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Using Macroinvertebrates to Determine Effects of Stream Restoration

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Abstract

Stream health is important because of its impact on biotic functions of aquatic and terrestrial ecosystems. By looking at small factors in streams, such as macroinvertebrates, it can oftentimes show you a larger picture and give you an overall view of a stream's health. The purpose of this study was to determine the ecological health of restored streams in western North Carolina compared to the previous pre-restoration condition, using macroinvertebrate populations. Populations were totaled and evaluated to find the mean percentage of invertebrates in orders Ephemeroptera, Plecoptera, and Trichoptera (% EPT) as well as the tolerance levels. Using the Hilsenhoff Family-Based Index of Biotic Integrity (FBIBI) and mean %EPT allowed for a mean number of tolerance levels for each stream to be found. To understand the causation of the population numbers, we tested substrate composition, flow velocity, water depth, FBIBI, and percent EPT. We found correlation between the levels of flow velocity and water depth in relation to the amount of EPT present and tolerance levels. We calculated the habitat quality using the FBIBI numbers for each site. We found that both restoration and reference sites were degrading, but 75% of restoration sites were degrading at a slower rate and therefore had a positive restoration index. The results of this study, allowed us to understand the rate at which the streams were degrading post restoration and that the streams which had been restored degraded at a slower rate compared to the reference sites.

1. Introduction

Rivers and streams are important to the ecological health of the surrounding area and can easily be contaminated and degraded. Although aquatic health is not something that can always be seen simply by looking at the stream, there are many ecological and anthropogenic factors that play a large role in the degradation of streams. As seen in the River Continuum concept, streams can differ from the headwaters to the downstream and are affected by the land use and habitat around them (Vannote, et al. 1980). Watershed use is very important and can be one of the main stressors and causes of degradation. Land surface disturbances caused by agricultural practices alter surface water runoff and sedimentation rates, and these processes are reflected in the size composition of surface substrate (Meehan 1991). Shapiro et al. (2008) tested the conditions of stream ecosystems in the US and found that sediment flow was a key cause of stream degradation. Decrease in land use stressors, to which streams are sensitive, typically lead to an increase in biodiversity (Palmer., et al., 2010).

In stream ecology, macroinvertebrate populations are often used to evaluate stream integrity and overall health. One reason for this is because macroinvertebrates are low on the trophic scale and can have a bottom-up effect on the rest of the stream. Lourenço-Amorim, et al., (2014) showed how the health and changing of lower trophic levels will have significant effects on the rest of the ecosystem. Macroinvertebrates are also very sensitive and good indicators of stressors to a watershed. Since the presence of EPT macroinvertebrates (Orders Ephemeroptera, Plecoptera, and Trichoptera) is considered to be one of the top indicators of stream health and biotic integrity due to their low tolerance levels, collecting macroinvertebrates in the stream is very crucial to stream ecology. Weigel et al. (2000) tested macroinvertebrate populations and found that agricultural use played the largest role in decreasing these populations. Macroinvertebrates alone cannot always be used to infer the response of other stream biota to the restoration, and a broad perspective is needed to range the full effects of the restoration (Ernst et al., 2012). This is why looking at how the macroinvertebrate populations have changed after the restoration will be giving a rare glimpse and better understanding of stream restoration ecology. A method that tests the presence of intolerant or tolerant species and allows for the abundance of sensitive macroinvertebrates is using the Hilsenoff Family-Based Index of Biotic Integrity (FBIBI), which gives a tolerance values to each macroinvertebrate population by family (Hilsenhoff et al. 1988).

A research project was done by a UNCA student in 2011 on five streams in Western North Carolina that were scheduled to be restored by the NC Division of Mitigation Services. The goal of that study was to monitor the EPT and FBIBI for macroinvertebrate indexes and the substrate in all of the different streams as well as the reference sites. This gave a clear idea of the conditions of the study sites pre-restoration and how the land use around them was affecting the streams. I completed a follow-up evaluation of the study sites, ten years after the first evaluation was completed. I recreated the same field study to compare the EPT index and substrate habitat after the completion of the restoration. Understanding the flow and depth levels in comparison to previous pre-restoration years is also important for interpreting the results of FBIBI and EPT levels. Stressors in the watershed are ever-changing, so it will be beneficial to see what environmental impacts are being made on the streams ten years later and if restoration was effective in improving macroinvertebrate populations and habitats.

There has been little follow-up on restored creek functions in stream ecology based on watershed stressors, which prevents any analysis improvement and quality of the stream after restoration has been completed. Thus, by completing this research, we are able to have a pre and post snap-shot of a decade-long project of local stream restoration and see if these methods could be applied further in restoration ecology. Stream ecology and restoration are still relatively new concepts, and this study will be beneficial to evaluate modern stream restoration methods and their effectiveness. By comparing the restoration streams to the reference sites, it allows us to understand the effectiveness and positive or negative outcomes of the restoration project.

2. Methodology

2.1 Study Sites

Our six study sites are located in Henderson, McDowell, Iredell, and Catawba Counties. All sites were observed in the previous pre-restoration study, as well as one reference site for each restored site. Beaver Creek is a private property that is currently stewarded by The Department of Environmental Quality (DEQ) Stewardship. It is a predominantly forest covered creek that flows through farm and residential areas. Five Mile Branch is a North Carolina Department of Transportation (NCDOT) owned property and is currently stewarded by NCDOT. This stream is relatively similar to Beaver Creek in that it is largely forest covered and flows through agricultural areas. The UT to Cane Creek/ Fletcher-Meritor site is private property currently stewarded by DEQ Stewardship. This stream is a largely agricultural creek and has little to no forested coverage. Shadrick Creek is a current Degradation Management Services (DMS) site that has been proposed for closeout in the summer of 2021. This means it has met the qualification standards to no longer be considered for restoration and monitoring. This stream has predominantly forested coverage and flows through residential and agricultural areas. Bob’s Creek is also a current DMS site that is proposed for closeout in the summer of 2021. The stream is also largely forested and flows through agricultural and forest land. Walton Crawley Branch is located in McDowell Co. and is a current DMS site that is also proposed for closeout in the summer of 2021. The stream is mostly agricultural and flows through farm land with little forest coverage.

We had intended to sample at the same six locations as the previous 2011 study. Unfortunately, the North Carolina Department of Environmental Quality changed where they had previously decided to restore sections of our six study site streams. We still sampled at the six locations and collected data for all of them, but only four of our previous sites (Walton Crawley, UT Cane Creek, Beaver Creek, and Fifth Creek) were able to sample at the exact same location. To avoid false representation of restoration success, we will only be reporting on these four sites where restoration was completed at the same location as in 2011.

2.2 Macroinvertebrate Sampling

Macroinvertebrate sampling was completed at five points at each site. Surber samplers were used to capture macroinvertebrates; turning over rocks and digging in the sediment was also done to ensure best results. Macroinvertebrates were preserved in 70% Ethanol and then identified to the family in the lab. The mean percent of EPT and standard deviation was then be then found by comparing the Ephemeroptera, Plecoptera, and Trichoptera captured to the total amount of macroinvertebrates captured in each study site. Then, using the Hilsenoff Family-Based Index of Biotic Integrity, the macroinvertebrates captured were given a number that represents the biotic integrity of the study site (Hilsenhoff, 1988). To determine the rate at which each site was degrading, we completed an analysis of the index of restoration. To follow previous sampling methods, sampling was done at the end of May and beginning of June.

2.4 Substrate and Flow Velocity Sampling

It is important to understand the habitat of the study sites, as this could explain some of the finding of the macroinvertebrate populations. Substrate provides clues to local and watershed influences on stream habitat quality. The flow velocity and depth was measured using a Global Water Flow Probe Series Water Velocity Meter and a meter stick. The study sites were measured out into four sections to test the substrate and flow velocity. Substrate categories were determined by size and included boulder, cobble, pebble, sand, and silt.The substrate sampling was then recorded and compared by the study site. The data was organized into spreadsheets to allow for the mean and standard deviation to be found and compared between study sites.

2.5 Data Analysis

To evaluate the differences between the study and the reference sites, as well as the previous study and reference sites observed in the 2011 project, we used an index of restoration. To compare results and figures completed in 2011, we collected and evaluated our data in 2021 in the same format as the previous study. Once all specimens had been identified, a tolerance level was assigned to each specimen based on the Hilsenhoff Family Based Biotic Integrity (FBIBI) ranking. To understand FBIBI values, a lower number on the FBIBI scale means a better quality stream, with 0 being the best, 5 being the middle ranking, and 9 being the worst. A total percent and mean FBIBI was calculated for both reference and restored sites at each location. The standard deviation was also calculated to determine the error bars of the results. We then graphed the reference and the restored sites side by side to determine the shift in FBIBI values. The graphs were made to look identical to the previous studies to show change post restoration. Once the habitat assessment was made for each site, we compared the previous FBIBI totals to the current for both restored and reference sites. To do this, we subtracted the restored 2011 site from the restored 2021 site and then we divided this by the reference 2011 site subtracted from the reference 2021 site. This gave us a rate at which the restored site was degrading compared to the reference site. Any number that was below 1 (<1) was considered to be a positive restoration effect because it was degrading at a slower rate than the reference site, while anything larger than 1 (>1) was considered to be a negative restoration effect because the change was happening faster than the reference site.

3. Results

3.1 FBIBI and Habitat Assessment

In the figures, the graphs created in the previous 2011 studies are on the left in grey and the graphs created in 2021 are in white. All sites, except for Bob's Creek and Five Mile Branch, showed no change in reference and restoration FBIBI values in comparison with 2011 collections and 2021. In all study sites, it was found that overall FBIBI values increased from 2011 to 2021. Using the FBIBI totals for each site, a habitat assessment was completed to determine the change in habitat quality. We found that all sites became worse in relation to the habitat assessment. For Walton Crawley, the total FBIBI value for 2021 in both the reference and restoration site increased compared to the 2011 FBIBI values. There was no change in the reference site being better than the restored site (figure 1). For UT Cane Creek the total FBIBI value for 2021 in both the reference and restoration site increased compared to the 2011 FBIBI values. There was no change in the reference site being better than the restored site (figure 2). At Five Mile Branch, the total FBIBI value for 2021 in both the reference and two restoration sites increased compared to the 2011 FBIBI values. Fifth Creek (longer) had a lower FBIBI value in 2011 in comparison to Beaver Creek (shorter). In 2021 it has now switched and Beaver Creek (shorter) now has the lower FBIBI value (figure 3).

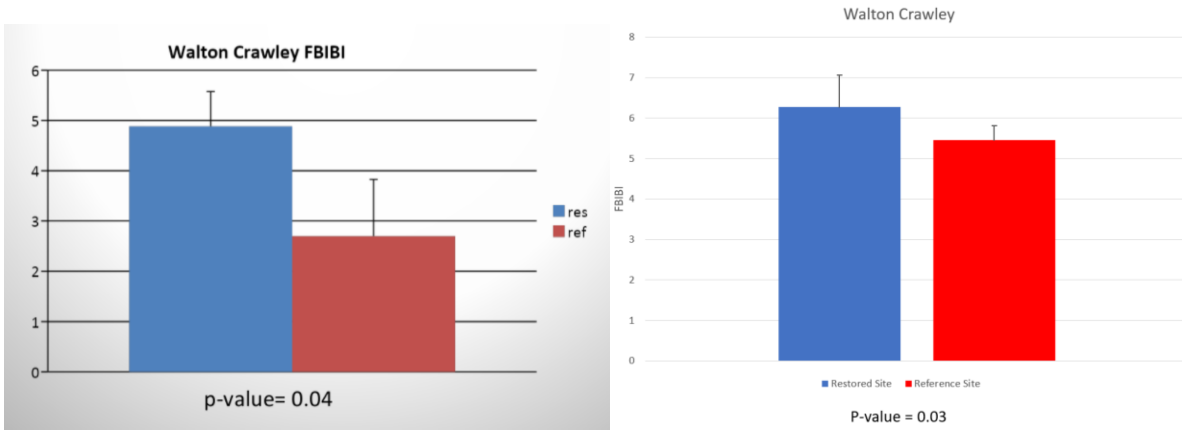


Figure 1. Walton Crawley 2011 (left) and 2021 (right) FBIBI Comparison

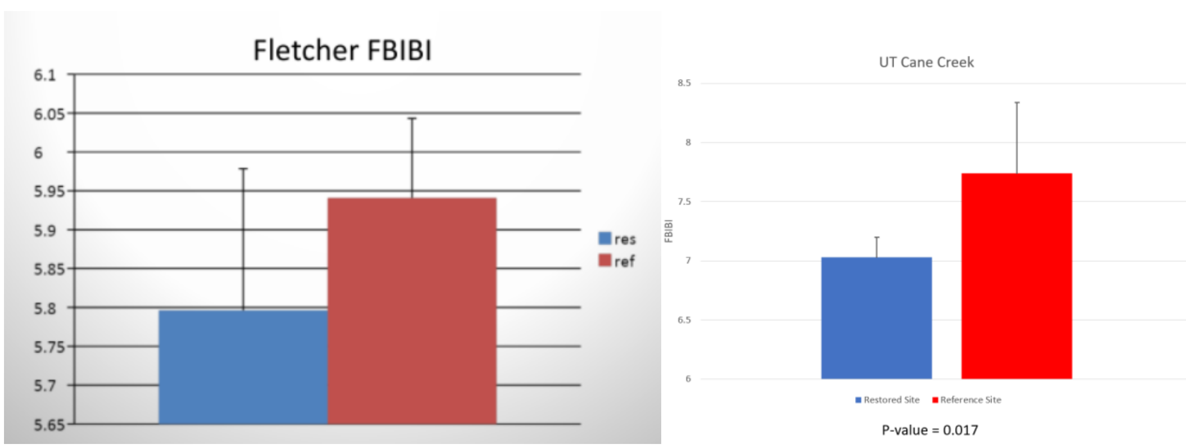
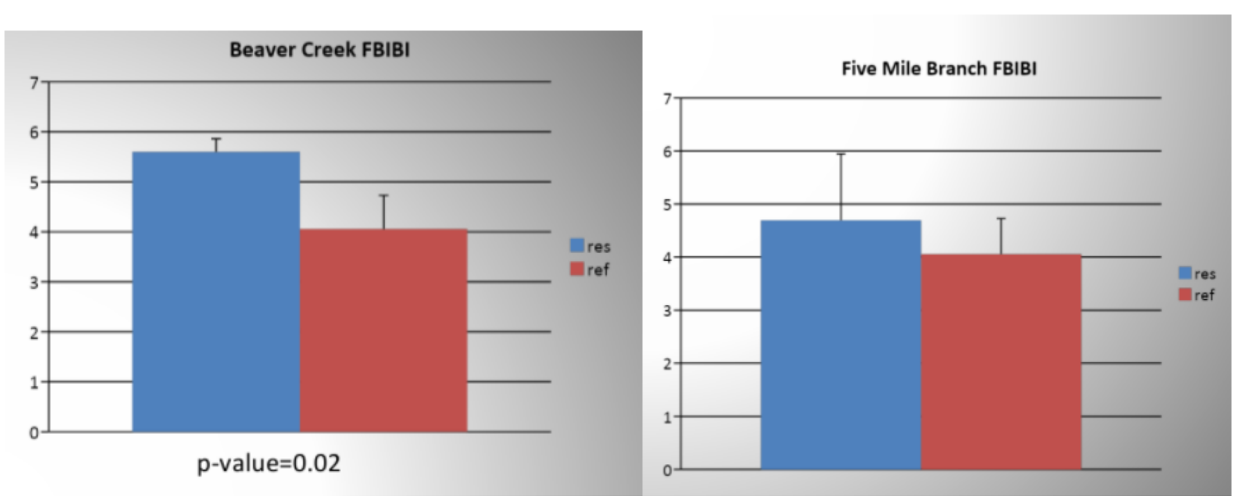


Figure 2. UT Cane Creek (formerly named "Fletcher") 2011 (left) and 2021 (right) FBIBI Comparison



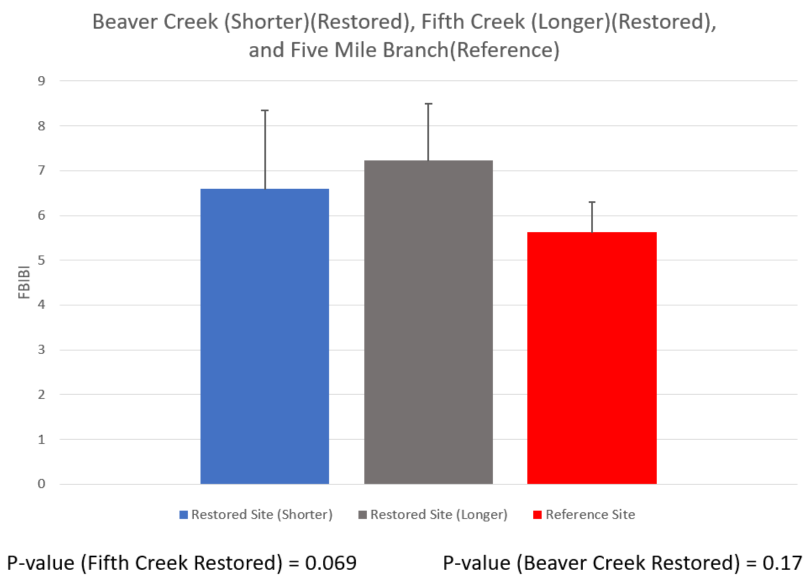


Figure 3. Beaver Creek (shorter), Fifth Creek (longer), and Five Mile Branch (Reference) 2011 (top graph) and 2021 (lower graph) Comparison

Table 1. Comparison of habitat quality from 2011 and 2021.

2011 Site	FBIBI	Quality	2021 Site	FBIBI	Quality
UT Cane Creek Restored	5.8	Fair	UT Cane Creek Restored	7.0	Fairly Poor
UT Cane Creek Reference	5.9	Fair	UT Cane Creek Reference	7.7	Poor
Bob's Creek Restored	5.1	Good	Bob's Creek Restored	4.7	Good
Bob's Creek Reference	4.4	Very Good	Bob's Creek Reference	5.8	Fair
Beaver Creek Restored	5.6	Fair	Beaver Creek Restored	6.6	Fairly Poor
Fifth Creek Restored	4.7	Very Good	Fifth Creek Restored	7.2	Fairly Poor
Five Mile Branch Reference	4.1	Good	Five Mile Branch Reference	5.6	Fair
Walton Crawley Restored	4.8	Good	Walton Crawley Restored	6.3	Fair
Walton Crawley Reference	2.3	Excellent	Walton Crawley Reference	5.5	Good
Shadrick Creek Restored	6.0	Fair	Shadrick Creek Restored	6.0	Fair
Shadrick Creek Restored	5.8	Fair	Shadrick Creek Reference	5.4	Good

3.2 EPT

To compare results and figures completed in 2011, we collected and evaluated our data in 2021 in the same format as previous studies. Once all specimens had been identified, each specimen that was included as part of EPT (Ephemeroptera, Plecoptera, and Trichoptera) was labeled. A total number of EPT present was calculated for each site. Having a higher mean EPT present is a way to indicate better stream quality and tolerance levels. A total percent and mean EPT was calculated for both reference and restored sites at each location. The standard deviation was also calculated to determine the error bars of the results. We then graphed the reference and the restored sites side by side to determine the shift in EPT values. The graphs were made to look identical to the previous studies to show change post restoration. EPT is not as clear of an indicator of stream health as FBIBI but does give us a direct look at the number of EPT present. The change in amounts varied at sites, with Walton Crawley, Bob's Creek, and UT Cane creek increasing in amount of EPT present. At Walton Crawley, the total EPT value collected at the restored site in 2021 is higher than the amount collected in 2011. The amount collected at the reference decreased compared to 2011 collections (figure 4). At UT Cane Creek the EPT levels increased in 2021 for both the reference and restoration sites. The reference site continued to have lower levels of ET present (figure 5). At Five Mile Branch, The amount of EPT collected at both the reference and restoration location in 2021 was significantly lower than what was collected in 2011. The exception is the amount found at Beaver Creek was larger in 2021 than in 2011. There was no EPT collected at Fifth Creek in 2021 (figure 6).

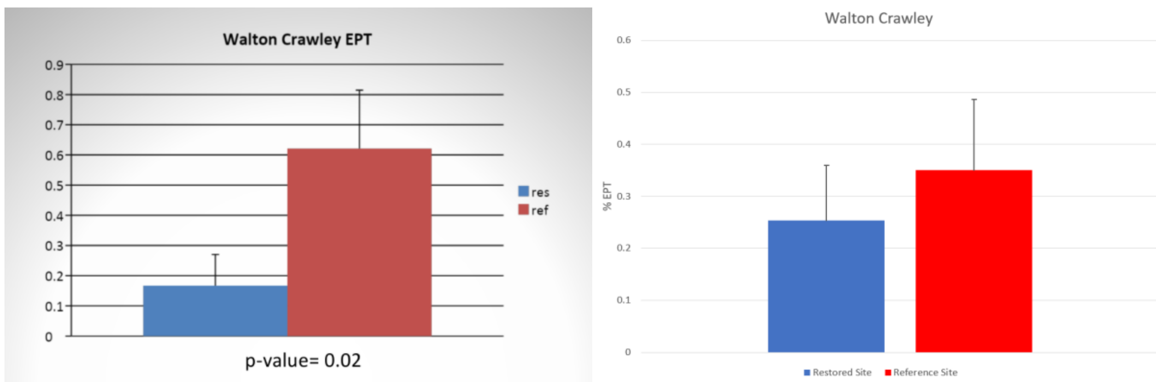


Figure 4. Walton Crawley 2011 (left) and 2021 (right) EPT Comparison

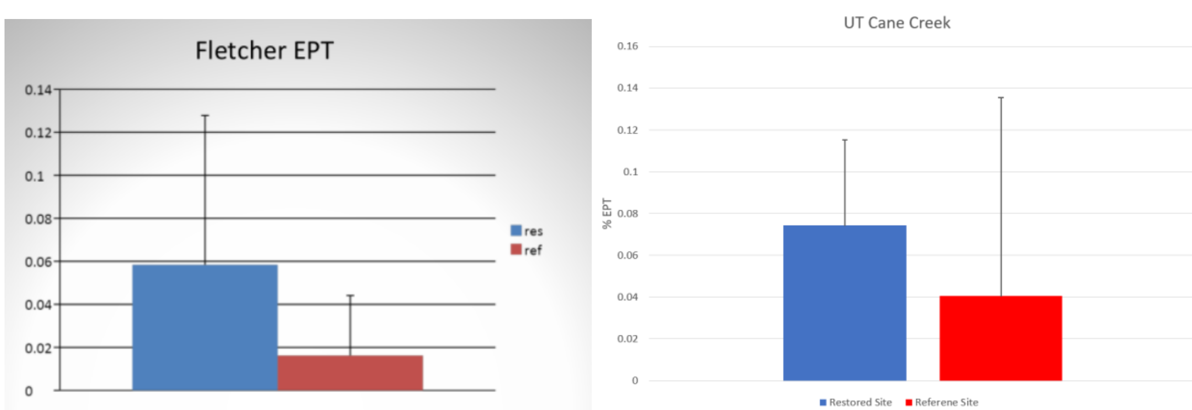
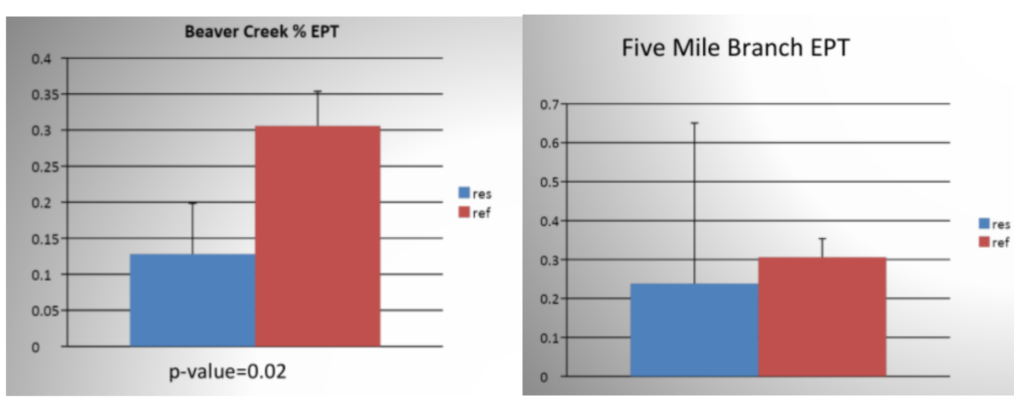


Figure 5. UT Cane Creek (formerly named “Fletcher”) 2011 (left) and 2021 (right) EPT Comparison



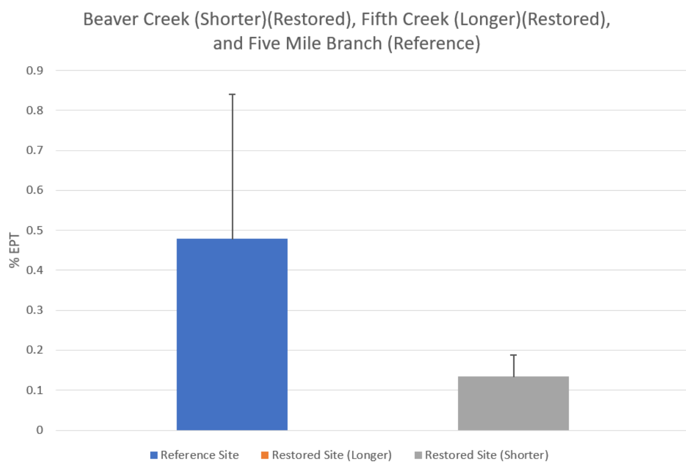


Figure 6. Beaver Creek (shorter), Fifth Creek (longer), and Five Mile Branch (Reference) 2011 (upper graph) and 2021 (lower graph) Comparison

3.3 Flow and Depth

Depth (cm) is plotted on the x-axis and flow (ft/s) on the y-axis. We included standard deviation lines to determine the errors. There was no data for Shadrick Creek from 2011, so we were unable to create a comparison. We found that the results in change in flow in depth varied between the sites. Walton Crawley, Bob's Creek, and Beaver Creek restored sites saw an increase in depth and flow. Other sites, such as UT Cane Creek and Fifth Creek saw an increase in flow while there was a decrease in depth for the restored sites. At Walton Crawley,.the flow and depth was increased for the 2021 restored site. The depth of the reference site in 2021 increased significantly, but decreased in flow (figure 9). At UT Cane Creek, the flow increased for the 2021 restored site, while depth decreased. The 2021 reference site increased in both depth and flow compared to 2011 numbers (figure 10). At Beaver Creek, flow and depth increased slightly at the 2021 restored site. The Beaver Creek 2021 reference decreased in flow but increased in depth. At Fifth Creek, Flow increased slightly in 2021 at the restored site, while depth decreased. The reference site in 2021 increased in depth but decreased in flow (figure 11).

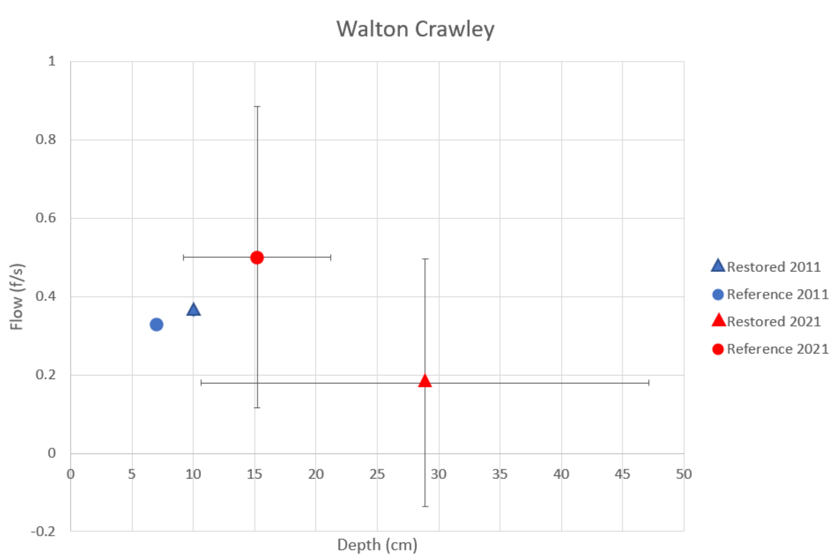


Figure 9. Walton Crawley 2011 and 2021 Flow and Depth Comparison

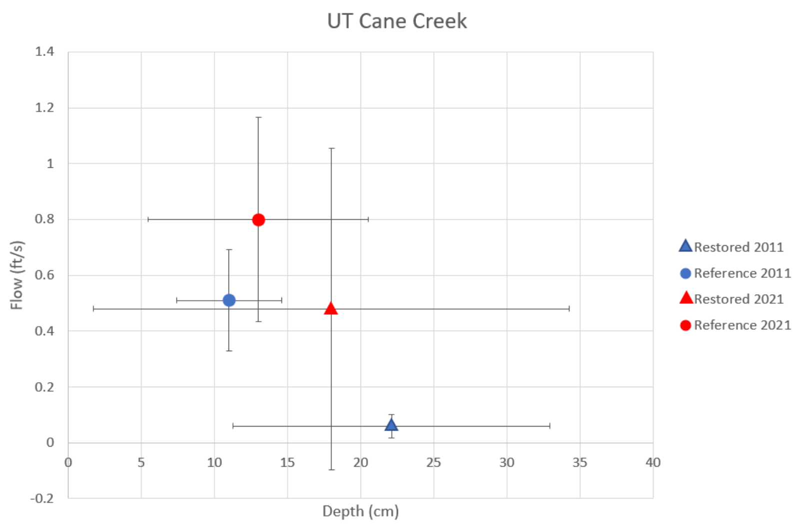


Figure 10. UT Cane Creek (formerly named “Fletcher”) 2011 and 2021 Flow and Depth Comparison

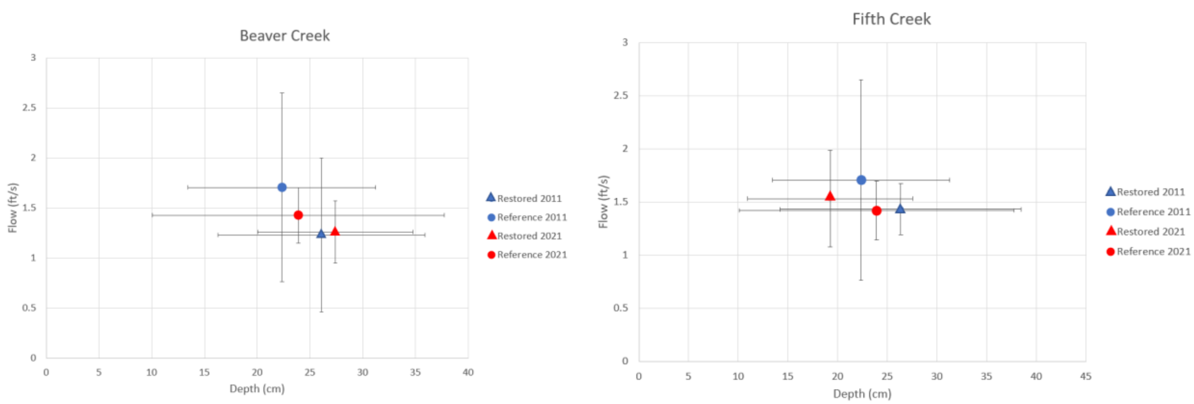


Figure 11. Beaver Creek (shorter), Fifth Creek (Longer), and Five Mile Branch (Longer) 2011 and 2021 Flow and Depth Comparison

3.4 Index of Restoration

Seventh-five percent of our sites were found to have a positive restoration effect, including Walton Crawley, UT Cane Creek, and Beaver Creek. Fifth Creek had a result that was greater than one and was determined to have a negative restoration effect. Walton Crawley (0.46), UT Cane Creek (0.66), and Beaver Creek (0.60) all had an index number less than one (<1) and positive restoration effect. Fifth Creek had a negative restoration effect because the index number (1.60) was greater than one (>1) (figure 12).

Site	Formula	Values	Difference	Index	Comparison	Effect
Walton Crawley	$\frac{Restored\ 2011 - Restored\ 2021}{Reference\ 2011 - Reference\ 2021}$	$\frac{4.8-6.3}{2.3-5.5}$	$\frac{-1.5}{-3.2}$	0.46	< 1	Positive Restoration Effect
UT Cane Creek	$\frac{Restored\ 2011 - Restored\ 2021}{Reference\ 2011 - Reference\ 2021}$	$\frac{5.8-7.0}{5.9-7.7}$	$\frac{-1.2}{-1.8}$	0.66	< 1	Positive Restoration Effect
Beaver Creek	$\frac{Restored\ 2011 - Restored\ 2021}{Reference\ 2011 - Reference\ 2021}$	$\frac{5.6-6.6}{4.1-5.6}$	$\frac{-1}{-1.5}$	0.60	< 1	Positive Restoration Effect
Fifth Creek	$\frac{Restored\ 2011 - Restored\ 2021}{Reference\ 2011 - Reference\ 2021}$	$\frac{4.7-7.2}{4.1-5.6}$	$\frac{-2.5}{-1.5}$	1.60	> 1	Negative Restoration Effect

Figure 12. Index of Restoration

4. Discussion

Monitoring the change in habitat quality post-restoration is important to understand the effects and success of the restoration project. By using% EPT, flow and depth, and FBIBI values, we are able to understand the change in habitat quality from the pre-restoration conditions to the now post-restoration. Flow and depth levels were changed due to the geomorphological modifications made to the stream channel during the restoration process. We looked at the collected data in 2011 on flow velocity and depth and compared it to the measured levels from our study in 2021. We found varying levels of change over all study sites and there was no significant trend in change post-restoration. Change in depth and flow levels are assumed to have an effect on macroinvertebrate populations, but it is difficult to prove that this was true for our study and that it had a significant effect on the macroinvertebrates because of the lack of correlation.

To assess the change in macroinvertebrate populations, we looked at levels from 2011 and 2021. We determined that EPT levels increased for both Walton Crawley and UT Cane creek. This indicates there were more EPT species collected at both of these sites after the restoration project was completed. Having a higher EPT value can be an indicator of healthier stream quality because, oftentimes, EPT are very intolerant species and cannot live in poor habitat quality. In contrast, Beaver Creek and Fifth Creek decreased in the amount of EPT present. EPT is not always the most reliable or accurate representation of habitat quality because there are some EPT species that have higher tolerance values than others. We found that even though there was an increase in EPT species at two of the sites, habitat quality was not increased at either of these sites. We believe that using the Hilsenhoff method which looks at the tolerance levels of the families found is a more accurate way of determining the overall tolerance levels of the specimens collected at a specific site (Hilsenhoff, 1988).

FBIBI is arguably the most accurate in showing change in habitat conditions and effects of restoration. Species are given a tolerance number, and through this, it categorizes the overall habitat quality based on the level of macroinvertebrate tolerance found at each site. While the reference site FBIBI values remained lower than the restoration sites, overall, there was a significant increase in FBIBI values for all of the study sites. From 2011 to 2021 Walton Crawley's conditions changed from "good" to "fair", UT Cane Creek's changed from "fair" to "fairly poor", Beaver Creek's changed from "fair" to "fairly poor", and fifth creek had the largest change from "good" to "fairly poor". These changes in habitat quality indicate that the species that we collected have an overall lower tolerance average than what was previously collected in 2011.

We wanted to understand if this change in habitat quality is in direct relation to the restoration projects or if it could be something that is naturally occurring. To do this, we compared the change in habitat quality of the restoration sites to the change in quality of the reference sites. In a "perfect world" situation where naturally occurring degradation is happening, the restored sites and the reference sites would be degrading at the same 1:1 raito. We found that at 75% of our sites (Walton Crawley, UT Cane Creek, and Beaver Creek) the index of restoration was lower than the 1:1 ratio. This indicates that the restored sites were degrading in habitat quality slower than the reference sites. We considered this to be a positive restoration effect. Fifth Creek's index of restoration was greater than the 1:1 ratio, therefore it was a negative restoration effect, and the habitat of the restored site was changing in relation to the reference site at a faster rate. By understanding this index of restoration, it allows us to see how the restoration project was successful in slowing the process of change in habitat quality from naturally occurring processes.

Although experiences with ecological restoration continue to accumulate, the effectiveness of restoration for biota remains debated (Plilotto et al. 2018). The results of this study demonstrate the need for further analysis of restoration processes and how the stream responds post-restoration. Sunderman et al. (2011) conducted a similar study where they looked at the responses of stream restoration and analysed effects of hydromorphological restoration on benthic invertebrate assemblages. They concluded that poor water quality, including stream channel geology and substrate conditions, was probably one factor impeding recolonisation and preventing the upward mobility of habitat quality and macroinvertebrate populations. The results of their study showed that isolated restoration measures do not necessarily result in positive effects on aquatic biota and that better understanding of the interconnectedness within a catchment is required before one can adequately predict biotic responses to structural river restoration (Sundermann et al. 2011). The need for connectivity between stream channel restoration and benthic macroinvertebrate communities is a factor that cannot be ignored when a goal of the restoration is to improve the habitat quality and biotic integrity. Restoration actions that do not address stream connectivity issues or overcome land use influences elsewhere in the riverscape will not govern the responses of aquatic macroinvertebrates (Schumann 2021).

A concept that would have been beneficial to the restoration goals of the North Carolina Department of Environmental Quality is incorporating potential restoration efforts that will improve and serve macroinvertebrate populations and demands. Flow and depth had little to no correlation with the macroinvertebrate populations in our study. This contributes to the idea that there needs to be actions in the restoration project, outside of the channel alterations, which would allow for the success of future biotic populations and overall biotic integrity of the restored streams.

5. Conclusion

This study provides a rare snapshot of how macroinvertebrate populations respond to stream restoration and if the restoration was successful in improving the biotic index and habitat quality. By monitoring the change in benthic macroinvertebrates over the course of ten years, pre-restoration and post-restoration, we were able to gain an understanding of how the habitat quality changed throughout the restoration process and what this looks like for the macroinvertebrate community. Flow and depth levels also allow us to understand just how these conditions changed geomorphologically and if the change in macroinvertebrate levels were simply functions of the restoration stressors or a result of the changing habitat. We found that the FBIBI values increased and overall habitat quality became worse from the initial 2011 study and can be understood as a degradation from previous levels. To allow us to determine the rate at which the sites were degrading, we analyzed if the levels of degradation at the restoration sites were on a 1:1 ratio with the reference site. We found that at 75% of our study sites, the restoration index was a positive one (<1) meaning that the restoration sites were degrading at a slower rate than the reference sites. We concluded that the restoration projects had a positive restoration effect in preventing degradation at the same rate as the reference sites in the same watershed. Our study also substantiated the concept that there needs to be interconnectivity between stream channel morphology restoration and improvement of macroinvertebrate habitat for adequate biotic integrity improvement. Using this information could be beneficial to further restoration projects and allow for further study to understand what we can do to prevent our streams from degrading at alarming rates and to eventually begin to improve their habitat quality.

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