4-1-2023

Measuring Wetland Restoration Success through Water Quality and Invertebrate Community Indices

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Abstract

Wetland restoration projects are essential to preserving these imperiled ecosystems. While restoring lost or degraded wetlands is the first step, determining the success of these restoration efforts is often difficult or only focuses on one aspect of an ecosystem (e.g., water quality testing). I plan to measure the success of wetland restoration through traditional (i.e., water quality testing) and non-traditional methods (i.e., terrestrial and aquatic insect sampling) in native (i.e., control) and restored (i.e., experimental) wetlands in Ohio. I will use sweep nets for aboveground insect collection and a dip net for aquatic macroinvertebrate collection. These samples will be sorted, counted, and identified (to at least the family level) in the lab, where we will determine how terrestrial insect and aquatic macroinvertebrate community indices (e.g., Shannon diversity, richness, evenness) indicate the health of restored wetlands. Water quality testing will be performed using a YSI probe, measuring dissolved oxygen, pH, conductivity, temperature, and nitrates. The values collected for these characteristics will be compared to native wetlands and known standard water health metrics. By combining traditional (i.e., water quality testing) with non-traditional sampling techniques, the results of this project will provide a novel method to determine the health of restored wetlands. Using these results, we will be able to work with and advise local soil and water conservation districts how best to invest their money and resources for wetland preservation. This project will be essential for the health of our wetlands in Ohio.

Acknowledgements

This project was made possible by funding from the University of Dayton Dean's Summer Fellowship and Honors Thesis Fellowship. I want to thank my co-advisors, Dr. Ryan Reihart and Dr. Chelse Prather as well as my lab-mates, Matthew Carroll, Grace Jackson, Samantha Urquidez, and Stephanie Murray for all their work on this project. Thank you to the organizations that allowed us to sample: Bowyer Farm, The Beavercreek Wetland Association, Five Rivers Metroparks, and Greene County Parks and Trails.

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Introduction

Wetlands are among the most productive and diverse ecosystems (Mitsch et al. 2013). They also provide many ecosystem services, as wetlands provide food for many organisms at higher trophic levels, regulate decomposition and nutrient cycling, and are home to many threatened species (Brinson, 1981). Despite the importance of these ecosystems, wetlands have been extensively used by humans, and in many cases, these valuable ecosystems have been lost or extensively degraded.

Over 90% of wetlands in Ohio have been destroyed due to drainage for agricultural purposes since the 1780s (Little, 2017). To prevent further wetland destruction, many governmental projects have attempted to restore degraded wetlands through improved hydrology, with the goal of returning them to healthy, high-quality, biodiverse systems. Restoring these threatened ecosystems has helped to mitigate some loss of biodiversity; however, the success of the restoration efforts is not always effective in returning the wetland to how it once functioned.

Water quality is one of the most important indicators of the health of any aquatic ecosystem. Healthy wetlands often have low turbidity, which allows for a diverse community of macrophytes (Rameshkumar et al. 2019). Macrophytes create habitat for macroinvertebrates, which are also excellent bioindicators for pollution (Cummins et al. 2022). Without healthy, unpolluted water, many species are unable to thrive, and the wetlands do not provide the same services that we rely upon. Unfortunately, in Ohio, over-fertilization and heavy pesticide use of agricultural lands often result in storm nutrient runoff into wetland ecosystems. According to a 2013 study by Bashir et al, increased runoff of inorganic nitrogen can reduce dissolved oxygen, increase conductivity, and acidify standing water in wetlands. Plant and macroinvertebrate species are unable to adapt quickly enough to these environmental changes and these degraded wetlands may become an ecological trap (Zhang, et al. 2020). These ecological traps draw in species and ultimately harm them due to the high levels of pollutants.

Plant communities provide food and habitat structure for higher trophic levels in wetlands, and thus, having diverse plant communities in wetlands is important (Haddad et al. 2001). For example, wetlands with increased plant diversity often have higher water quality and more diverse animal communities than wetlands with lower plant diversity (Brisson et al. 2020). They are also integral in nitrogen fixation to remove large amounts of inorganic nitrogen from the soil coming in from agricultural runoff (Brisson et al. 2020). Monitoring the community during restoration is essential to ensure restoration efforts meet target trajectories.

Furthermore, invertebrate communities – both aquatic and terrestrial – rely on clean water and high-quality food to survive. Diverse aquatic macroinvertebrate communities are indicative of a healthy wetland ecosystem because many aquatic macroinvertebrates are pollution intolerant (Hodkinson, 2005). Having a diverse aquatic macroinvertebrate community is important, because these organisms help with decomposition, nutrient cycling, and provide food for higher trophic levels. Terrestrial insects, on the other hand, feed on the plants above the water in wetlands, and play an important role in these ecosystems, although they are often overlooked as an important aspect in wetland restoration monitoring. Monitoring both aquatic and terrestrial invertebrate communities in wetland restoration is novel and may offer a better overview of the health of wetlands in southwest Ohio.

Evaluating the success of wetland restoration is essential to ensure restoration goals are met. My research focuses on determining the success of wetland restoration in Southwest Ohio using traditional (i.e., water quality, plant communities) and non-traditional (i.e., biomonitoring of both aquatic and terrestrial insect communities) metrics. I sampled restored and established wetlands to determine the trajectory of restoration efforts in Southwest Ohio and if goals are being met. The parks I have worked with throughout the summer do not have specific restoration goals. However, the goal of my research is to ensure these restoration sites are functioning comparably to established wetland sites. Revitalizing wetlands is essential to conserve biodiversity in these imperiled ecosystems and improve water quality.

Methods

Study Sites

This study was conducted in three counties of southwestern Ohio (Montgomery, Greene, and Warren). Wetlands were once a prominent feature in Ohio that covered nearly 20% of the state, but these wetlands remain as scattered fragments throughout the state (ODRN). Before beginning sample collection, wetland sites, both established and restored wetlands, were chosen for comparison in this project. Proper research permits were obtained through Fiver Rivers Metroparks, the Beavercreek Wetland Association, and Greene County Parks and Trails. Over the past decade, these organizations have received grants to mitigate the loss of wetland ecosystems. Therefore, there are many established and restored wetlands in southwestern Ohio, which makes it an ideal location to determine the success of the ongoing mitigation efforts to restore Ohio's native wetlands.

Seven total wetland sites were sampled during June and July 2022, three of which were established wetlands and four of which were restored wetlands. We sampled three established wetland sites (Koogler Wetland Reserve, Beavercreek Wetland Reserve, and Wetland Park East) to determine reference wetland water quality, plant composition, as well as macroinvertebrate and aboveground insect abundance and diversity. Four restored wetland sites (Woodman Fen, Pearl's Fen, Bowyer Farm, and Germantown Metropark) were sampled to compare with established sites. Each site was sampled twice during the summer, once in June, and once in July of 2022.

Established wetland sites for this project were defined as undisturbed wetlands that have been part of a nature reserve. These sites are well-functioning wetlands without any major issues due to human activities. The restored wetland sites, however, were significantly degraded or non-existent wetlands that have been reconstructed with restoration efforts beginning in various time frames. Pearl's Fen is the oldest restoration project, which began in 1985. Restoration of Woodman Fen began in 2003 and Bowyer

Farm's reconstruction began in 2012. The newest restoration site was Germantown Metropark, which began in 2018.

Data Collection

In both established and restored wetlands, sample collection consisted of water quality testing, which included: (1) dissolved oxygen, (2) pH, (3) conductivity, and (4) temperature. Water quality variables were measured using a YSI probe giving the percentage of dissolved oxygen, and a multi-parameter water analyzer PCSTESTR 35 to measure pH, conductivity, and temperature. The YSI probe and the PCSTESTR 35 were deployed from the bank of the standing water before dip netting occurred to ensure the most accurate reading of each parameter before disturbing the water. Unfortunately, not every established wetland site had standing water, for this reason, we only collected water samples from sites containing standing water.

We identified all plants to species, or in some cases morphospecies, and estimated the percent composition of the plant community in established and restored wetlands by using 0.25 m rings. Each site was sampled in June and July, five times each. The 0.25 m ring was a basis for estimation of plant species richness and the percentage of each different plant species within the ring, including bare ground. Field guides were utilized to identify plants to species.

Macroinvertebrates were sampled using a dip net measured sweep (DiFranco 2006). At each wetland, the dipnet was placed in standing water and was bounced up and down, moving horizontally for approximately one meter per sweep. At each site with standing water, we collected a total of five sweeps, from the banks in all cardinal directions and the deepest pool, which were compiled into a single sample. In both June and July, we collected macroinvertebrates using this method from Wetland Park East, an established site, and Bowyer Farm, Pearl's Fen, Woodman Fen, and the Germantown Metropark, restored sites. No macroinvertebrates were collected from Koogler Wetland Reserve, and Beavercreek Wetland Reserve, both established sites, as they did not hold standing water in either month. The dip net samples were stored in Whirl-Pak bags containing 70% EtOH. They were then sorted in the lab to order utilizing field guides.

Terrestrial insect communities were collected using a sweep net. To collect insects, a total of 100 sweeps were taken at each site by collecting 4 sets of 25 sweeps. Each set of 25 sweeps was compiled into a single sample and stored in a gallon Ziploc bag. The sweep nets were inverted into the gallon Ziploc bag to ensure no insects escaped from the net. The 4 sets of sweeps were taken in different areas to ensure a more thorough sample, accounting for the varying habitats of these insects (Spafford 2013). All seven sites were sampled with this technique during each collection day. In the lab, these sweep net samples were placed in the freezer to euthanize the insects humanely. Each sample was sorted by the naked eye for one hour, followed by one hour under a dissection microscope. Insects were sorted to order.

Data Analysis

Using the four factors of water quality, combined with our measures of plant richness, aboveground insect abundance, and aquatic macroinvertebrate abundance, restoration sites can be compared to the established sites to determine the success of wetland restoration. Because only one established wetland site contained standing water throughout the summer, we did not conduct statistical analyses comparing water quality in established and restored wetland sites. Instead, we calculated averages of our water quality metrics for simple comparison. For plant richness, we checked for normality and conducted a t-test to compare the mean plant richness in established and restored wetland sites. For both terrestrial and aquatic invertebrates, we compared the mean abundance of invertebrates in established and restored wetland sites by conducting a t-test. Additionally, we ran a linear model with plant richness as the explanatory variable and terrestrial insect abundance as the response variable to determine if plant richness may be driving insect abundance in wetlands. All statistical analyses were conducted in R Studio (R Studio Team 2020).

Results

Water Quality

Water quality data were collected from all four restored wetland sites but only one of the established sites due to a lack of standing water. Because of the small sample size from established wetlands, we were unable to perform statistical analyses on water quality. We found that, on average, established wetlands had slightly lower dissolved oxygen (average ± SE; 90.45 ± 46.25) than restored wetlands (95.8 ± 18.59). However, pH remained similar in both established (7.54 ± 0.2) and restored sites (7.74 ± 0.18). The temperature of the water was similar between established (23.6 ± 2.1) and restored wetlands (23.8 ± 2.82). Conductivity, however, was found to be much higher in established wetlands (1103.5 ± 223.5) than in restored wetlands (360.5 ± 101.76).

Plant Composition

Overall, we identified a total of 35 different species in restored wetlands and 25 species of plants in established wetlands. Only 8 of these species were common in both established and restored wetlands. We found that plant richness of established (12 ± 1.1) and restored (15.75 ± 2.05) wetlands was statistically similar between sites ($p = 1.07$), although restored sites tended to have a slightly higher plant richness.

Invertebrates

Terrestrial invertebrates were collected from each wetland site whether standing water was present or not. When sorted to order, we found that the most common terrestrial insect orders were Hemiptera, Diptera, and Hymenoptera, in descending order. Hemiptera made up 35.4%, Diptera made up 29.2%, and Hymenoptera made up 8.98% of total insects found in established wetlands. Hemiptera made up 30.4%, Diptera made up 28.7%, and Hymenoptera made up 10.5% of total insects found in restored wetlands. We found a significant difference (Figure 1; $p = 0.04$) in the average abundance of terrestrial insects in established (274.67 ± 27.9) and restored (387.5 ± 38.7) wetlands. Furthermore, we found that terrestrial insect abundance significantly increased as plant richness increased (Figure 2; $p = 0.05$; $R^2 = 0.29$), which tended to be higher in restored wetlands.

The total number of individual aquatic macroinvertebrates identified from restoration was over 5 times greater than the number of individuals found in established sites because we were only able to collect macroinvertebrates from one established wetland site. Therefore, we were not able to perform statistical analyses comparing the average abundance of macroinvertebrates in established and restored wetlands. In terms of the average number of macroinvertebrates, we found that established sites (88 ± 24) tended to have a lower average abundance of macroinvertebrates compared to restored sites (119.4 ± 14.6; Figure 3). We found that members of the gastropoda were most common at Bowyer Farm, making up 83.3%, and at Woodman Fen making up 54.5% of all macroinvertebrates found at each site. Gastropods were also most common at Wetland Park, making up 37.5% of macroinvertebrates. Chironomidae were most common at Pearl's Fen, making up 62.5%, and at Germantown Metropark, making up 50% of macroinvertebrates found at each site.

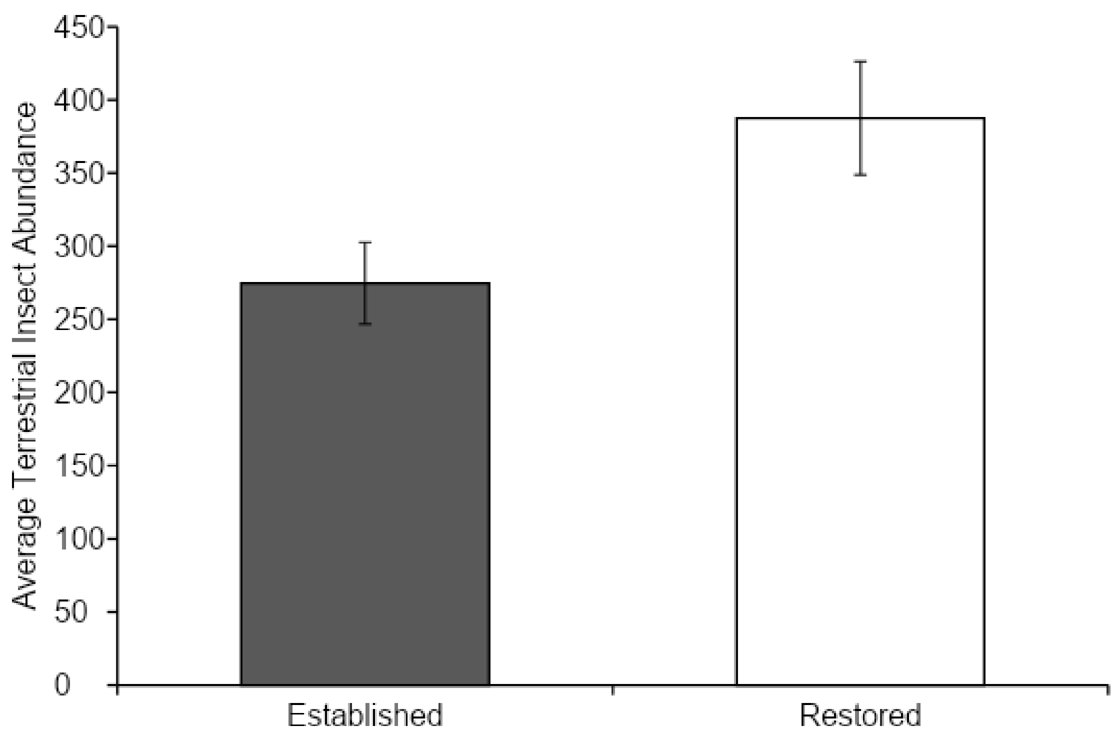

Figure 1: Average abundance (mean ± SE) of terrestrial insects collected from sweep nets in established (gray bars) and restored wetlands (white bars).

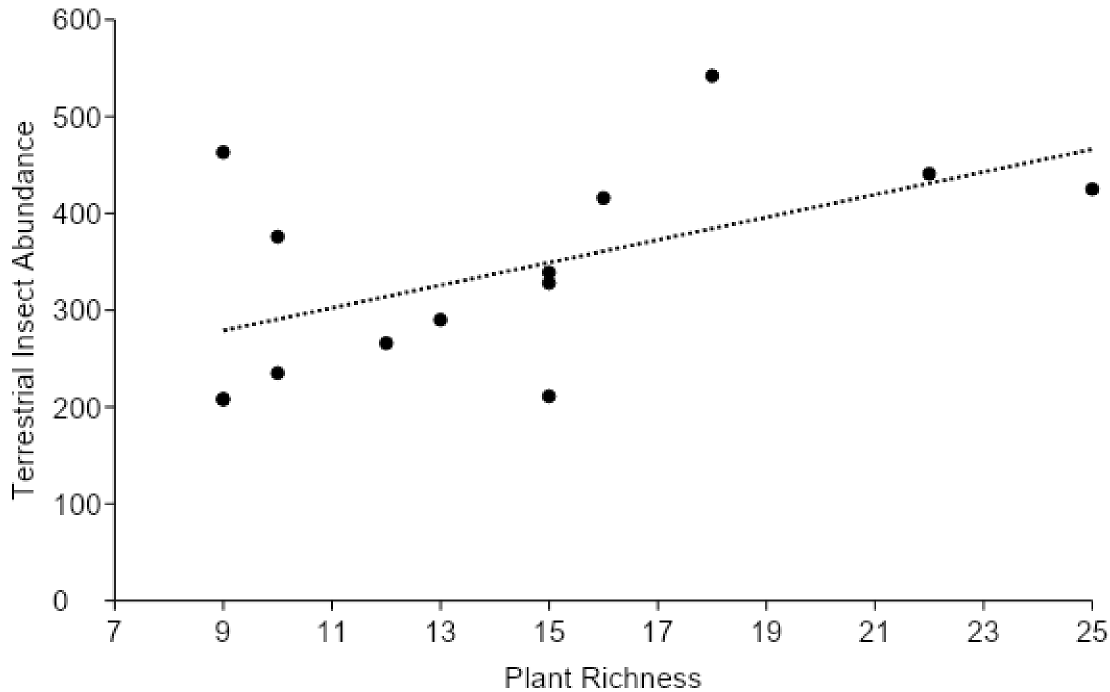

Figure 2: Effect of plant richness on terrestrial insect abundance from sweep nets collected from established and restored wetland sites.

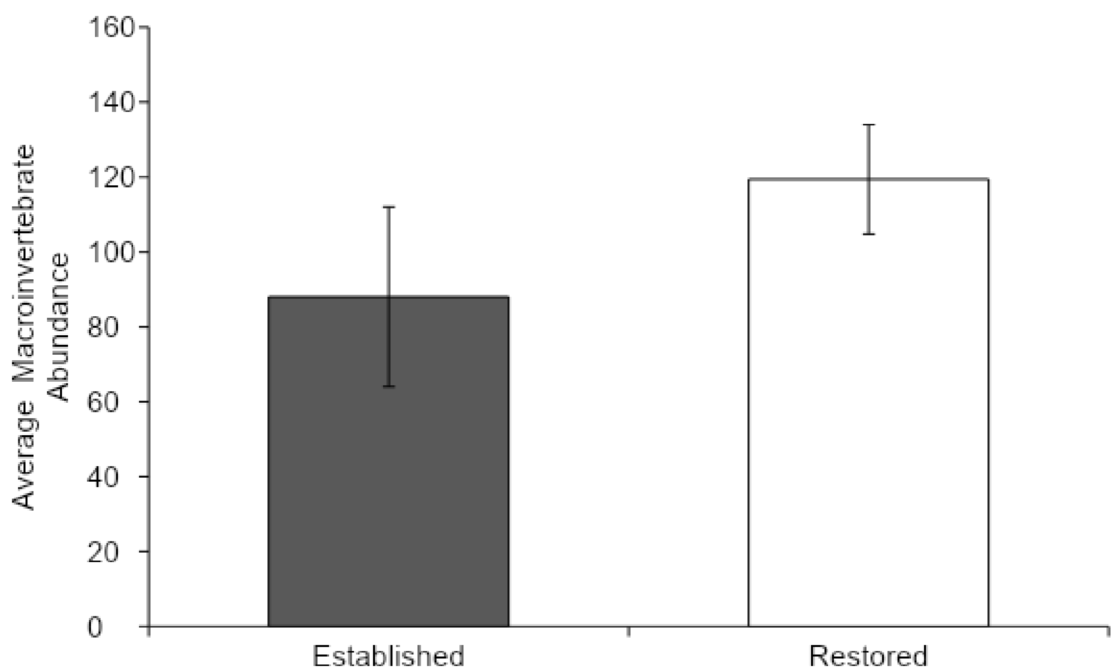

Figure 3: Average abundance (mean ± SE) of aquatic macroinvertebrates collected from dip nets in established (gray bars) and restored wetlands (white bars).

Discussion

In this experiment determining the success of wetland restoration in southwestern Ohio, we found that there was a significantly higher number of terrestrial insects in restored wetlands compared to established wetlands. It was also found that an increase in plant species richness may be a driving factor for insect abundance in restored wetlands. Macroinvertebrate abundance also tended to be higher in restored wetland sites. Here, we will discuss why we may have found differences in terrestrial insect and aquatic macroinvertebrate abundance, potential mechanisms driving differences in insect abundance, and why water quality may not be the best metric for determining the restoration success of wetlands.

Macroinvertebrate abundance and terrestrial insect abundance were both found to be higher, on average, in restored wetlands. Having an abundant and diverse community of both terrestrial and aquatic invertebrates is important because invertebrates are often bioindicators of wetland health, help to recycle nutrients, and are a key resource for higher trophic levels. Life history traits are important in determining which species establish over time within any ecosystem. Established wetlands, therefore, may have had fewer terrestrial and aquatic insects due to having only species that can tolerate potential stressors from competition and depleted resource availability. Restored wetlands, on the other hand, had a significantly higher abundance of terrestrial insects and tended to have more aquatic macroinvertebrates. These trends were mostly driven by an increase in abundance of hemipteran and dipteran species. These changes in species composition and abundance, though, are often a product of changes in associated vegetation within ecosystems.

Plant species in a wetland site provide water filtration and habitat for insects and higher trophic levels. In our experiment, plant species richness tended to be higher in restored wetland sites, which may explain why insect abundance was higher in restored wetlands. In other studies, plant species richness and plant functional group richness have been shown to have positive effects on total insect species richness (Murdoch et al. 1972; Haddad et al. 2001). For terrestrial and aquatic invertebrates in restored wetlands, the increase in plant richness may have provided a greater availability of alternative plant resources or greater vegetation structure (Haddad et al. 2001). As the plant communities in our restored sites continue to change through time, and likely lose species due to competition and resource depletion, the abundance and composition of insects in both restored and established wetlands may look more similar. Alternatively, we may have found differences in both terrestrial and aquatic invertebrate abundance due to differences in water availability and quality.

In our study, all restored wetlands contained standing water, which supported aquatic macroinvertebrates, while only one established wetland contained standing water. This may help to explain why we found more dipteran species in restored wetland sites, as members of the Chironomidae were abundant in our dip net samples. Despite this, we found a higher conductivity at established wetlands than at restored wetland sites, which may mean that established wetlands have plants that have higher plant quality, due to the role that conductivity plays in plant nutrient uptake. Higher water conductivity may be due to a high level of plant decomposition explained by the differing age of the sites or potential human disturbance, like agricultural runoff. Water quality is very important for aquatic macroinvertebrates, as they are often intolerant to pollutants that may be in the area. However, because we only took water quality data from one established wetland, future research should consider soil composition and saturation levels to make the dataset more robust for better statistical analysis.

Terrestrial and aquatic invertebrates are seldom considered in the monitoring of wetland restoration, but in this study, we show differences in the abundance of these groups. Our results point to invertebrates being an important indicator of restoration success and point to what future research can investigate. Future research should determine if species composition and diversity of terrestrial and aquatic invertebrates provide more insight into measuring restoration success and why plant species richness drives insect abundance in wetlands. It would also be interesting to see how insects affect wetland function over time. Our research gave excellent preliminary results and can be used as a basis for future work in these areas. Overall, our project has shown that wetland restoration efforts have been successful in southwestern Ohio, but work must continue to ensure these ecosystems continue to thrive in Ohio.

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