WA (Figure 1). This project was intended to compensate for wetland impacts resulting from the I-5/Salmon Creek Interchange project (NWS-2010-185) and the SR 502 Corridor Widening project (NWS-2009-1093). Cedars Wetland was established to replace several wetland functions lost through construction of these projects, such as wildlife habitat, water quality, headwaters storage, and flood flow attenuation (WSDOT, 2019).

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 1. *Cedars Compensatory Wetland Mitigation Site (image from WSDOT, 2019).*

The site is distinguished by five different ecological zones: Emergent Wetland, Scrub-shrub Wetland, Forested Wetland, Upland Buffer, and Wetland Preservation (Figure 1). The 17.46 acres of Wetland Preservation serve as reference conditions for this site. Stratified random sampling was used to designate four sample locations in each zone, with a total of 20 samples throughout the site.

3.2 Soil Samples

The Cedars Wetland mitigation site was mapped using ArcGIS Pro, with polygons symbolized by ecological zone (Figure 2). Sample point locations were designated within each polygon type using the Create Random Points tool to generate points in each zone. Additionally, a 10ft buffer was made around each sample point, delineating the area in which the soil samples would be collected from. A schema was designed in ArcGIS pro to collect additional qualitative data at each sample point (i.e., dominant plant species, cover estimates, wildlife indicators, etc.). A FieldMaps app was created from this dataset for more efficient and accurate data collection as well as offline navigation.

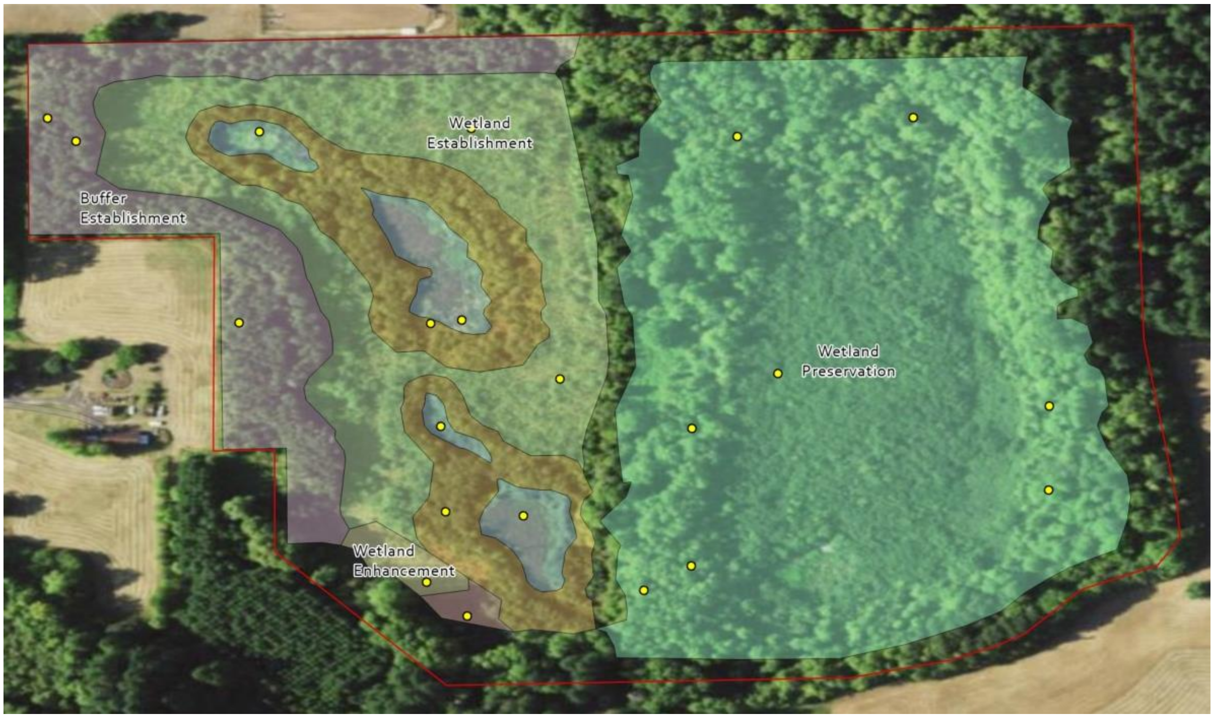

Figure 2. Site map of Cedars Wetland.

Wetland Establishment zones are seen on the left, including Buffer Establishment, Wetland Establishment, and Wetland Enhancement, while the wetland preservation zone is shown on the right. The colors of each polygon represent the various Cowardin Types present at this site: Upland Buffer Establishment (purple), Forested Wetland Establishment (light green), Scrub-Shrub Wetland Establishment (orange), Emergent Wetland Establishment (blue), Forested Wetland Enhancement (yellow), Scrub-Shrub Wetland Enhancement (pink), and Forested Wetland Preservation (dark green).

Prior to entering the field, labels acquired from Midwest Labs were attached to each soil sample bag with their respective sample location identifiers. Each bag was provided with an additional bag, which would be used as an extra layer of protection of the soil. Roughly 10-15 soil samples were collected at each sample point radius using a ¾" soil corer at 20cm depth. Soil samples were double-bagged and later transferred to a cooler until transported to refrigeration and prepared for delivery to Midwest Labs. Each sample was then dried for 24 hours before being put back into bags. Lastly, soil samples were shipped to Midwest Laboratories in Omaha, Nebraska to await analysis of soil nutrients.

Soil samples were sent to Midwest Lab for analysis of various soil properties included in their S3C package. The soil nutrients tested were Organic Matter, Available Phosphorus (P1 Weak Bray and P2 Strong Bray), Exchangeable Potassium, Magnesium, Calcium and Hydrogen, Soil pH, Buffer Index, Cation Exchange Capacity, Percent Base Saturation of Cation Elements, Nitrate-Nitrogen, Soluble Salts, Sodium, and Excess Lime, Sulfur, Zinc, Manganese, Iron, Copper, and Boron (Midwest Laboratories, 2024). This package is recommended for sites not previously sampled. Not all soil nutrients listed were used in this analysis, however, all results will be passed along to WSDOT's Wetlands Program and may be used in future research.

Results were received from Midwest Laboratories for the 21 sample points throughout the Cedars Wetland mitigation site shortly thereafter via their online portal. Samples 1-13 were obtained from the Wetland Establishment, Buffer Establishment, and Wetland Enhancement areas of the site. These points are collectively grouped as the *restored* wetland samples for statistical analyses. The restored wetland portions of the mitigation sites include four wetland classes, based on their associated Cowardin type (Cowardin et al., 1979). These zones are designated as Emergent Wetland, Scrub-Shrub Wetland, Forested Wetland, and Upland Buffer. Each of these wetland creation sample points are situated on the western side of the mitigation site. Samples 14-21 were collected from the Wetland Preservation section of the site and are categorized as the *natural* wetland samples. The Wetland Preservation zone was observed to be of the Forested Wetland type. All Wetland Preservation samples were collected from the eastern portion of Cedars Wetland.

3.3 Data Analysis

Laboratory soil nutrient results were analyzed to explore relationships between soil properties and mitigation type (natural or created/restored). Eight soil nutrients were used in this analysis: Soil Organic Matter (SOM), pH, Sulfur (S), Potassium (K), Cation Exchange Capacity (CEC), Phosphorus P1 (weak bray), Phosphorus P2 (strong bray), and Nitrate (NO_3). Using the *vegan* package (Oksanen et al., 2022) in R (R Core Team, 2023), the ordination method 'nonmetric multidimensional scaling' (NMDS) was used with a site x soil properties matrix to examine associations between mitigation type and soil property metrics. The function *metaMDS* in *vegan* uses Bray-Curtis dissimilarity (Oksanen et al., 2022). An analysis of similarity (ANOSIM) was also performed on the ordination results to test for significant differences in soil properties between natural and created/restored sites, with p-values calculated by a permutation test (Oksanen et al., 2022).

4. RESULTS

Soil nutrient levels for the 21 soil samples were obtained from Midwest Laboratories. Eight soil properties known to be important to wetland soils, namely Soil Organic Matter (SOM), P1 Phosphorus (Weak Bray), P2 Phosphorus (Strong Bray), Potassium (K), soil pH, Cation Exchange Capacity (CEC), Nitrate-N (FIA), and Sulfur (S) were used in this analysis (Table 1, also see Appendix).

Table 1. Results from Midwest Laboratories for eight soil nutrients: Soil Organic Matter (OM), P1 Phosphorus (P1), P2 Phosphorus (P2), Potassium (K), Soil pH (pH), Cation Exchange Capacity (CEC), Nitrate-Nitrogen (NO3-N), and Sulfur (S).

SAMPLE ID	OM (%)	P1 (ppm)	P2 (ppm)	K (ppm)	pH	CEC	NO3-N (ppm)	S (ppm)
1	7.7	39	78	149	5.6	13.8	4	12
2	6	31	51	138	5.7	11.7	10	9
3	5	27	54	144	5.7	12.8	23	12
4	2.7	11	27	191	5.8	11	11	20
5	4.7	34	83	119	5.3	11.9	26	31
6	5.1	45	76	237	5.7	13	11	12
7	2.4	10	50	196	5.9	11.1	7	34
8	4.6	29	72	165	5.4	11.5	10	29
9	9.4	39	89	182	5.6	13.1	5	16
10	6.5	32	53	211	5.3	13.2	15	15
11	7.1	28	42	193	5.4	12.3	12	15
12	5.4	18	47	153	5.3	14.3	2	30
13	6.8	27	53	159	5.4	11.6	13	20
14	4.9	18	23	96	4.8	8.6	3	24
15	8.1	30	37	88	4.9	6.5	1	17
16	12.2	14	19	100	5.1	8.7	1	12
17	20.6	84	123	24	5.2	2.9	1	9
18	13.6	14	21	80	5.3	8.1	1	10
19	13.8	23	32	45	5.1	4.5	1	10
20	15.8	19	22	74	4.9	4	1	13
21	13.2	27	50	43	5.1	3.1	1	9

These laboratory results of soil characteristics at Cedars Wetland reveal distinct patterns between mitigation type and nutrient level (Figures 3-4).

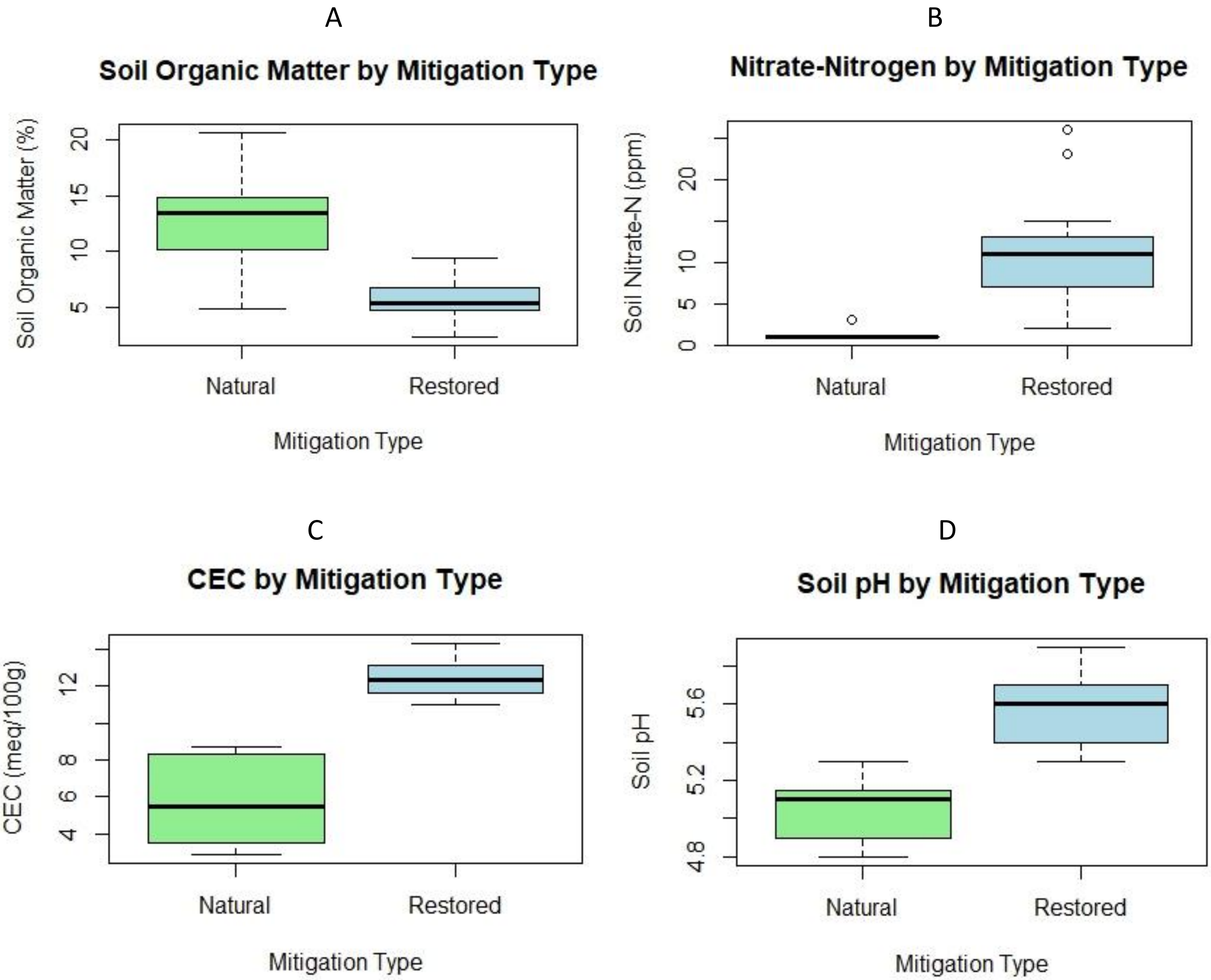

Figure 3. *Boxplots of soil nutrients by mitigation type (Natural n = 8, Restored n = 13): Soil Organic Matter (A), Nitrate-Nitrogen (B), Cation Exchange Capacity (C), and Soil pH (D)*

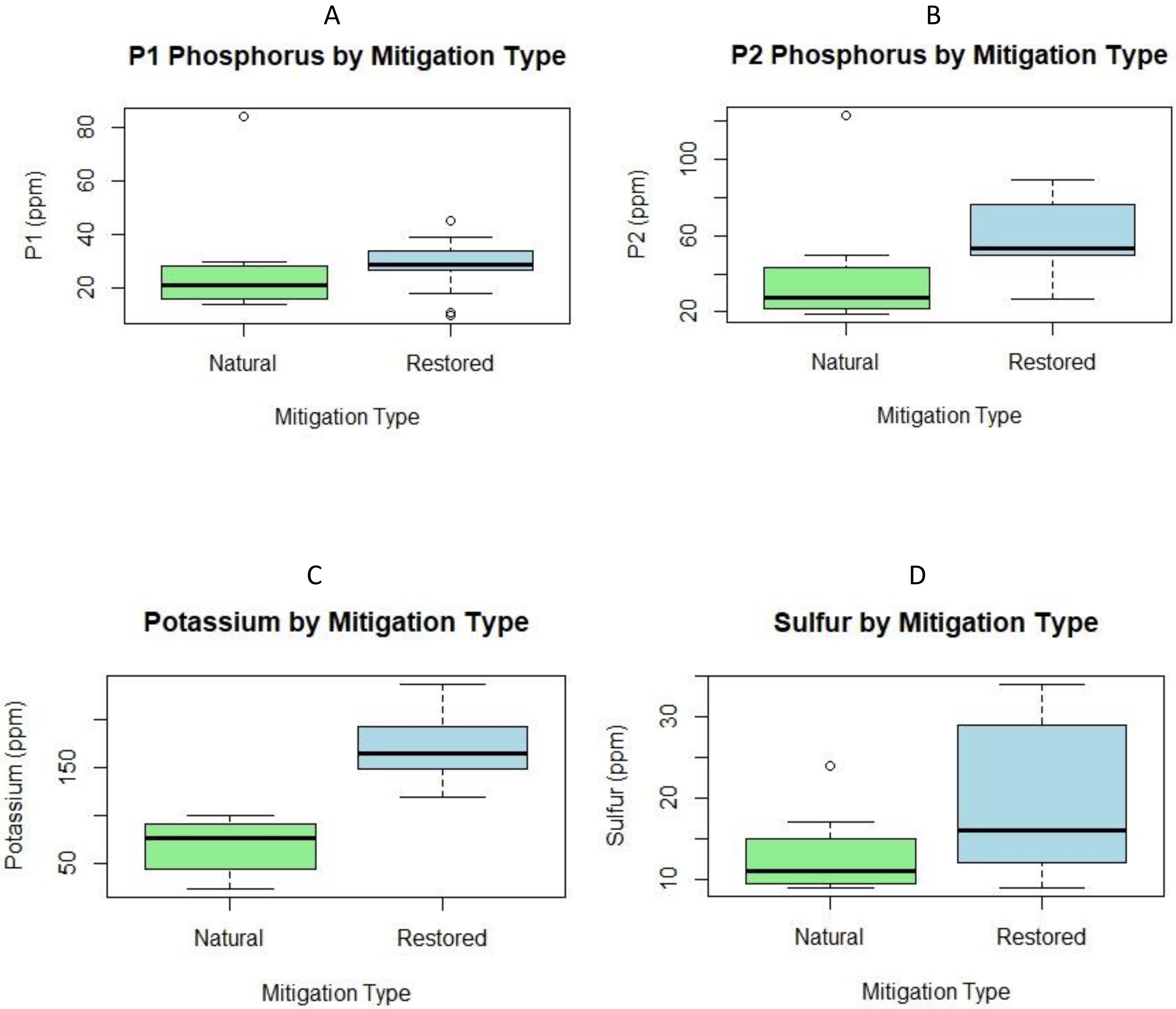

Figure 4*. Boxplots of soil nutrients by mitigation type(Natural n = 8, Restored n = 13): P1 Phosphorus (A), P2 Phosphorus (B), Potassium (C), and Sulfur (D).*

The NMDS ordination was appropriate for the soil properties data (stress = 0.077, R^2 = 0.978, Figure 5). Soil properties (the ordination included SOM, P1, P2, K, pH, CEC, NO_3-N, and S) of natural and restored sites are significantly different (Figure 6, ANOSIM, $p < 0.001$). Negative values on the NMDS1 axis are strongly correlated with soil organic matter (Figure 7) and are more strongly associated with the natural wetland soil samples. Samples collected from the natural wetland mitigation portion of the site generally had higher percentages of SOM compared to the wetland creation points (Figure 3A). Positive values of NMDS1 are more strongly associated with Cation Exchange Capacity, Nitrate-Nitrogen, and Potassium (Figures 6-7), with higher levels of those properties in the wetland creation soil samples (Figures 3-4). The strongest correlations of individual soil properties are found with the NMDS1 axis (Figure 7), but both phosphorus metrics (P1 and P2) are negatively correlated with NMDS2 (Figure 7).

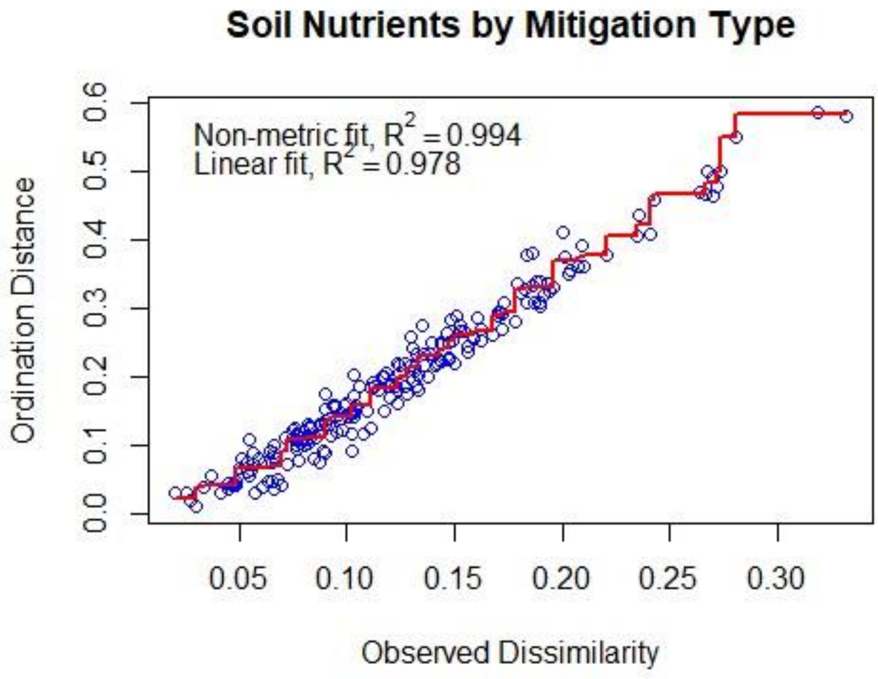

Figure 5. *Stress plot of NMDS ordination (8 soil properties in 21 soil samples, stress = 0.077)*

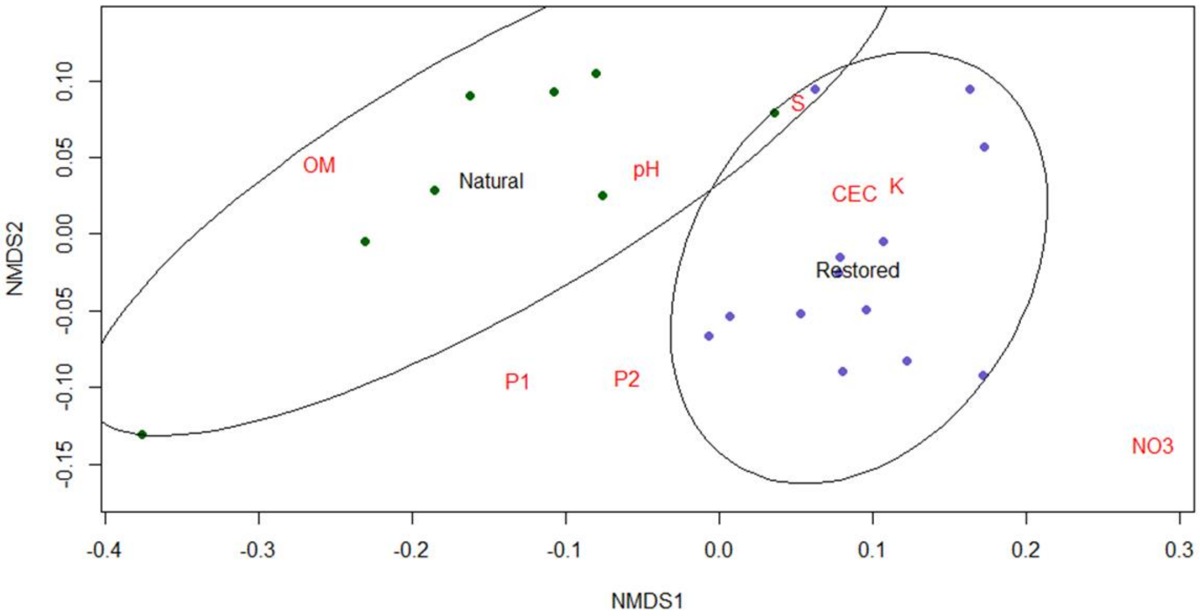

***Figure 6**. NMDS ordination results. Points are individual soil samples in natural (n = 8) and restored (n = 13) mitigation types, and the 8 soil properties are labeled in red.*

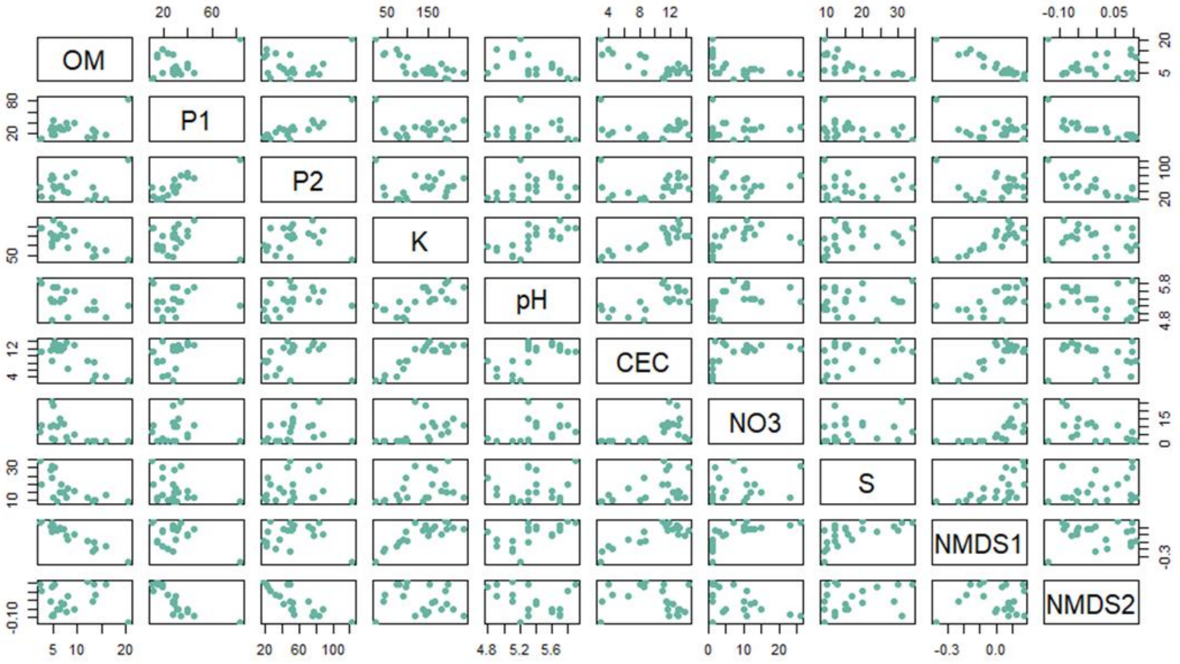

***Figure 7.** Correlation plots of 8 individual soil properties and NMDS1 and NMDS2 score.*

5. DISCUSSION & CONCLUSION

This research is an early step into exploring the benefits of soil monitoring as an additional aspect of quantitative wetland monitoring methodologies at WSDOT. Present standards for quantitative wetland monitoring at WSDOT are predominantly focused on vegetation metrics (Bergdolt et al., 2005; Schafer & Ossinger, 1990). However, previous studies have demonstrated the need to lend some of this emphasis to incorporate more functional attributes of wetland development, such as soil metrics, into mitigation monitoring protocols (Windham et al., 2004; Ballantine et al., 2011; Schafer & Ossinger, 1990). Potential improvements could include moving towards inclusion of soil indicators in performance standards, changes in construction techniques of future mitigation projects, more careful site selection, an increase in the incorporation of organic soil amendments, and more (Ballantine et al., 2011). Such alterations in the wetland mitigation monitoring process would likely demand increased accountability for the compensation of wetland losses due to necessary roadway and land developments.

This thesis provides insight into how well created and restored wetlands stand up to existing, or preserved, wetlands within a single site. Additionally, this pilot study provides an example of how soil monitoring could be integrated into WSDOT's wetland monitoring practices in the future, and evidence for the importance of soil quality in wetland mitigation projects. Future research into the differences in soil properties would contribute to a stronger understanding of the relationships between soil health and wetland mitigation dynamics. For this study at Cedars Wetland, statistical analyses were based on differences in nutrient levels by mitigation type, as the tests revealed more prominent patterns than comparing nutrient levels by Cowardin type. However, this may not be the case for all WSDOT compensatory wetland mitigation sites. As such, there is an opportunity to explore additional relationships found in wetland mitigation sites at WSDOT.

Based on the results from this study, it is clear there is a distinct difference in soil nutrient properties between natural and restored wetlands. Considering that these sections of mitigation are adjacent, these differences could be revealing to the level of wetland function replacement achieved by this project. With further research, additional conclusions could be made about the overall efficacy of wetland compensation in the form of wetland establishment and enhancement. Although compensatory wetland mitigation is not a perfect system, and not all wetland habitats can be fully replaced through these methods, it is important to recognize that large efforts are being made to meet the overall goal of "no-net-loss". Furthermore, roadway and land development are inevitable, and the fact that the Wetlands Program at WSDOT is dedicated to offsetting impacts from such practices should be appreciated. With their adaptive management approach, I believe there will be an ongoing evolution of the wetland mitigation and monitoring process at WSDOT.

As previously discussed, Soil Organic Matter (SOM) is most crucial to the development and function of wetlands. The data from this research shows that, at this particular site, SOM in restored wetland zones does not stand up to their preserved wetland counterparts. A potential explanation for this is that the wetland preservation area is much older than the restored areas, and, therefore, the wetland preservation soil has had more time to build up organic material. As such, I suggest further investigation into more mature compensatory mitigation sites to see whether it is age or mitigation type that determines soil nutrient quality. Additionally, it would be interesting to have this study at Cedars Wetland duplicated in the future to see if there are changes in the patterns of soil nutrients between the two categories of wetland mitigation type with more time for soil development in the restored zones.

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APPENDIX

Soil properties as received from Midwest Laboratories.

SAMPLE ID	ORGANIC MATTER		PHOSPHORUS				POTASSIUM		pH	CATION EXCHANGE CAPACITY	NITRATE-N (FIA)	SULFUR	
	OM		P1 (weak bray)		P2 (strong bray)		K		SOIL pH	CEC	SURFACE	S	
	L.O.I.		1:7		1:7				1:1	meq/100g	0-6 in	ICAP	
	percent	RATE	ppm	RATE	ppm	RATE	ppm	RATE			ppm	ppm	RATE
1	7.7	VH	39	VH	78	VH	149	H	5.6	13.8	4	12	L
2	6	VH	31	VH	51	H	138	H	5.7	11.7	10	9	L
3	5	VH	27	H	54	H	144	H	5.7	12.8	23	12	L
4	2.7	M	11	L	27	M	191	VH	5.8	11	11	20	H
5	4.7	VH	34	VH	83	VH	119	M	5.3	11.9	26	31	VH
6	5.1	VH	45	VH	76	VH	237	VH	5.7	13	11	12	L
7	2.4	L	10	L	50	H	196	VH	5.9	11.1	7	34	VH
8	4.6	VH	29	H	72	VH	165	H	5.4	11.5	10	29	VH
9	9.4	VH	39	VH	89	VH	182	VH	5.6	13.1	5	16	M
10	6.5	VH	32	VH	53	H	211	VH	5.3	13.2	15	15	M
11	7.1	VH	28	H	42	H	193	VH	5.4	12.3	12	15	M
12	5.4	VH	18	M	47	H	153	H	5.3	14.3	2	30	VH
13	6.8	VH	27	H	53	H	159	H	5.4	11.6	13	20	H
14	4.9	VH	18	M	23	M	96	M	4.8	8.6	3	24	H
15	8.1	VH	30	H	37	M	88	M	4.9	6.5	1	17	M
16	12.2	VH	14	L	19	L	100	M	5.1	8.7	1	12	L
17	20.6	VH	84	VH	123	VH	24	VL	5.2	2.9	1	9	L
18	13.6	VH	14	L	21	M	80	L	5.3	8.1	1	10	L
19	13.8	VH	23	H	32	M	45	L	5.1	4.5	1	10	L
20	15.8	VH	19	M	22	M	74	M	4.9	4	1	13	M
21	13.2	VH	27	H	50	H	43	L	5.1	3.1	1	9	L