LONG-TERM MONITORING RESULTS OF BENTHIC MACROINVERTEBRATE COMMUNITIES IN GWINNETT COUNTY

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Abstract. Since 2004, the Gwinnett County Department of Water Resources (GCDWR) has implemented a long-term monitoring program as a part of the County's Watershed Protection Plan (WPP). As part of the Plan, GCDWR conducted annual monitoring of benthic macroinvertebrates to assess stream conditions. From 2004 through 2015, GCDWR collected 348 individual samples from up to 34 long-term monitoring stations, on an annual basis. Additionally, GCDWR collected pre- and post-construction macroinvertebrate data from Watershed Improvement Program (WIP) projects, including 36 individual samples from seven stream restoration projects, to evaluate the effects of restoration on the benthic community. GCDWR evaluated the benthic community using the Georgia Department of Natural Resources (GADNR) Multi-metric Index (MMI) as well as other ecological metrics.

Overall, benthic macroinvertebrate scores for most long-term sampling locations indicated some level of environmental degradation compared to scores from reference locations with fewer environmental stressors. Nonetheless, over the past 11 years, MMI scores indicated a statistically significant ($p < 0.05$) increase in the mean distribution of scores between 2005 through 2010 and 2011 through 2015, 33.89 and 39.07, respectively.

Benthic macroinvertebrate data collected at WIP projects also demonstrated notable shifts in community composition associated with improved channel bed and bank conditions and increased habitat diversity. Among the seven WIP locations monitored before and after restoration, Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa, demonstrated a statistically significant increase (median pre = 2.0; median post = 5.0) while other functional feeding groups (FFG) demonstrated statistically significant shifts as well; collector/gatherer taxa decreased (median pre = 41.89%; median post = 16.51%) and filterer taxa increased (median pre = 7.51%; median post = 35.08%). These results along with other notable trends from the study will help to inform future watershed management decisions by Gwinnett County.

INTRODUCTION

The Gwinnett County Department of Water Resources (GCDWR) conducts long-term benthic macroinvertebrate monitoring to track changes in watershed conditions for environmental permit compliance with National Pollutant Discharge Elimination System (NPDES) discharge and stormwater permits, as well as Total Maximum Daily Load (TMDL) implementation plans for eleven 303(d)-listed stream segments for impacted biota. Additionally, the County conducts these long-term monitoring efforts according to the Countywide Watershed Protection Plan (WPP). Following an initial baseline assessment in 1998, GCDWR completed annual long-term monitoring every year since 2004, with the exception of 2008.

All monitoring stations within the County were located in one of three major river basins, including, the Chattahoochee River to the west, the Ocmulgee River to the south, and the Oconee River to the southeast and east. The Chattahoochee River is part of the larger Apalachicola-Chattahoochee-Flint (ACF) River basin, which flows south to the Gulf of Mexico. The Ocmulgee and Oconee Rivers parallel each other, flowing south and joining on the Coastal Plain to form the Altamaha River, which then flows eastward to the Atlantic Ocean. The entire County is located in the Piedmont physiographic province and in Ecoregions 45a (Southern Inner Piedmont) and 45b (Southern Outer Piedmont) (Wharton, 1978; Griffith et al., 2001; Edwards et al., 2013).

In 2015, 34 monitoring stations were sampled as part of the long-term monitoring efforts, see Figure 1. Stations were selected based on watershed characteristics such as land use, 303(d) listing status, point source discharges, solid waste facilities, nonpoint pollutant sources, sewer and septic service areas, water supply intakes, physical habitat condition, and perennial stream flow. Originally, 30 long-term monitoring stations were established as part of the WPP. More recently, four additional monitoring stations were added to track conditions within completed Watershed Improvement Program (WIP) projects and on new 303(d)-listed stream segments.

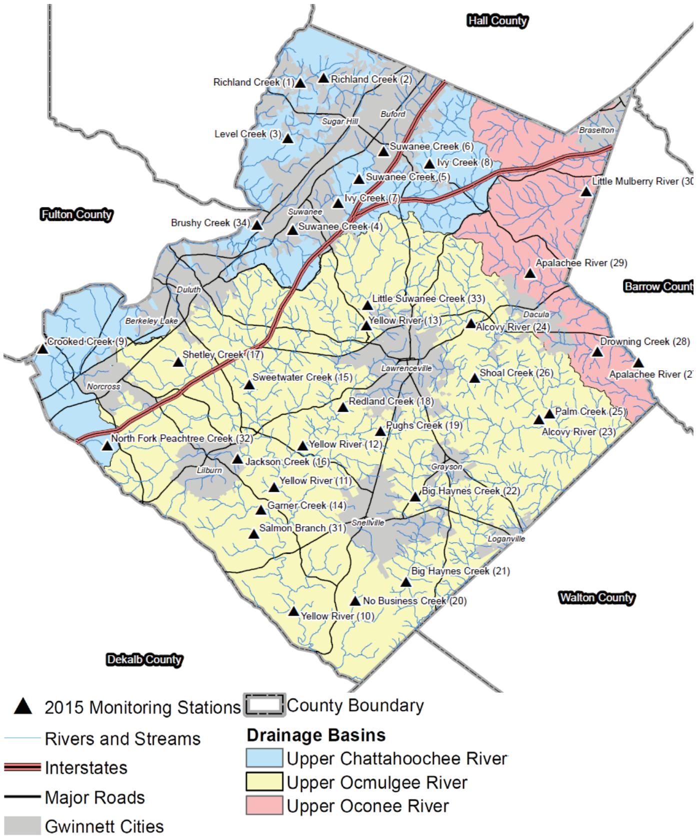

Figure 1. Gwinnett County Monitoring Stations

In addition to the long-term monitoring associated with the WPP, GCDWR monitored benthic data at several other WIP projects. Benthic macroinvertebrates are valuable indicators for overall aquatic integrity and function (Plafkin et. al, 1989; Harman, 2012) and are quick to respond to both environmental improvements and degradation (Karr, 1991; Loeb and Spacie, 1994).

Some deliberation remains among the scientific community regarding the magnitude at which traditional stream restoration, with a focus on structural improvements, may improve overall biological function (Palmer et. al, 2014; Tullos et. al, 2008). Additionally, there is debate regarding which biological indicators may be the most appropriate for evaluating the response of benthic communities (Tullos et. al, 2006; Vlek and Nijboer, 2004). Gwinnett County, for its part, has utilized a variety of approaches to improve in stream habitat and function, including reconfiguring stream channel profile, pattern and dimension, augmenting streambed substrate, enhancing riffle and pool habitat, utilizing natural stabilization materials such as logs, brush and live cutting, and improving or protecting riparian vegetation. Additionally, Gwinnett County has evaluated multiple biological metrics to determine the effects of stream restoration on benthic macroinvertebrate communities.

Between 2006 and 2015, the County constructed more than 45 WIP projects for stream restoration or structural stormwater control to reduce streambank erosion and sedimentation as well as improve in stream water quality and physical habitat conditions. To evaluate the performance of these efforts for stream restoration projects, Gwinnett County conducted pre- and post-restoration benthic monitoring at seven stream restoration projects including 36 individual sample collections. GCDWR also evaluated data from four unrestored "baseline" long-term monitoring stations to use as a control for comparison to the restoration data.

TECHNICAL APPROACH

Benthic macroinvertebrate communities were sampled at each sampling station following Georgia Department of Natural Resources (GADNR) most recent Standard Operating Procedures (SOPs) (GADNR, 2007). The assessment includes a multi-habitat approach that maximizes efficiency of fieldwork and analysis. It is consistent with U.S. Environmental Protection Agency's (USEPA) Rapid Bioassessment Protocols (Barbour et al., 1999) and involves obtaining samples from the various habitats for analysis and data evaluation, including, riffles, soft sediments, undercut banks, and wood debris.

Benthic macroinvertebrates were identified to the lowest taxonomic level practical, in order to calculate the GADNR Multi-metric Index (MMI), consisting of five metric categories, specific to the ecoregion (45a or 45b) in which the samples were collected. Each metric or index represents a different component of community structure and/or function and together provide a measure of biotic integrity. In addition to MMI, other established metrics to further evaluate ecological diversity and benthic community function. These included, Ephemeroptera, Plecoptera and Trichoptera (EPT) taxa, Margalef's Richness Index, Shannon-Wiener Index, Pielou's Eveness Index, Hilsenhoff Biotic Index and percent Functional Feeding Group (FFG) for scraper, shredder, collector/gatherer, filterer and predator taxa.

A comparison of the mean distribution for the 34 long-term monitoring stations was conducted using parametric paired statistical analyses (T-Test and Z-Test) (α = 0.05) between two groupings, 2005 through 2010 (excluding 2008) and 2011 through 2015. For WIP project benthic data, a comparison of the median distribution was conducted using a nonparametric paired statistical analysis (Wilcoxon-Rank Sum Test) (α = 0.05) between pre-restoration vs. baseline, baseline vs. post-restoration, pre- vs. post- and pre- vs. post-restoration.

RESULTS

The monitoring results for benthic communities demonstrated a number of trends regarding baseline aquatic conditions and the performance of WIP projects. Long-term data generally indicated an improving trends for MMI scores, between 2004 and 2015, with a slight decrease in 2007, which coincided with severe drought conditions. County wide MMI scores were compared between 2005 through 2010 (mean = 33.89) and 2011 through 2015 (mean = 39.07) in Table 1. The result of the analysis indicated a statistically significant (Z-Test and T-Test $p < 0.05$) increase in the mean distribution of MMI scores between these time periods.

These improvements were typically attributed to increased species abundance of moderately tolerant to tolerant taxa (tolerance value > 7.0) over the same period of time. While these increases in species diversity and abundance were noteworthy and may indicate some improvements to available in stream habitat, the consistency of species tolerance may indicate that benthic communities remain somewhat limited by additional watershed factors such as altered hydrology and hydraulics and water quality.

Through a multivariable analyses, summarized in the Year 11 Annual Monitoring Report (CH2M, 2016), GCDWR determined that the benthic community MMI scores are influenced strongly or significantly by numerous independent variable such as land cover, climate, hydrology, watershed slope, in stream available habitat, water quality as well as stormwater management strategies.

The median values for benthic data from WIP projects as well as the paired statistical results are summarized in Tables 2 and 3. The results indicated several trends regarding the effects of stream restoration on the benthic community. Overall, post-restoration data compared to pre- indicated significant increases for EPT taxa ($p = 0.009$) and percent filterer taxa ($p = 0.001$) as well as a decrease for percent collector/gatherer taxa ($p = 0.000$).

These significant differences were also generally true longitudinally when comparing pre-restoration data to multiple years post-restoration. Post-restoration data demonstrated a significant decrease in the overall equity, measured using Pielou's Index, ($p = 0.043$) of the benthic community compared to baseline long-term monitoring stations. Many of the other benthic indices evaluated, such as MMI, Margalef's, Shannon, Pielou's, Hilsenhoff, percent scraper, shredder, and predator, did not show a significant difference between pre- and post-or baseline and post-restoration; however, some important differences were noted for these other indices and are discussed below.

Table 1. Statistical analysis results of countywide long-term benthic macroinvertebrate data

	Benthic MMI Scores 2005-2010	2011-2015
Count	150	167
Mean	33.89	39.07
Median	33.00	39.00
Standard Deviation	9.65	9.40
Coefficient of Variance	0.28	0.24
Variance	93.10	88.34
alpha	0.05	
p-value (two-tailed F-Test)	0.74	
p-value (two-tailed Z-Test)	0.000001	
p-value (two-tailed T-Test)	0.000002	
Result:	**Significant Increase of Mean**	

Table 2. Summary of median benthic indices for restoration sites and representative baseline monitoring stations

Indices	**Pre-Restoration (n=13)**	**Unrestored Baseline (n=32)**	**Post-Restoration (n=23)**
MMI	33.00	30.50	31.00
EPT	2.00	5.00	5.00
Margalef's Richness Index	5.59	6.84	6.34
Shannon-Wiener Index	2.37	2.97	2.79
Pielou's Evenness Index	0.73	0.83	0.78
Hilsenhoff Biotic Index	6.35	6.67	6.78
Percent Scraper	1.65%	5.42%	7.33%
Percent Shredder	3.35%	3.22%	2.88%
Percent Collector/Gatherer	41.89%	31.76%	16.51%
Percent Filterer	7.51%	23.10%	35.08%
Percent Predator	5.44%	10.80%	8.07%

Table 3. Wilcoxon rank sum test for significance

Indices	**Pre vs. Baseline**	**Baseline vs. Post**	**Pre vs. Post**
MMI	0.651	0.726	0.921
EPT	**0.002**	0.744	**0.009**
Margalef's Richness Index	0.051	0.338	0.179
Shannon-Wiener Index	**0.015**	0.072	0.093
Pielou's Evenness Index	**0.015**	**0.043**	0.169
Hilsenhoff Biotic Index	0.339	0.966	0.435
Percent Scraper	0.095	0.695	0.087
Percent Shredder	0.617	0.851	0.754
Percent Collector/Gatherer	**0.033**	**0.001**	**0.000**
Percent Filterer	**0.045**	**0.002**	**0.001**
Percent Predator	0.460	0.302	0.730

The improved number of EPT taxa was likely due to increased presence of opportunistic EPT taxa from families such as Baetidae (Ephemeroptera) and Hydropsychidae (Trichoptera), which are known to quickly colonize available habitat (Tullos et. al, 2008). These taxa, although pioneering, may be an indication that stream restoration created improved or at least additional available habitat. Increased percent filterer taxa, such as Hydropsychidae, pre- vs. post-restoration, may be a result of the additional available surface for filter taxa to colonize. Additionally, stream restoration often created a more concentrated baseflow regime within the channel environment, which may have improved the ability of filter taxa to feed. It should be noted that this study did not conduct empirical measurements of fine particulate organic matter (FPOM) availability.

The significant decreases noted for collector/gatherer taxa, post-restoration compared to pre-restoration, were more difficult to determine because this FFG typically includes the most numerous taxa. However, it is known that collector/gatherer taxa are dependent on an accumulation of FPOM with an unrestored stream reach. Many of the stream restoration projects included substantial channel modifications which may temporarily reduce accumulated FPOM and for that matter coarse particulate organic matter (CPOM) from the system. There may be an associated lag time for the accumulation of these organic materials in the post-restoration stream channel to produce a rebound in the percent collector/gatherer taxa.

The analysis indicated that the MMI metric did not demonstrate a significant difference between pre- vs. post- or baseline vs. post-restoration datasets. While the MMI metric may be beneficial for a broader evaluation of the benthic community, it did not appear to capture narrower changes among the benthic community. Species abundance and diversity, which were measured using Margalef's, Shannon, and Pielou's Indices, also did not demonstrate a statistical difference between pre-and post-restoration.

Percent scraper and shredder taxa did not indicate a significant difference between overall pre- and post-restoration averages, however noteworthy trends were noted for individual post-restoration monitoring years for scraper and shredder taxa and were in fact inverse of one another. In other words, percent scraper taxa decreased through time post restoration while percent shredder taxa increased through time post restoration. This trend may be associated with decreasing in stream temperatures as well as more diverse food availability after the initial years following construction. These observations were also documented by Sweeney et. al. (2004).

CONCLUSIONS

Through the implementation of post-development stormwater management practices since 2000 and other activities associated with the WPP and the WIP, long-term benthic macroinvertebrate community data suggested that aquatic conditions are being maintained and are not experiencing further degradation. Watershed changes due to land clearing prior to the mid-20th Century resulted in excessive sedimentation within stream channels. Since the 1970s, population growth in the County has accelerated, leading to dramatic increases in suburban and urban land uses. While some structural stormwater controls were present to prevent flooding, changes in the frequency, intensity, and duration of stormwater flows persisted. Since the early 2000s, stormwater design standards have been in place to further standardize the performance of stormwater controls to improve water quality, channel morphology, and flood protection resulting from impervious areas. However, much of the County was already developed prior to these current standards. Since the early to mid-2000s, which coincide with DWR's long-term monitoring program, stream conditions appear to have stabilized. However, the results of the monitoring data suggest that overall aquatic conditions remain degraded, compared to reference conditions, for much of the County, which may primarily be associated with the impacts from pre-2000 development activities.

Benthic macroinvertebrate monitoring at WIP projects, suggested that stream restoration has produced a number of beneficial results including improved channel bed and bank conditions that have increased habitat diversity and stability and generated conditions favorable for a variety of benthic taxa. The results also suggest that benthic macroinvertebrate communities demonstrated a functional response pre- and post-restoration, which were consistent with other studies (Tullos et. al, 2008; Poff et. al, 2006), as well as a statistically significant improvements in EPT richness. While the results suggested that the benthic macroinvertebrate communities were not comparable to reference conditions, these improvements were an indication that DWR's management activities had a positive influence.

The goals for WIP projects are multifaceted and include reducing streambank erosion and sedimentation as well as improving in stream physical habitat and water quality conditions. Going forward GCDWR will continue to address these reach-scale impairments along with watershed-scale factors such as upstream hydrology and water quality inputs. Through the long-term monitoring program, GCDWR has gained an understanding of the functional dynamics of the benthic community in response to stream restoration, which has informed design strategies. Additional strategies that may be incorporated that use benthic functional traits to guide or enhance restoration outcomes were suggested by Tullos et. al. (2008), and include, 1) utilize pre-restoration monitoring to identify missing ecosystem functions or habitats (such as coarse bed materials, woody debris, leaf packs and fine root hairs) to further define restoration objectives; 2) develop restoration designs to replace missing ecosystem functions/habitats and enhance existing impaired functions/habitats; 3) use informed post-restoration monitoring to evaluate both short-term and long-term responses of benthic macroinvertebrate communities to expected functional outcomes.

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