Defining limits for small stream biological criteria for use in stream restoration monitoring

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List of Abbreviations

Table 1. List of Abbreviations

Abbreviation	Description
BAU	Biological Assessment Unit
Corps	US Army Corps of Engineers
DENR	Department of Environment and Natural Resources
DWQ	Division of Water Quality
DWR	Division of Water Resources
EPT	Ephemeroptera Plecoptera Trichoptera
BI	Biotic Index

Table of Contents

List of Tables

List of Figures

Section 1 – Report Introduction and Background

1.1 Executive Summary

Millions of dollars are spent every year on stream restorations that have nebulous goals such as "improving water quality". North Carolina Division of Water Quality has measured the water quality of its streams for nearly 30 years by looking at the macroinvertebrate community. In 2009 NC DWQ developed biological criteria for rating headwater streams, streams with watersheds smaller than three square miles, which is where most stream restorations are built. The problems with wide spread use of the criterion were the small sampling period (April and May) for which it was tested and that no samples collected were in streams smaller than 0.5 mi^2. The work done as part of this grant was designed to evaluate if this criterion could be used in months in addition to the April - May index period or if seasonal corrections could be applied to compare other months to this criterion. In addition, intermittent and perennial streams smaller than 0.5 mi^2 were sampled to document the smallest stream size where these criteria apply and to determine whether any criteria in addition to Biotic Index could be used to measure water quality.

One hundred and twenty-five macroinvertebrate samples were collected from watersheds of different sizes in twelve streams, six in the mountains and six in the piedmont, during every month of the year. Samples were collected using the DWR Qual4 method, which has been determined to be the appropriate sampling method for small streams by DWR's Biological Assessment Unit.

It was determined that samples collected in March, April, May, June, October and November all yielded comparable results and therefore the index period could be expanded to include these months. No seasonal corrections for other months were identified. A large percentage of piedmont streams dried during the summer of 2012, so there were insufficient samples collected outside the index period to determine appropriate correction factors.

It is possible that EPT Taxa Richness and Specific Conductance could also be used to identify sites under stress. With the exception of streams with very low specific conductance (<= 15 µS), EPT Taxa Richness captures impacts due to sedimentation in mountain streams that are not reflected in the Biotic Index. Specific conductance values >100µS in this study were only found in streams with bioclassifications of Fair or Poor. A larger study done by Gale (Appendix 3) found this impaired/unimpaired cut off for specific conductance in NC piedmont streams to be 150µS.

Efforts to link water quality to land use, using a Land Development Index developed for wetlands, were not as successful as hoped. Estimates of land use were at best moderately correlated with water quality (r^2 values ranging from 0.20-0.55). Correlations were generally higher in the Piedmont than the Mountains, probably due to the Piedmont sites having a wider variety of land use types.

Thirty-six samples were collected in stream segments with drainage areas less than 0.5 mi^2. The smallest watershed sampled was 0.07mi^2 (45 acres). While this criterion could not be used in streams that dried during the year (intermittent), the limit below which a perennial stream was too small to be rated by this method was a physical one – the stream had to be deep enough for water to flow into the net.

In a separate database collected over the last ten years, macroinvertebrates have been repeatedly sampled before and after construction at 22 stream restorations using Qual 4 methods. Six of these restorations were monitored during the six month index period so bioclassifications were assigned to these historic stream restoration benthic data. An increase of one or two bioclassifications appears to be an achievable success criterion for stream restorations whose goals include improving water quality. It also appears to be the case that streams with Good or Excellent water quality before restoration will be unlikely to see a measurable increase in bioclassification.

1.2 Project Introduction and Background

For the millions of dollars spent on stream restorations every year in North Carolina, assessing the success of a restoration has tended to be rather simplistic compared to the variety of ecological factors that are regularly claimed to be improved by a restoration project. In addition, the Federal Mitigation Rule (USACE and USEPA, 2008) requires the use of ecological performance standards for determining success.

Currently, general stream stability and adequate buffer regeneration are the major measures of success as recommended in the 2003 Stream Mitigation Guidelines (USACE et. al., 2003). However, historical and current success criteria do not necessarily provide a clear indication of water quality or functional improvement of the aquatic system, which are listed as goals in the majority of stream restoration plans. This grant reviewed long-term stream restorations to document water quality improvements using a recently validated small stream metric (Biotic Index) (Fleek 2009). Also, since the majority of stream restoration projects have occurred on these small (first and second order) streams, we tested and refined the Biotic Index's discriminatory power in very small streams with an eye toward using this method to document ecological uplift in future stream restorations for the next version of the Stream Mitigation Guidelines.

The work completed in this grant was an expansion and fusion of work previously done by North Carolina stream biologists. From 2001-2004, David Penrose collected macroinvertebrate data from a subset of stream restoration projects to document changes in the aquatic community before and after stream restoration (EPA grant CD984487-98). At the time, the usefulness of his work was limited because there was no metric that had been proven to measure water quality improvement (ecological uplift) in these small (first and second order) streams. Thus there could be no success criteria by which to demonstrate instream biological success of stream restorations.

In 2009, Eric Fleek (BAU) developed a monitoring metric that accurately assessed water quality using benthic macroinvertebrates for mountain and piedmont small streams down to 0.5 to 1 mi^2 watersheds sampled during the months of April and May (Fleek 2009). This metric has the potential to be useful for assessing the ecological uplift of stream restoration projects. However many restorations built today are in headwater systems that are smaller than the 0.5 square mile (320 acres) watershed lower limit of this metric's testing, therefore determining what the applicable lower limit of this biological metric is essential for assessing stream restoration biocriteria success in very small watersheds.

While there is some lower limit to this metric's ability to accurately assess water quality, it was estimated that it probably occurred between a stream's intermittent/perennial point (mean size 12 acres in the mountains and 30 acres in the piedmont of NC (Periann Russell DWQ Personal communication) and the 320-640 acres that was the limit of testing for this project.

The grant tested this metric at these smaller stream sizes over a wider window of sampling dates (index period) to increase the number of stream restoration projects whose ecological uplift, and thus biological success, could be measured using this metric. Once the full extent of this metric's usefulness is known, it can be used to document ecological uplift in current stream restoration projects, which could lead to more accurate awarding of mitigation credit. It would also allow DWR staff to revisit historic restoration projects (collected by Dave Penrose and others) to determine how long after restoration it may take a stream to demonstrate the ecological uplift promised by the restoration provider and credited as mitigation. This metric can then be potentially incorporated into Corps stream mitigation guidance and rules as is appropriate.

1.3 Project Study Objectives

The project study objectives are the following:

- Determine if there is a reference sampling period within which the biological criteria will be applicable beyond the current April- May period.
- Determine the lower size limit of watersheds (< 320 acres / ½ square mile) where the Biotic Index metric can provide accurate biocriteria for assessing stream quality.
- Investigate whether there are any other metrics in addition to Biotic Index that can assess water quality.
- Assess how much ecological uplift can be expected from a restored stream and how long it might take a restored stream to demonstrate this uplift.
- Develop a tool that could be utilized as a monitoring metric for future stream restoration projects that claim ecological uplift of the aquatic system as one of the goals of the project.

1.4 Project Study Design

A key task in this project was to develop a statistically sound method for collecting and analyzing benthic macroinvertebrate data and determine what watershed size and what time of year could provide accurate bioclassifications using small stream biocriteria. Currently criteria have been validated for streams with watersheds greater than 0.5 mi^2 when sampled in the months of April and May. Sampling at selected sites in April or May and again in other months will address the temporal component, while sampling a stream greater than one square mile drainage, then sampling at multiple locations upstream addressed the spatial component.

Section 2 – Methodology

2.1 Site Descriptions and Location

Twelve streams, six in the mountains and six in the piedmont, were selected for this study. These streams were selected, as much as possible, in different counties and river basins. Four stations/site were sampled, station 1 was <0.1 mi^2 while station 4 > 3 mi^2. The following maps and photos attempt to give the reader an idea of where these streams are and what they look like.

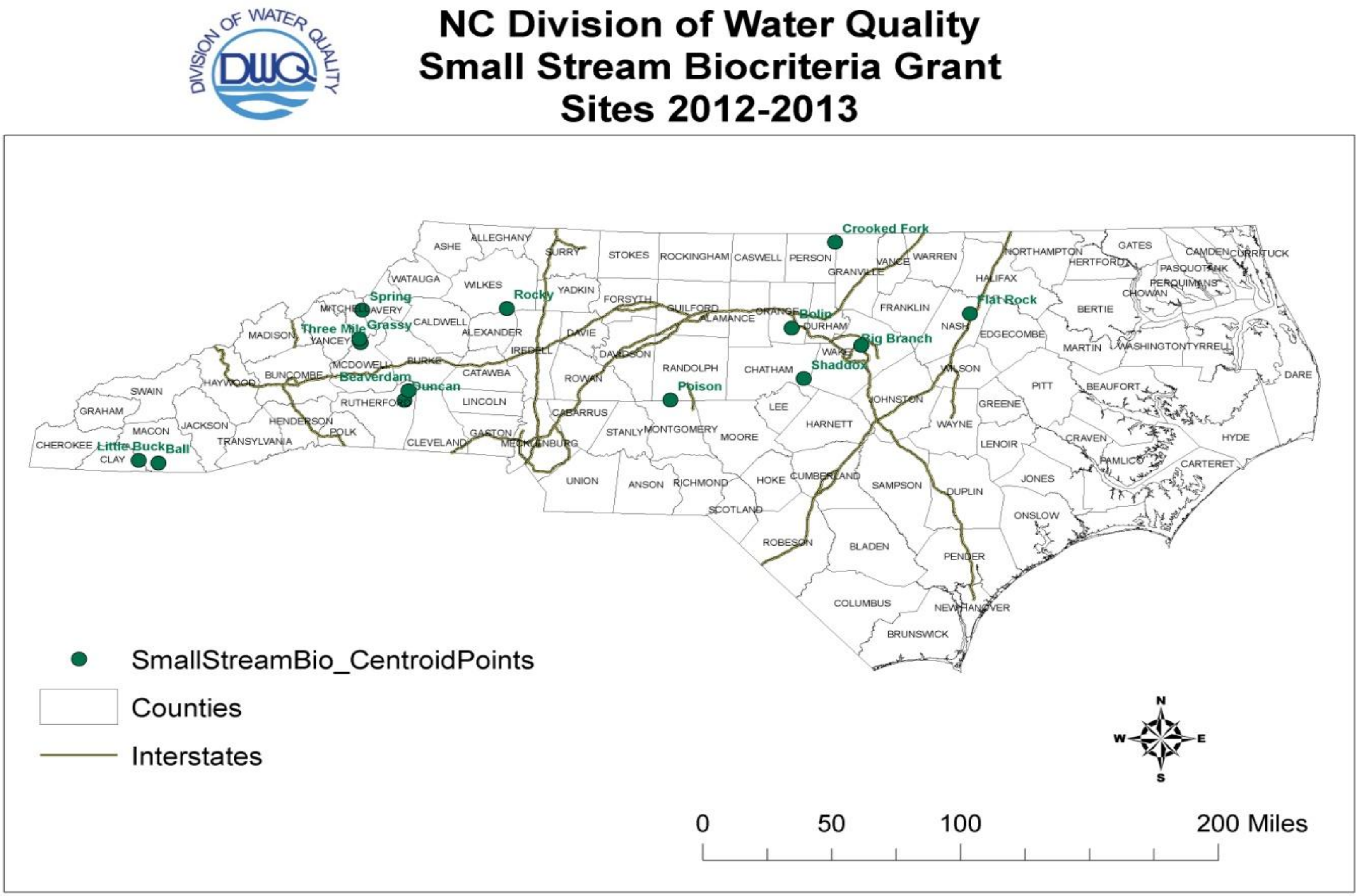

Figure 1. Site Location Map

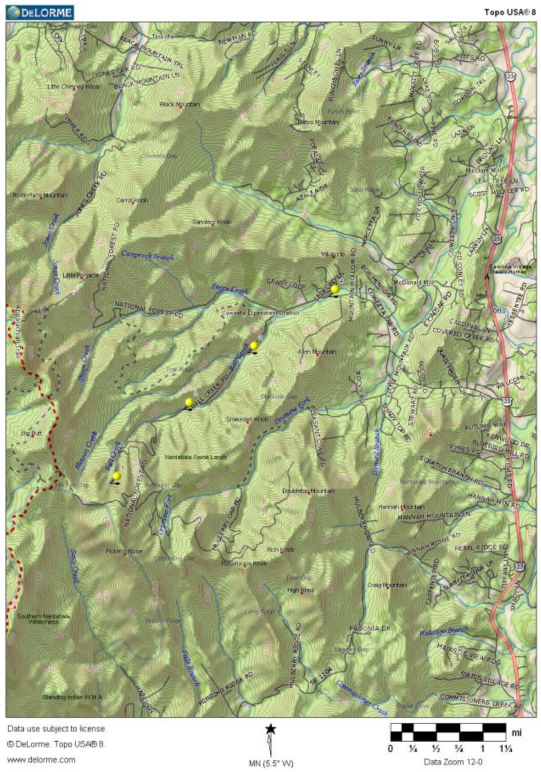

Figure 2. Ball Cr, Macon Co Site

Figure 3. Ball Cr # 1

This stream is located within the Coweeta Hydrological Station and is arguably the most unimpaired stream in this study, with specific conductance values regularly below 15 µS. The macroinvertebrate sample collected in October 2012 had a Biotic Index value of 1.4 (on a scale of 1-10), the lowest in this study.

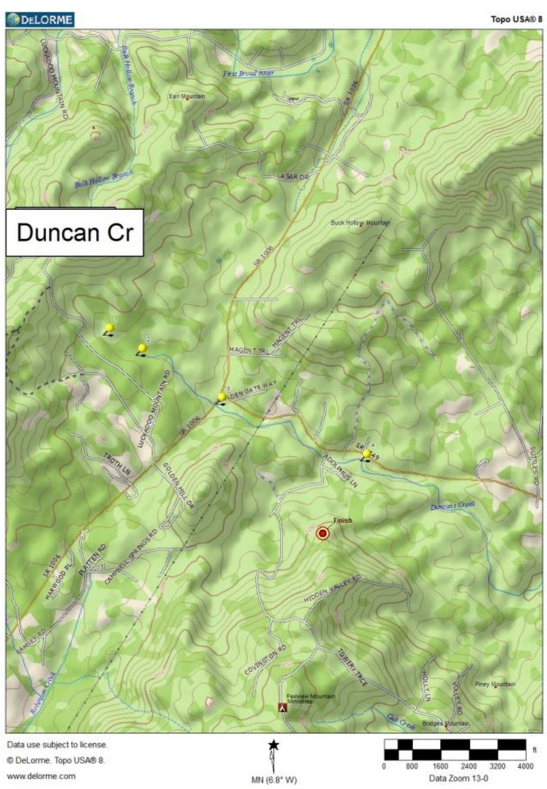

Figure 4. Duncan Creek, Rutherford Co Site

Figure 5. Duncan Creek #1

Duncan Creek begins in a mostly undisturbed catchment. Increasing amounts of development and decreasing slope downstream allows for a very sandy substrate in the lower sections. Active pasture above station 4 is probably responsible for the decline in Bioclassification at that station.

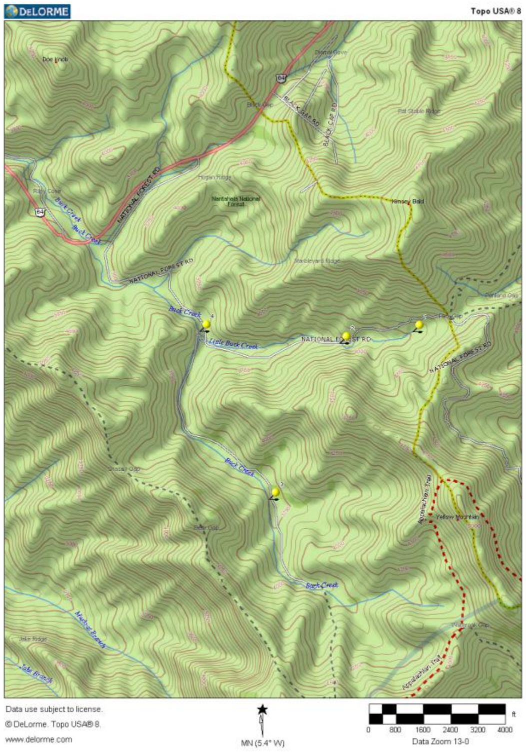

Figure 6. Little Buck Creek, Clay Co Site

Figure 7. Little Buck Cr #1.

Little Buck Creek is a minimally impacted stream in the Nantahala National Forest. Station 2 was impacted by beavers who built dams that flooded most of the reach midway through the study. Station 3, on Buck Creek, was not sampled because of a forest service gate across the access road.

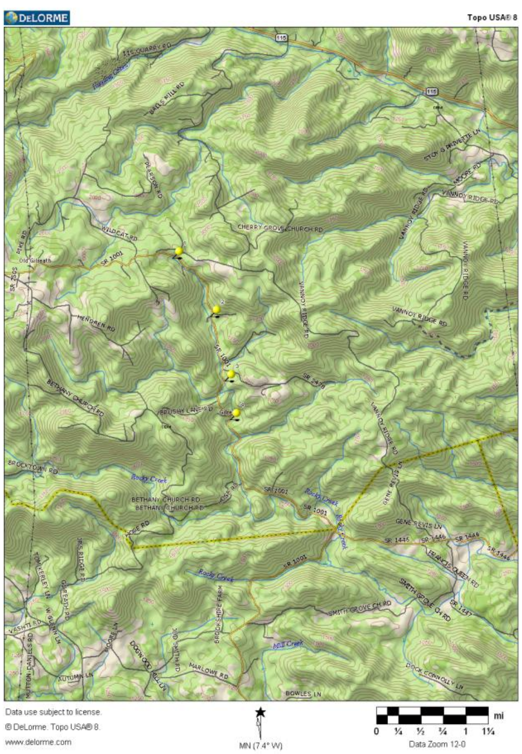

Figure 8. Rocky Creek, Wilkes Co Site

Figure 9. Rocky Creek #4

This stream, draining the Brushy Mountains, was the furthest east mountain site in this study. In the spring of 2013, two very rare mayflies, *Barbaetis benfieldi* and *Baetopus trishae,* were collected at Station 3; a significant range extension for both species.

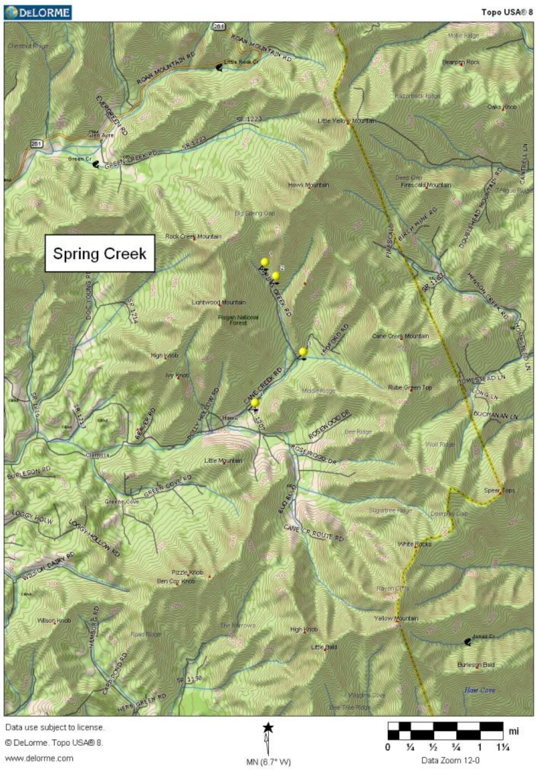

Figure 10. Spring Creek, Mitchell Co Site

Figure 11. Spring Creek #2

This steep stream begins in a wooded watershed with increasing levels of development beside the stream. Station 4 had been channelized. The site pictured above is home to a midge previously unknown to science.

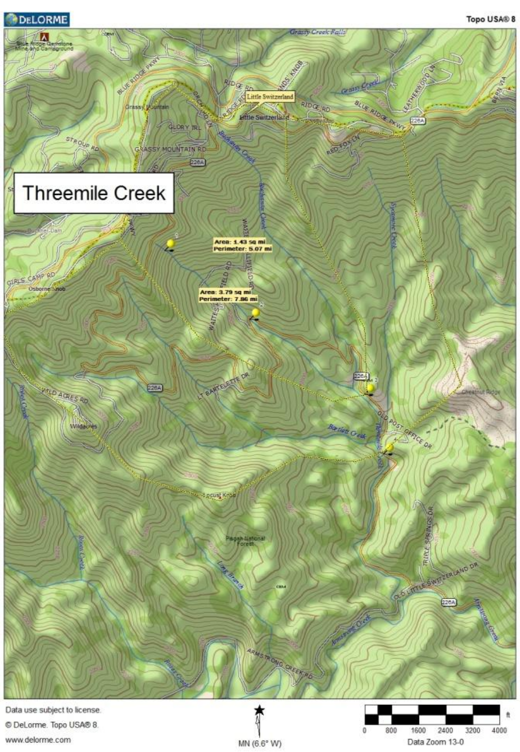

Figure 12. Threemile Creek, McDowell Co

Figure 13. Threemile Creek #2

The headwaters of this stream include the Blue Ridge Parkway near Little Switzerland. This stream suffered from large amounts of sediment (pictured above) and high specific conductance values (80-100 μS) from an undetermined source.

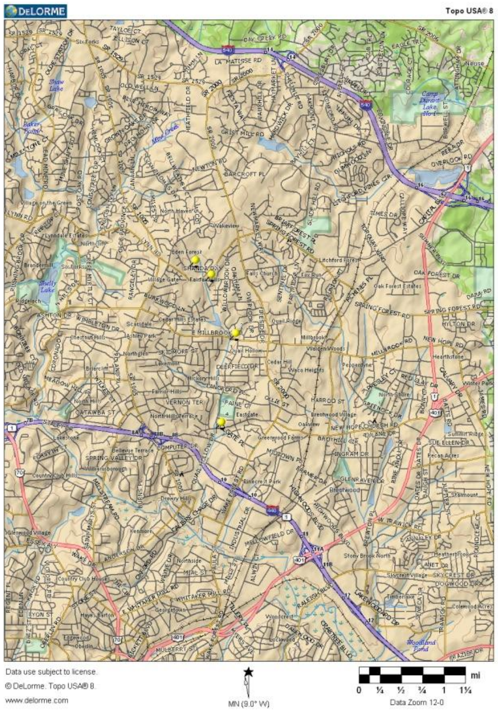

Figure 14. Big Branch, Wake Co Site


Figure 15. Big Branch #4

This stream was the most heavily urbanized in this study. Its origen was a stormwater culvert with evidence of urban impacts throughout its length. As a result it had some of the highest Biotic Indices (most tolerant aquatic communities) in this study.

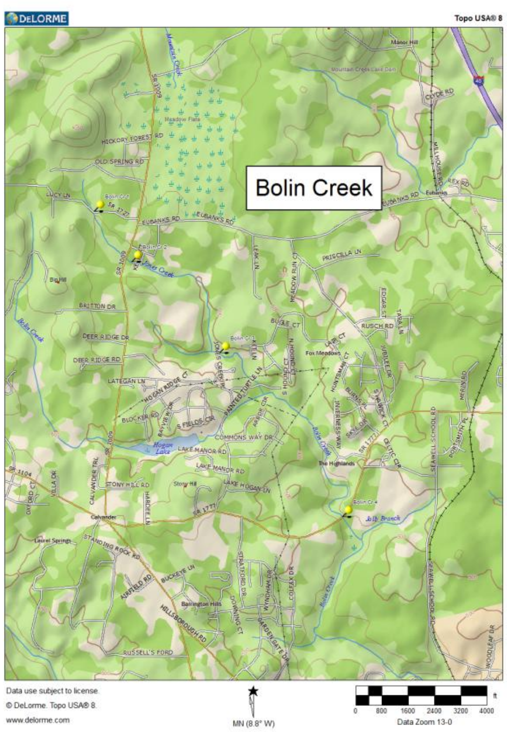

Figure16 . Bolin Creek, Orange Co Site


Figure 17. Bolin Creek #4.

In this study, three streams were located in the Triassic Basins and Slate Belt Ecoregions. The station pictured above was the only site of those three that did not dry during the summer. Even so, this station is impacted by runoff from suburban Carrboro.

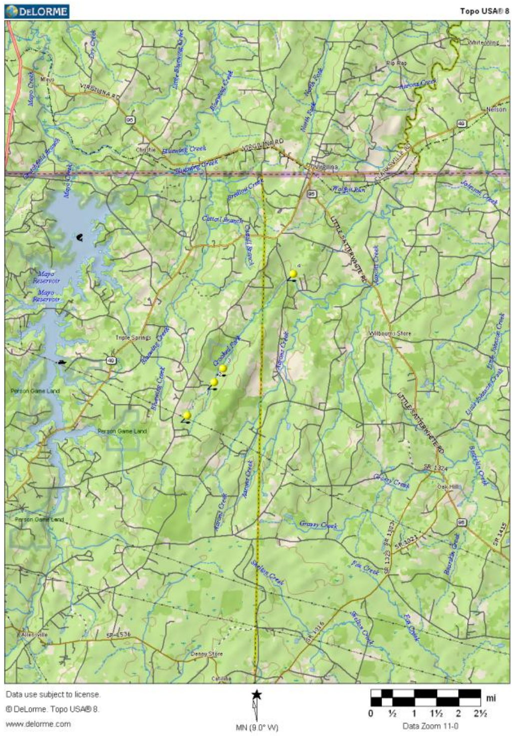

Figure 18. Crooked Fork, Person and Granville Counties Site


Figure 19. Crooked Fork #4 August 2012

Like Streams in the Triassic Basins, streams in the Slate Belt had poorly defined headwaters and tended to dry up in the summer. The site pictured above had a four square mile watershed. Land use in the watershed was a mix of forest and row crops.

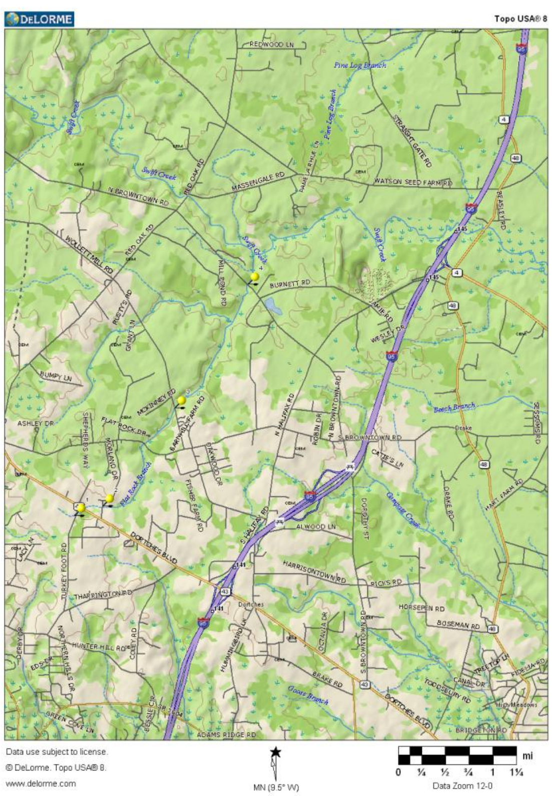

Figure 20. Flat Rock Branch, Nash Co Site


Figure 21. Flat Rock Branch #1

This stream starts in a pasture next to a feed lot (note algae mats in photo). The upper portion of the stream is dissected by a series of instream ponds. Station 2 was not sampled because the site was one of these ponds. Further downstream the agricultural impacts are lessened, however algae is a recurring problem.

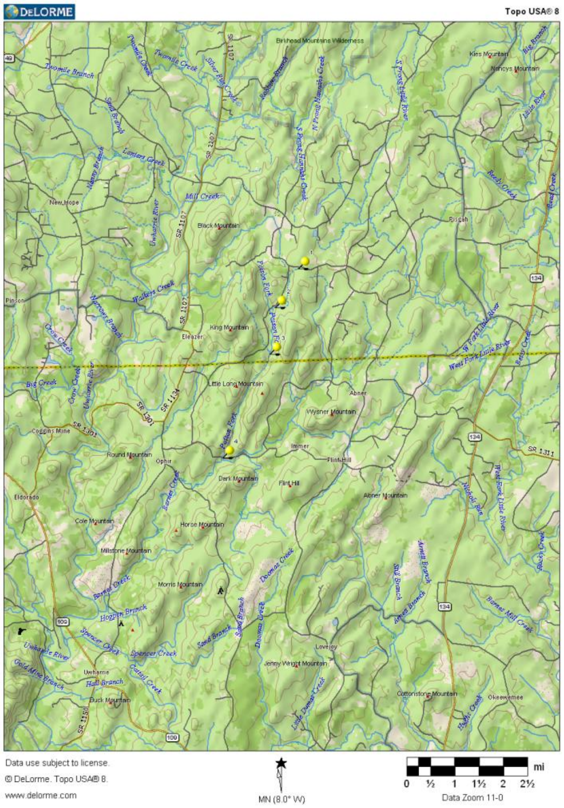

Figure 22.Poison Fork, Montgomery Co Site

Figure 23. Poison Fork #1.

Despite its name, this stream was the closest in the study to a reference Piedmont stream. Land use was almost entirely forested with the occasional single family dwelling. Unlike Crooked Fork, the other Slate Belt stream in this study, Poison Fork never dried or even stopped flowing for the duration of this study.

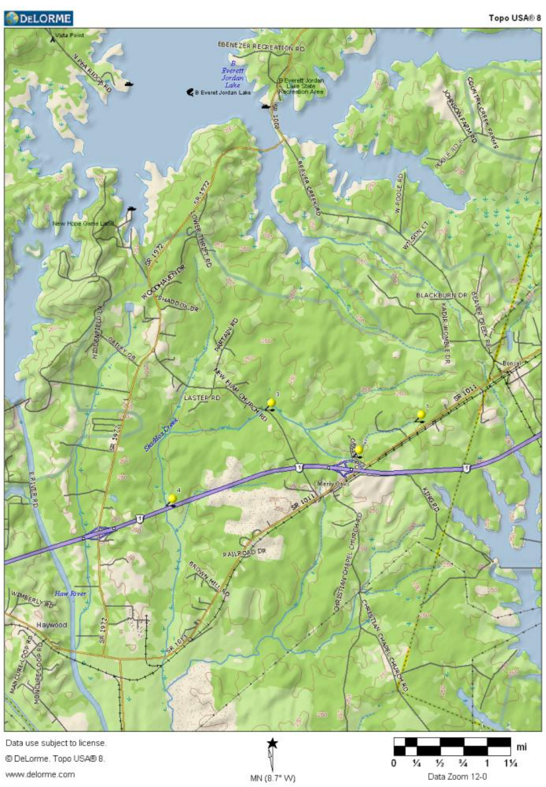

Figure 24.Shaddox Creek, Wake Co Site

Figure 25. Shaddox Creek #4, August 2012

The watershed of Shaddox Creek was primarily forested with a mix of single family houses. During the study several hundred acres of forest above Station 3 were cleared for development. Located in the Triassic basin, Station 4 (Figure 25), with a 5.3 mi^2 watershed, dried in the summer.

2.2 Sampling Methodology

Aquatic macroinvertebrates collected for this grant were collected using DWQ's Qual 4 collection technique (NCDENR 2012). The Qual 4 is an abbreviation of the standard qualitative method designed to be used only in small streams, originally defined as those that are less than 4 meters wide, now defined as having a drainage area $\leq$ 3 square miles. In this method, 4 samples are collected: one Kick, one Sweep, one Leaf-pack, and a visuals examination of rocks and logs to collect rare or tightly attached taxa. Samples are picked and preserved in the field and all taxa are collected to an abundance of up to ten individuals.

Following collection, samples were returned to the office where they were identified to the lowest practical taxonomic unit and the taxa list compiled on bench sheets. Summary statistics, such as Total Taxa Richness (TOTS), EPT Taxa richness (EPTS) and Biotic Index, were calculated. Bench sheets and habitat assessment forms were entered into Excel spreadsheets while awaiting quality assurance (QA) from the Division's Biological Assessment Unit (BAU). After QA, sample data will be included in the BAU invertebrate database and samples will be archived with other BAU samples. Interesting mature crayfish and mollusks collected as part of this sampling were given to the North Carolina Museum of Natural Sciences for curation.

2.3 Data Analysis

The BAU database is designed to allow input only of previously accepted taxa names. While typing the taxa name appears on screen giving the data entry operator the opportunity to verify that each taxon was input correctly. Once data entry is done, summary statistics, such as total taxa entered, are displayed so data entry operators can check the total number of taxa on the bench sheet against the number of taxa in the data record.

A semiquantitative collection of the macroinvertebrate population at a site is, by definition, a variable thing. The community is shifting between seasons as well as years. For this reason, summary statistics describing the community are often more useful than comparing taxa lists. The main summary statistic used in this project is the Biotic Index – a measure of the overall intolerance of the aquatic community whose method of calculation is listed on page 13 of the BAU SOP (NCDENR 2012). Biotic Index (BI) was used to determine which months and watershed sizes give the same bioclassification at a site as the current index period of April and May on a stream with a watershed sized three square miles or smaller.

Section 3 – Results and Discussion

<u>Mountain Data Summary</u>

It appears that in the mountains, biotic index is unaffected by stream drainage area (Figure 26). For the three months currently used as the Index Period for this metric, a correlation of <1% (r^2 = 0.0087) between Biotic Index and Drainage Area in streams rated Excellent demonstrates that stream size does not affect the Biotic Index metric, thus making a very stable metric no matter how small the stream. This is very comparable to the original study, which found an r^2 of 0.010.

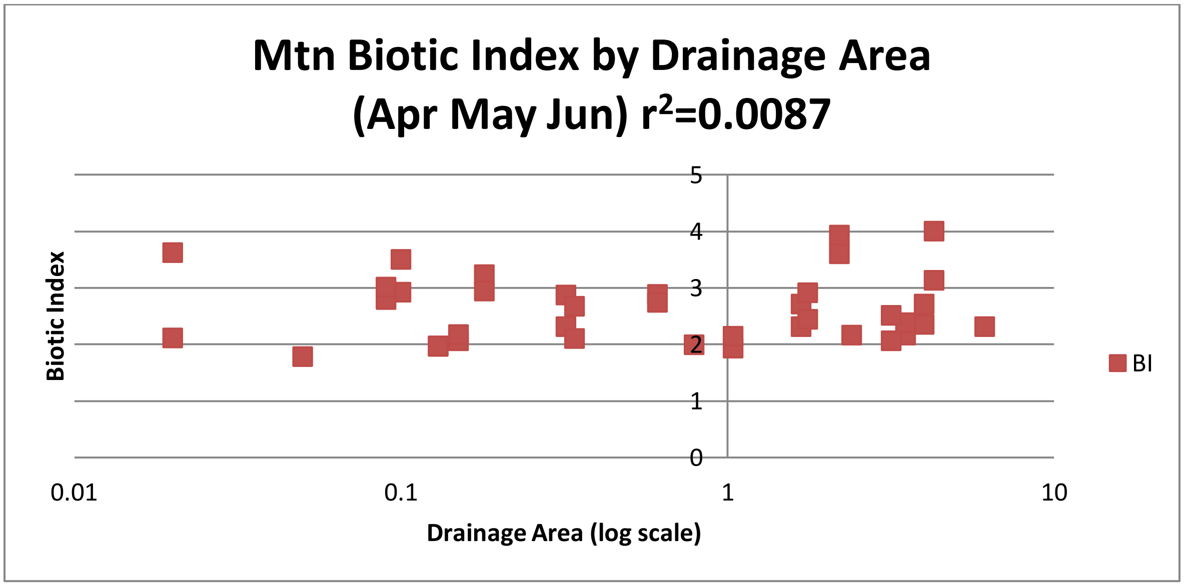

Figure 26. Biotic Indices for Mountain Streams by drainage area in index period.

Comparison of Biotic Indices by month (Figure 27), shows that the Index Period of this metric can be expanded to include the six months of March, April, May, June, October and November without resorting to seasonal correction. Two samples collected in the December – February window and two in the July – September window showed conflicting trends, so it was not possible to determine seasonal corrections with this small sample size outside the index period. Appropriate seasonal correction for non-index months may be determined with additional samples during these months.

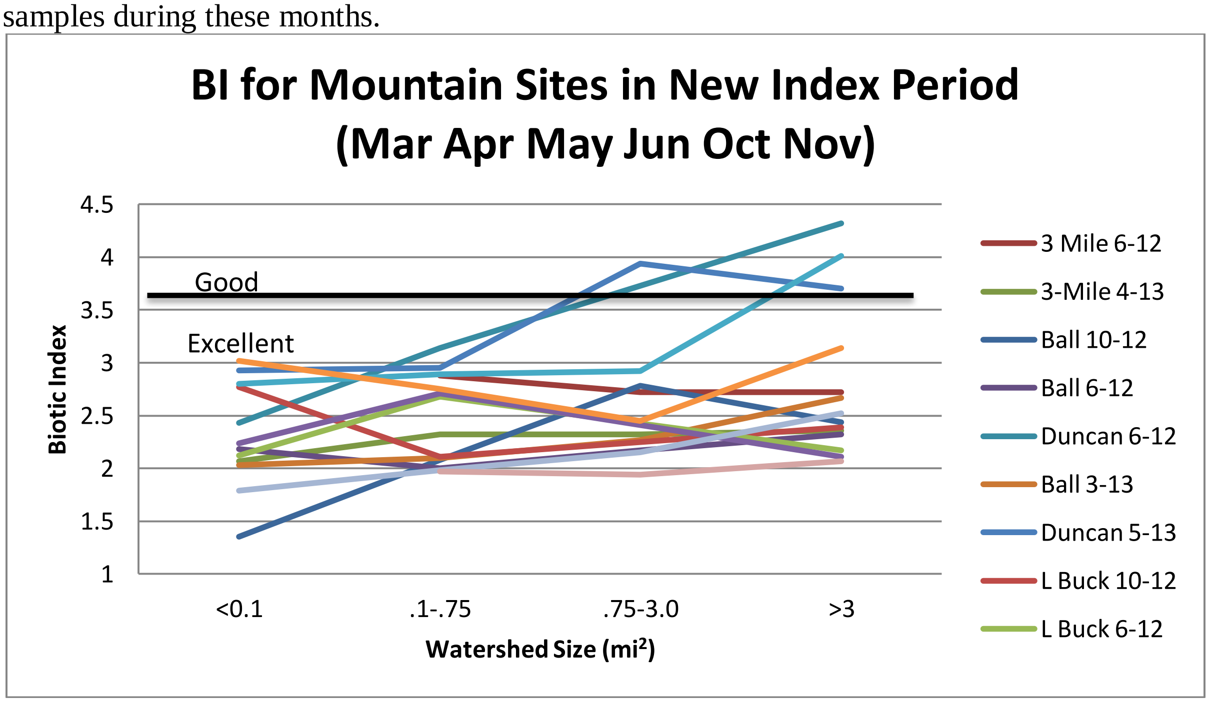

Figure 27. Biotic Indices for Mountain Streams in Six Index Months.

Unlike the Biotic Index, EPT taxa richness is correlated with drainage area (Figure 28). When graphed logarithmically, there appears to be a solid correlation (r^2=0.519) between EPT taxa richness and the log of the drainage area of the stream. Using the regression equation in Figure 28 to calculate the expected reduction in taxa richness as a stream gets smaller, Table 2 is a summary of how this reduced expectation of EPT taxa in small streams would affect biocriteria in progressively smaller watersheds.

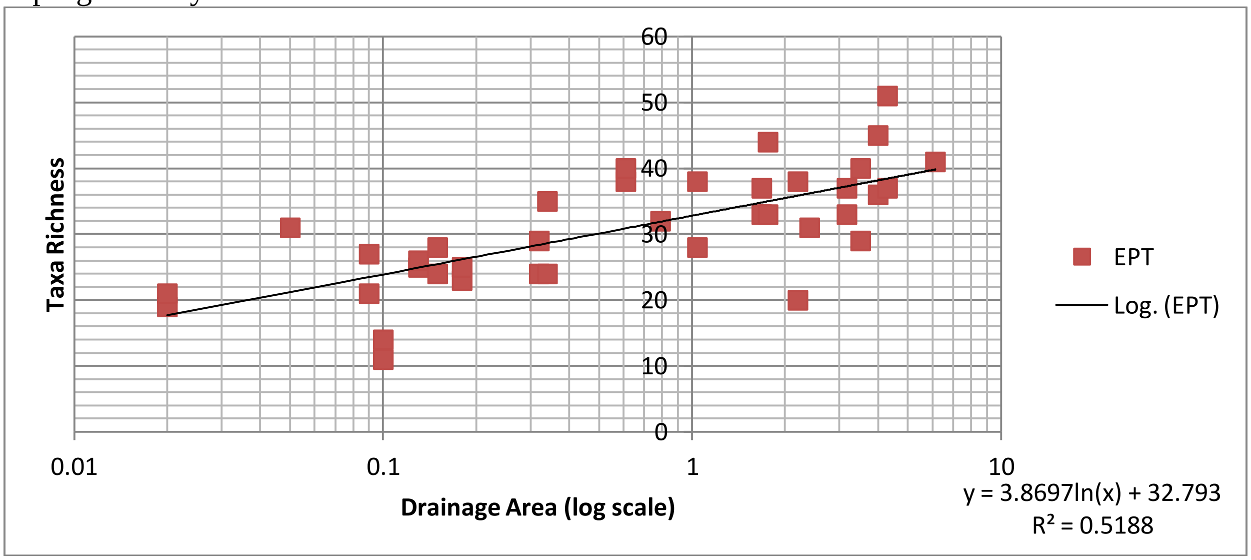

Figure 28. EPT Taxa Richness for Mountain Streams of Different Drainage Areas.

Of the 58 samples in this analysis, 29 (50%) were given a bioclassification based on EPTS that was different from the bioclassification given by BI. Ten of these 29 differences in classification come from Ball Creek and Little Buck Creek, streams with very low specific conductance (<15 µS) and no development in the watershed. Apparently the low number of ions in these streams means that there is a limited amount of, among other things, food particles suspended in the water column, thus limiting the number of individuals and taxa in these nutrient poor streams. This appears to be the main difference between the proposed Mountian criteria in Table 2 and the High Quality Small Mountain Stream Criteria adopted by BAU in 1991 (NCDENR 2012, page 20). These criteria were derived before BAU started regular widespread collection of meter parameters, but the streams for which these criteria were designed were these these high elevation, low conductivity streams. The correction factors, 1.25 for approximately 1-2 mi^2 streams, and 1.45 for 0.1-1 mi^2 streams also factors in this naturally reduced taxa richness.

Table 2. Proposed Mountain Biological Criteria for EPT Taxa Richness at Different Watershed Sizes.

Bioclass	>3 mi^2	2 mi^2	1 mi^2	0.5 mi^2	0.25 mi^2	0.1 mi^2
Excellent	>35	>35	>33	>30	>27	>24
Good	28-35	28-35	26-33	24-30	21-27	18-24
Good-Fair	19-27	19-27	18-25	16-23	14-20	13-17
Fair	11-18	11-18	10-17	8-15	7-13	6-12
Poor	0-10	0-10	0-9	0-7	0-6	0-5

There were two other instances where bioclassifications from the Biotic Index were different from bioclassifications based on Taxa Richness. The first was low scores (<=70) on the DWQ habitat Assessment Form, which often indicates observable water quality problems such as sedimentation and loss of aquatic habitat that can affect the number of individuals and taxa that can inhabit a section of stream. The other was streams with high specific conductance (>80 µS), which usually indicates impairment in mountains streams. Gale (Appendix 3) found that specific conductance above 66 µS in mountain streams usually correlated with impaired water quality. All instances of very high specific conductance in this study occurred in Threemile Creek, (Figure 13) which also had a heavy bedload of sand filling pools and interstitial spaces around rocks, thus reducing invertebrate refugia. All sites with low habitat scores were in open areas (fields or active pastures) where trees had been removed and thus banks were eroding badly. In both of these instances, it is likely that the reduction in Taxa Richness is reflecting an impairment to the stream that was not reflected in the Biotic Index.

Piedmont Data Summary

While piedmont sites were originally chosen to have urban and agricultural impacts as well as reference sites (Figure 29), an added layer of complication was also introduced – streams that dry in the summer (Figure 30).

The refence site, Poison Fork, had a mean Biotic Index value 4.24 for its headwaters during the index period (Excellent bioclassification is < 4.36). Of the two impaired sites, Big Branch was an urban stream, while Flat Rock Branch began near a livestock feed lot and ran through a series of ponds on agricultural land. It is interesting to note that the Biotic Index indicated declining water quality as the amount of urbanization in the Big Branch watershed increased, while in Flat Rock Branch, the Biotic Index suggested improved water quality as distance from the intensive agriculture (feedlot and ponds) increased. These data suggest that Biotic Index is a useful metric for perennial piedmont streams.

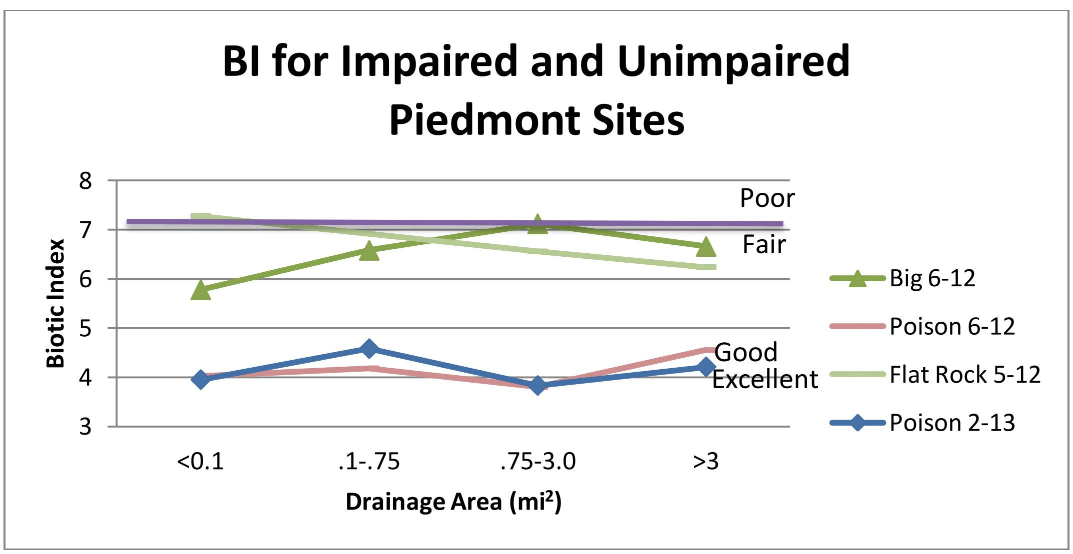

Figure 29. Biotic Indices for Impaired and Unimpaired Piedmont Streams Within Index Period.

The caveat in the previous statement appears to be perennial streams. Three streams in this study (Bolin Creek, Crooked Fork and Shaddox Creek), located in the Triassic Basins and Slate Belt ecoregions, dried in late summer 2012 (Figures 19 and 25) . Both regions are characterized by a thin layer of highly erodable soil overlaying a generally impermeable layer. In the Triassic Basins, that layer is a thick, impervious clay, while in the Slate Belt that layer is slabs of bedrock (Weaver and Pope 2001). As a result, small to mid size streams in these areas dry regularly by late summer which can be as great a stress on the community as anthropogenic inputs. These sites, with little developed land use, have Biotic Indices ranging from 5 – 6.8, which reflects benthic communities with moderate to severe stress (Good-Fair and Fair bioclassifications) (Figure 30). In August of 2012, the only site in any of these streams with water was the most downstream site on Bolin Creek (Figure 17). Probably as a result of its perennial nature, this site had much more consistent between-date BI values (around 6.0) than any other site in this Triassic/Slate Belt group. This reinforces the BAU position that for the Biotic Index metric to be reliable, sampling should only occur in streams with flowing water in them year round.

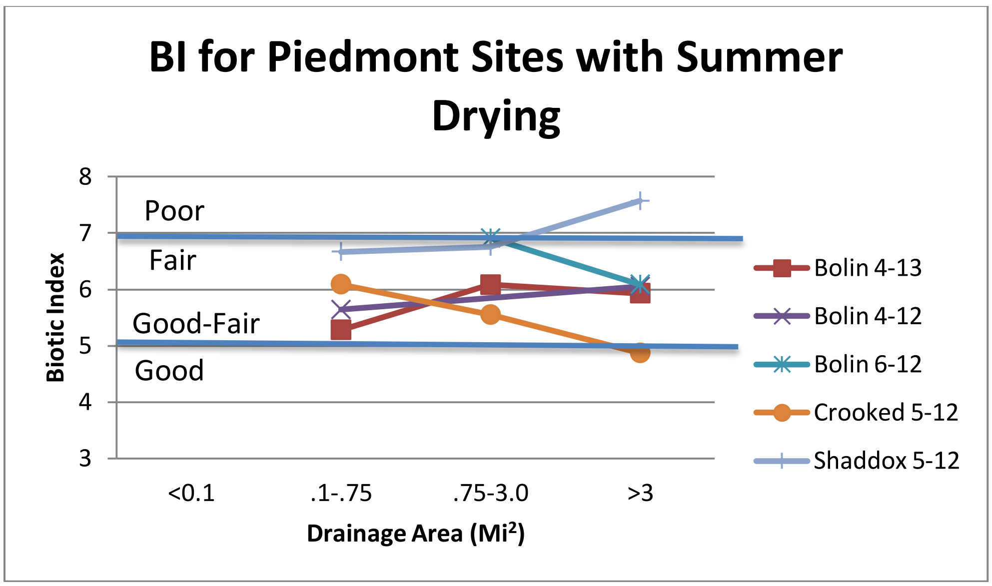

Figure 30. Biotic Indices for Piedmont Streams with Major Summer Drying

Another way of looking at these Piedmont sites is shown in Figures 31 and 32. While the Landuse Development Index (LDI) will be discussed further below, for the purpose of these graphs it is a method of quantifying major land use types into a single metric, as opposed to describing a watershed as X% forest, Y% agriculture and Z% urban. LDI values range from 1 to 8.5. Low LDI numbers indicate a high percentage of forest and other natural features while a high number indicates a high percentage of urbanization in the watershed. In this case, LDI is used to separate out not only reference, agricultural and urban watersheds, but also watersheds where streams dry in the summer (Figure 30). Figure 31 shows that the Biotic Index for sites impaired by agricultural and urban impacts are very similar (6.57 vs 6.70). It also shows that the biotic index of benthic communities in streams that naturally dry (6.17) is almost as high (nearly as stressed) as streams suffering anthropogenic impacts.

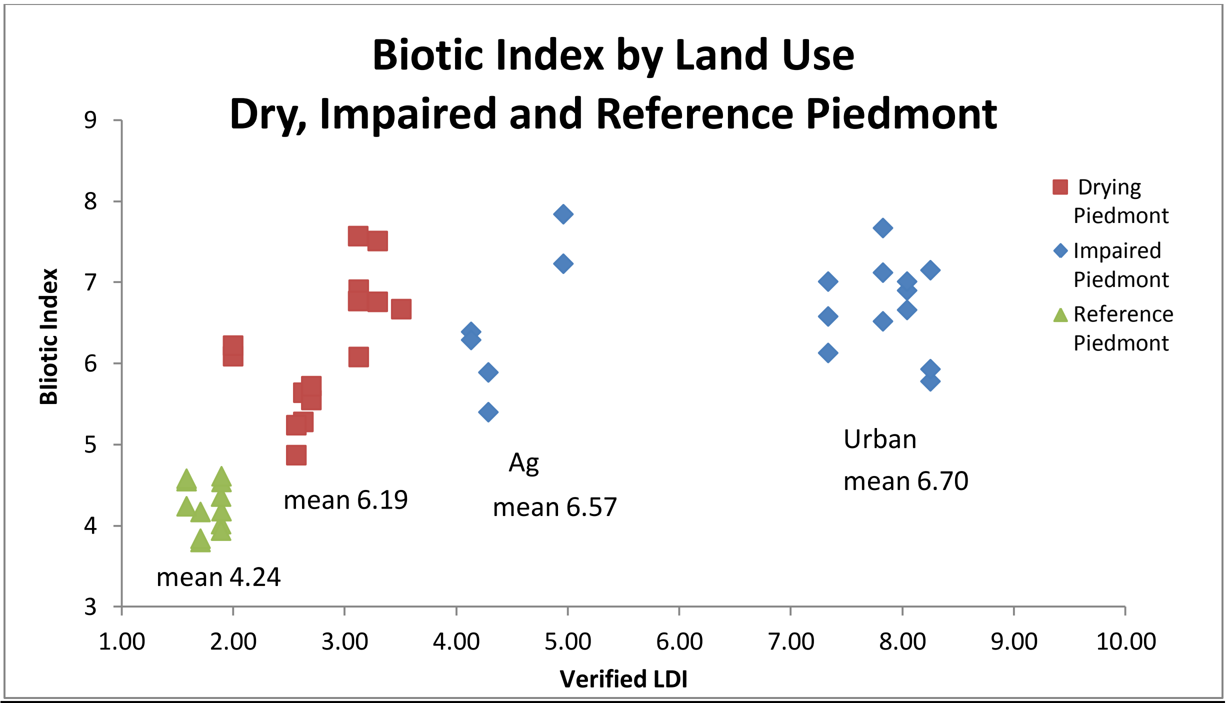

Figure 31. Biotic Index for Reference, Summer Dry and Impaired Piedmont Streams.

A similar graph with EPT Taxa Richness (EPTS), another frequently used metric related to water quality, shows a somewhat different, but no less interesting story (Figure 32). Whereas there was little difference in the BI of sites impacted by agriculture and urbanization, there appears to be more EPT taxa at agricultural sites than urban. Presumably agricultural impairments (primarily nutrients) may be less toxic than urban impairments (metals and hydrocarbons in stormwater runoff). The streams that were minimally impaired except for drying fell in between EPTS values for agriculture and urban sites, more indication that drying is very stressful to the benthic community. This is to be expected, since most of the same EPT taxa used for community assessment are also used to indicate perennial streams – streams that have water in them all the time (NCDENR 2010). One would expect a stream that dried (intermittent) to have few to no perennial indicators (most mature EPTs). In each of these dried streams, usually about 1/3 of the EPT taxa collected are species that are not icluded as perennial indicators (young larvae, winter stoneflies and the caddisfly *Ironoquia punctatissima*).

Also notable between these two graphs is the reference site data. The BI in Figure 31 shows a tight cluster, indicating very little seasonal or size variability with the metric, which has already been documented with a larger data set for mountain sites (Figures 26 and 27). The same is not true of the EPTS values in Figure 32, which shows a spread of nearly 20 taxa over the course of this study. This variability is a function of both seasonal variability and variability with stream size (Figure 28). The site with the smallest EPTS had the smallest drainage area (0.032 mi^2) during the most stressful period (summer), so it was likely the site that had been dry for the longest period, while the site with 30 EPT taxa was the site with the largest drainage area (3.43 mi^2) during the least stressful season (winter) so the expectation would be that this site rarely dried. While there were enough data in mountain sites to estimate this variability, that was not the case in the Piedmont, so any suggestion of how EPTS could be incorporated into small stream biocriteria in the Piedmont will have to wait until more data are collected.

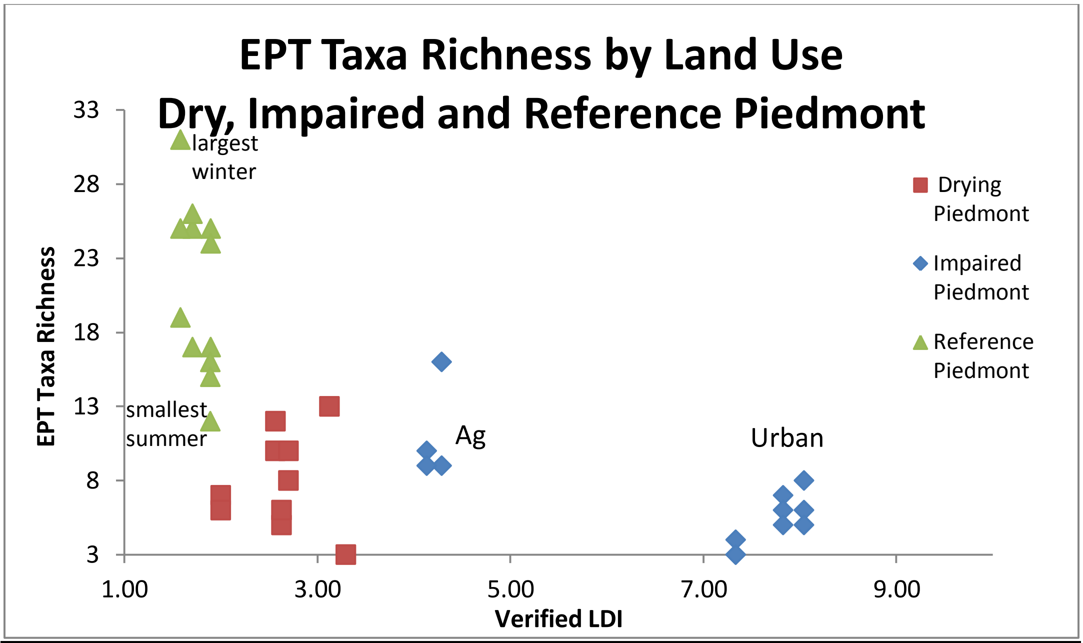

Figure 32. EPT Taxa Richness by Watershed Land Use

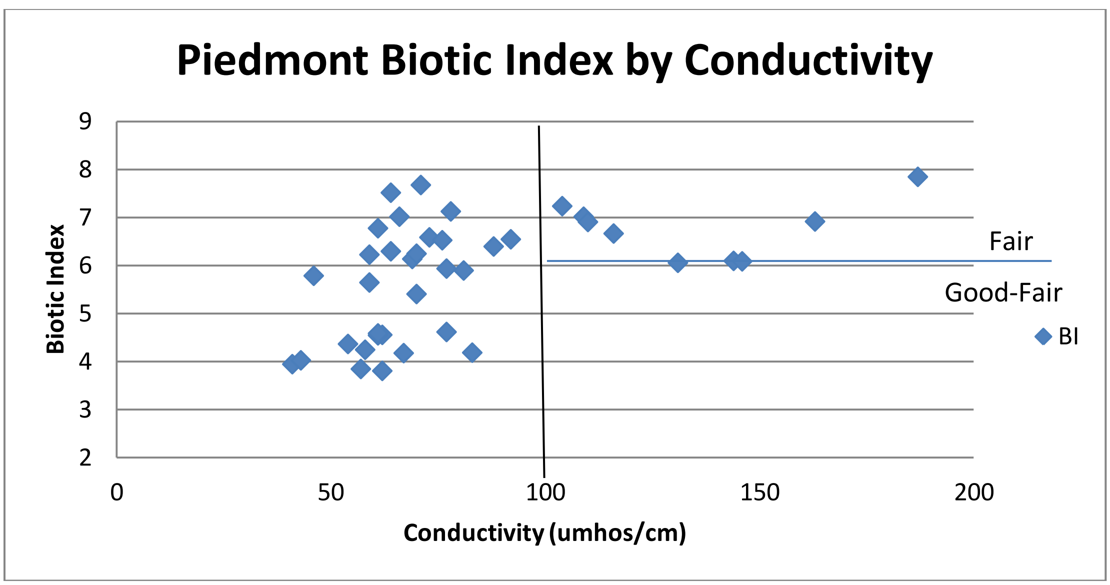

Figure 33. Biotic Index of Piedmont sites by Specific Conductance

Figure 33 looks at benthic community health in another way. Based on the several dozen samples collected as part of this study, there appears to be a threshold of Specific Conductance, around around 100 µS for Piedmont sites, above which most sites appear to be impaired, and another threshold above 150 µS where all sites are demonstrably impaired. Gale found in a study of hundreds of ambient monitoring stations where biological monitoring also occurred

(Appendix 3), that 150 µS was a statistically significant cut off between sites with Good-Fair and Fair bioclassifications. While Gale worked with a much larger dataset (hundreds of observations, rather than our several dozen), her streams were much larger than the ones in this study. It would be interesting to investigate if small streams have naturally lower conductivity than larger streams since they have had less time to pick up ions from sources within the watershed. It may also be the case, however, that as per the experience of David Lenat (personal communication), who has sampled all sizes of streams in NC for over 35 years, that good water quality can be found in urban areas by looking at headwater streams where it is easier to protect and buffer the entire watershed.

<u>Land Use</u>

Part of the discussion of why some sites may be impacted led to an assessment of land use as one metric to predict impairment. The USGS 2006 Land Cover Database (LCDB) was used to get an estimate of land uses for each watershed. LCDB estimates of 2006 data were verified for accuracy against recent (2010 – 2012) aerial photography from NC One Map and updated when necessary. Visual reinterpretation of LCDB land use estimates showed that LCDB regularly misclassified single family homes and small housing developments as either fields (agriculture) or forest (for partially wooded lots). The nine land use categories identified by LCDB and used in this study were combined into a Landuse Development Index metric (LDI) using a process described by Brown and Vivas (2005) developed and modified by DWR for other NC wetland uses. The NC LDI gives a weighted average land use (1= totally forested, 8.5= totally heavily urbanized).

LDI was assessed in two different ways. First was basinwide, while the second method involved only assessing the 50m buffer on each side of the stream (100m total buffer). This was done to address arguments that high stream buffer quality can mitigate for some percentage of impacts in the watershed (Figure 34).

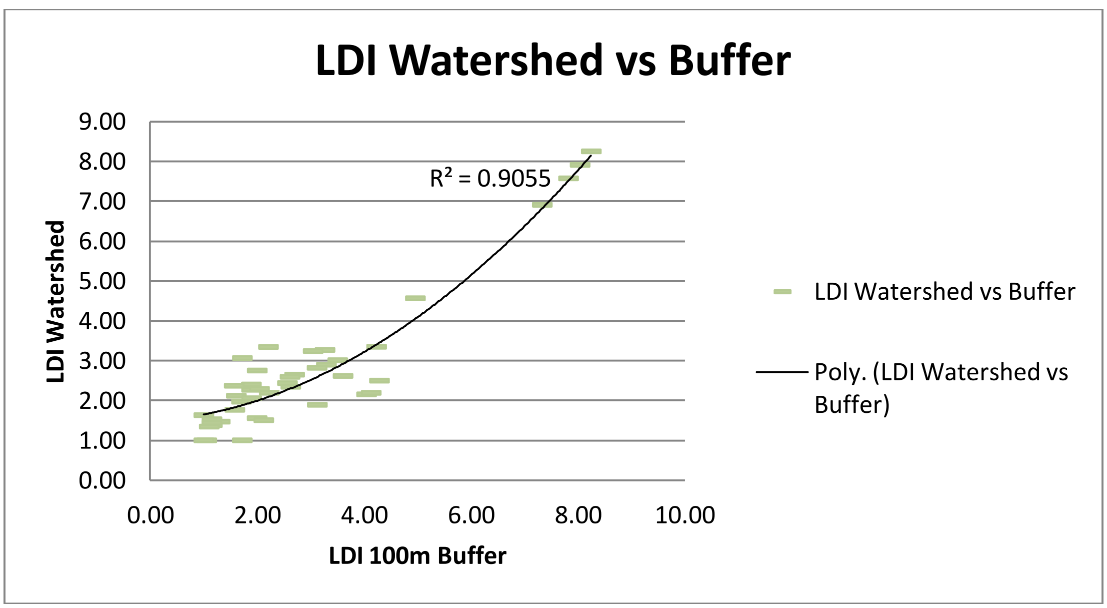

Figure 34. Watershed Land Use vs Buffer Land Use

Figure 34 shows that, there is a very high degree of correlation between the land use of the watershed and the land use of the buffer, with a 2nd order polynomial curve providing the best fit r^2 of > 90%. Even though the two LDI measures were tightly correlated, comparisons with LDI and water quality measures (BI and EPTS) as well as a NCDWQ Habitat Assessment Metric showed that in all cases, LDI for the watershed had a slightly higher correlation with BI, EPTS and instream Habitat than the LDI assessment for the buffer immediately adjacent to the stream (Figures 35, 36 and 37).

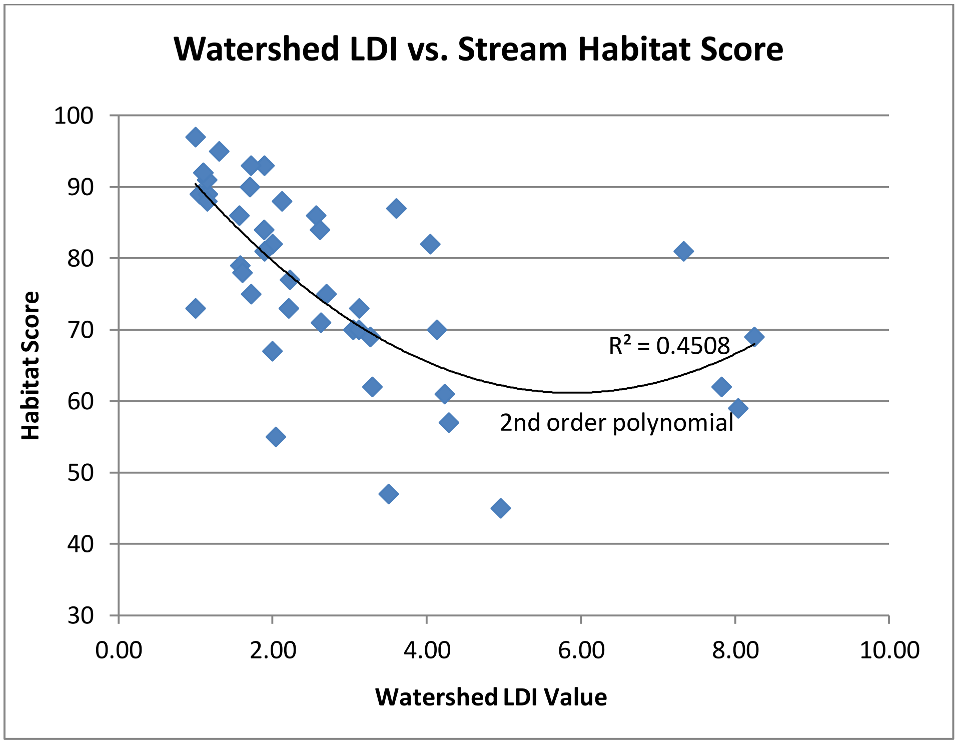

Figure 35. DWQ Habitat Score vs Watershed LDI

A case in point is the DWQ Habitat Score. This is a metric DWR has been using for almost 20 years to asses the quality of the instream habitat and the adjacent riparian area (NCDENR 2012 Appendix 5). One would expect a method designed, at least in part, to measure the riparian area would better correlate with estimates of the riparian buffer area (LDI). Even though the 2nd order polynomial yielded the highest correlation (r^2=.45), this correlation was consistently about 7% greater with the watershed LDI than the buffer LDI no matter whether the best fit curve was linear, logarithimic or a polynomial.

In all cases, land use explained more of the variability in biological metrics (Biotic Index and EPTS) in the Piedmont than in the Mountains (Figures 35 and 36). The best fit model for both the Piedmont ecoregion was 2nd order polynomials, which explained 56% of the variability in the Piedmont. Models for the Moutain ecoregion were not significantly improved over a linear regression that explained 33% of the variability in BI. The correlation of moutain sites was lower than piedmont sites largely because there was a more limited range of land use (mostly forest with a little agriculture and suburban areas) so the LDI was never much more than 4 out of 8.5. The Piedmont values, on the other hand included urban streams so the LDI values covered a much wider range. Even so, LDI appears to only explain a portion of the variability in the invertebrate community. This is in keeping with Hawkins and Vinson (2000), who found at best a weak correlation between their landscape classification and stream macroinvertebrates.

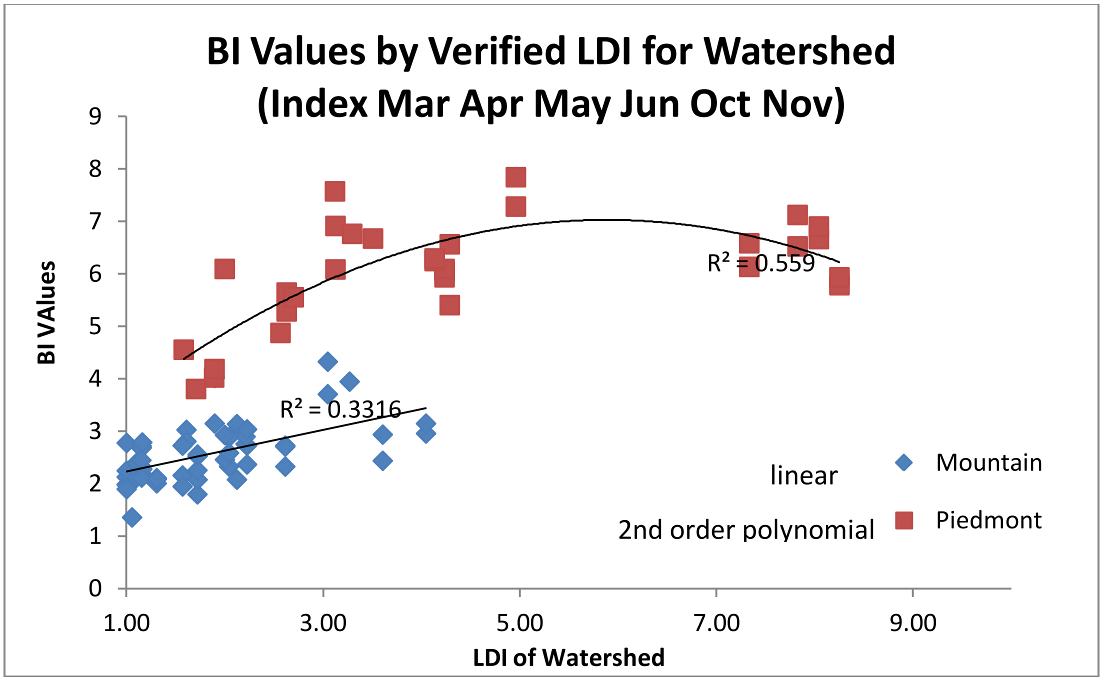

Figure 36. Biotic Index by Land Use.

EPT Taxa Richness appears to be slightly less correlated with land use than Biotic Index, requiring a 4th order polynomial model to even get close to the same correlation that could be achieved by a 2nd order model with Biotic Index. Clearly more factors than land use, especially at this coarse of a scale, are driving the biological metrics in these headwater streams.

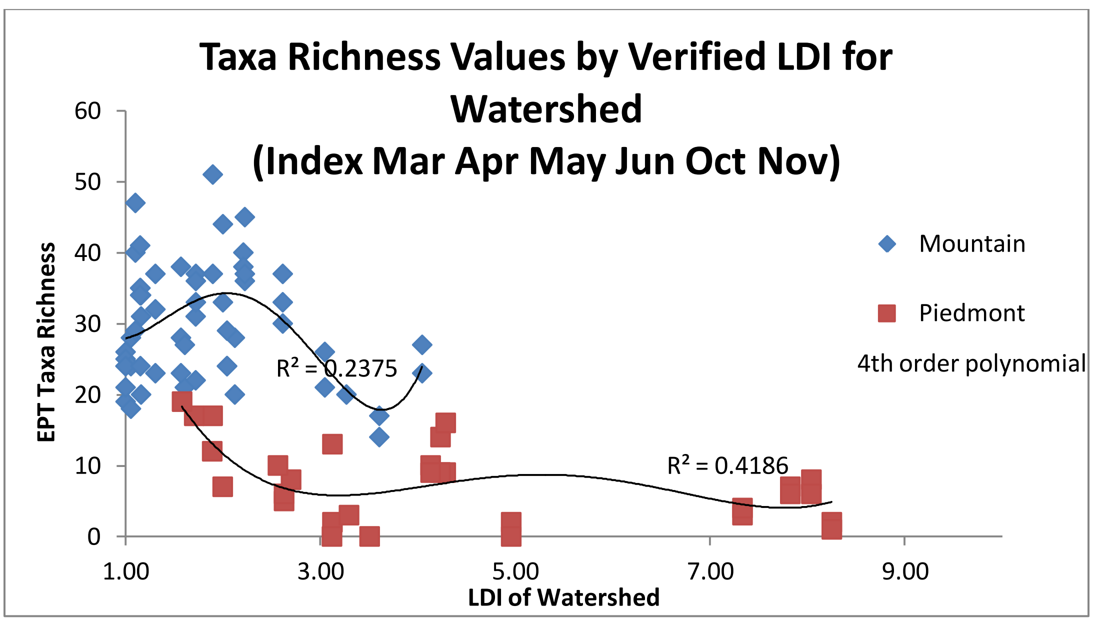

Figure 37. EPT Taxa Richness by Land Use (LDI)

Biocriteria for Restoration Projects

Biological (macroinvertebrate) monitoring of stream restorations has been ongoing in North Carolina since 1999 (Penrose 2002 and 2004). The problem with restoration monitoring has always been "how do you know when a restoration is successful?" Penrose has proposed various metrics over the years, including EPT Taxa Richness (EPTS): EPT Abundance (EPTN), Dominants in Common Index (DIC) and the presence of Keystone Taxa. The problem in each case has been to determine how much improvement a metric had to show to be declared "successful". Over his time at NCDWQ and NCSU, Penrose collected multiple years of restoration data at 22 streams. While many of these streams have been resampled in 2013, these data are not yet available, so Table 3 is a summary of the six restored sites sampled during the index period (Mar – Jun, Oct, Nov) between 2000 and 2010.

Table 3. Historic Restoration Projects in Index Period with New Bioclassifications

Restoration Project & Site	Pre-Const BI	Post-Const BI	Difference in BI	Bioclass Pre/Post
Beaver (Site 02)	4.33	4.59	0.26	G/G
Payne Dairy/Jumping Run (site 02)	5.68	4.89	-0.79	GF/G
Payne Dairy/Jumping Run (site 03)	6.2	5.64	-0.56	F/GF
Little Pine/ Brush (site 02)	4.12	4.34	0.22	G/G
Purlear (site 02)	4.55	4.23	-0.32	G/G
Purlear (site 03)	5.6	4.53	-1.07	GF/G
Purlear (site 04)	6.65	5	-1.65	F/G
Rendezvous Mountain (site D)	2.10	3.00	0.90	E/E
Yates Mill Stream (site 03)	6.84	6.85	0.01	F/F

The fourth column in this table, Difference in Biotic Index (BI) is color coded by whether the BI at each site indicated improvement (green) in the tolerance of the invertebrate community before and after restoration or not (red). The last column is the Bioclassification generated with this expanded sampling window before and after restoration. Of the five sites where BI suggested improvement (green), four showed enough improvement to increase at least one bioclassification, while the four sites in red maintained their bioclassifications, even though there was a small increase in the tolerance of the invertebrate community. In three of the four cases where BI did not improve from pre-restoration to post-restoration, and the single case where Bioclassification did not improve even though BI was reduced, the stream to be restored rated Good or Excellent before the restoration. This would suggest that any stream proposed for restoration due to a degraded biological community, should actually have a degraded community for there to be any expectation of improvement. The site with the least change pre-construction to post was Yates Mill, an eroded stream moved to a new, adjacent channel. Apparently the upstream agricultural impacts were not addressed in this project, only the erosion, so water quality was unchanged.

Section 4 – Conclusions

BI is a metric that is unaffected by stream size in perennial streams in both the mountains and the piedmont. As such, its usefulness as the primary metric for determining water quality in small streams is confirmed. It appears that the index period for this method can be expanded from the current April – May sampling period to March – June, plus October and November without needing to apply seasonal corrections. There were not enough samples outside of this six month period to determine what, if any, would be appropriate seasonal corrections for the other six months. It appears that in the mountains EPT Taxa Richness may also be used as a secondary water quality metric (e.g. Table 2) provided the specific conductance of the stream is not very low (<15 μS).

In the Piedmont, BI also appeared to be the primary metric for determining water quality. Further conclusions were made difficult because approximately half of samples collected were in catchments that went dry in the summer, which made their benthic communities so stressed that it was not possible to discern other signals such as possible seasonal or size corrections. It appeared that there was a threshold in Specific Conductance around 100 μS beyond which samples generally appeared to be impaired.

Estimates of land use (LDI) were at best moderately correlated with water quality (r^2 values ranging from 0.20-0.55). This correlation was generally higher in the Piedmont than the Mountains, probably due to the Piedmont sites having a wider variety of land use types. Correlations were higher with basinwide land use, rather than land use nearest the stream. There still appears to be no way to consistently predict the water quality of a stream based on the land use of its watershed, at least without more precise land use categories than what is available in North Carolina.

Using these proposed bioclassifications on historic stream restoration benthic data, it appears that success criteria of one or two Bioclassification increase appears to be an achievable endpoint for stream restorations whose goals include improving water quality. It also seems to be the case that streams with Good or Excellent water quality before restoration will be unlikely to see a measurable increase in bioclassification.

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Appendices

Appendix 1.Station information

Name	Sta #	County	DA (mi^2)	% Forest	Habitat	LDI	Buffer LDI
Ball Cr	1	Macon	0.15	99.2	89	1.05	1.00
Ball Cr	2	Macon	0.79	95.8	95	1.31	1.47
Ball Cr	3	Macon	2.4	97.8	89	1.16	1.38
Ball Cr	4	Macon	6.13	97.8	91	1.15	1.44
L Buck Cr	1	Clay	0.02	100	73	1.00	1.00
L Buck Cr	2	Clay	0.34	98.1	88	1.15	1.53
Buck Cr	4	Clay	3.51	98.5	92	1.10	1.34
Spring Cr	1	Mitchell	0.05	100	93	1.72	1.00
Spring Cr	2	Mitchell	0.13	100	97	1.00	1.63
Spring Cr	3	Mitchell	1.04	96.1	86	1.57	2.37
Spring Cr	4	Mitchell	3.17	93.8	75	1.72	3.06
3-Mile Cr	1	Mc Dowell	0.22	91	88	2.12	1.51
3-Mile Cr	2	Mc Dowell	0.32	87.7	55	2.04	2.29
3-Mile Cr	3	Mc Dowell	1.68	85.5	84	2.61	2.59
3-Mile Cr	4	Mc Dowell	4	88.8	77	2.22	2.19
Rocky Cr	1	Wilkes	0.09	91.9	78	1.61	2.12
Rocky Cr	2	Wilkes	0.61	82.6	73	2.21	3.34
Rocky Cr	3	Wilkes	1.76	88.3	82	2.00	2.75
Rocky Cr	4	Wilkes	4.29	87.1	81	1.90	2.06
Duncan Cr	1	Rutherford	0.1	86.3	87	3.60	2.62
Duncan Cr	2	Rutherford	0.18	76.1	82	4.04	2.15
Duncan Cr	3	Rutherford	2.2	66.8	69	3.27	3.27
Duncan Cr	4	Rutherford	3.59	69.9	70	3.05	3.24
Bolin Cr	1	Orange	0.07	95	71		
Bolin Cr	2	Orange	0.27	84.1	71	2.63	2.34
Bolin Cr	3	Orange	1.07	77.1	72	3.12	1.89
Bolin Cr	4	Orange	4.71	66.7	61	4.23	3.35
Big Br	1	Wake	0.06	0	69	8.25	8.25
Big Br	2	Wake	0.28	11.1	81	7.33	6.91
Big Br	3	Wake	1.1	7	62	7.82	7.57
Big Br	4	Wake	3	4.6	59	8.04	7.91

Flat Rock Cr	1	Nash	0.07	0.95	45	4.96	4.56
Flat Rock Cr	3	Nash	1.7	23.3	57	4.29	2.50
Flat Rock Cr	4	Nash	6.1	30.8	70	4.13	2.19
Shaddox Cr	2	Chatham	0.22	86.3	47	3.51	3.01
Shaddox Cr	3	Chatham	2.25	76.1	62	3.29	2.90
Shaddox Cr	4	Chatham	5.3	73.8	70	3.12	2.82
Crooked Fk	2	Person	0.55	86.3	67	2.00	1.56
Crooked Fk	3	Person	1.13	56	75	2.70	2.65
Crooked Fk	4	Person	4	63.2	86	2.56	2.44
Poison Fk	1	Montgomery	0.03	91.6	84	1.89	2.40
Poison Fk	2	Montgomery	0.58	82.9	93	1.89	2.27
Poison Fk	3	Montgomery	1.86	87	90	1.71	1.97
Poison Fk	4	Montgomery	3.43	91	79	1.58	1.77

Appendix 2. Collection information

Site	Date	EPTS	BI	Bioclass	Cond (mS)
3-Mile Cr 1	11/27/2012	20	3.13	Ex	95
3 Mile Cr 2	11/27/2012	24	2.58	Ex	86
3 Mile Cr 3	11/27/2012	30	2.7	Ex	97
3 Mile Cr 4	11/27/2012	37	3.03	Ex	73
3 Mile Cr 2	6/7/2012	29	2.88	Ex	100
3 Mile Cr 3	6/7/2012	33	2.72	Ex	101
3 Mile Cr 4	6/7/2012	36	2.72	Ex	79
3-Mile Cr 1	7/30/2012	19	1.7	Ex	No Meter
3 Mile Cr 2	7/30/2012	13	2.22	Ex	No Meter
3 Mile Cr 3	7/30/2012	28	2.21	Ex	No Meter
3 Mile Cr 4	7/30/2012	33	2.9	Ex	No Meter
3-Mile Cr 1	4/24/2013	28	2.07	Ex	No Meter
3 Mile Cr 2	4/24/2013	24	2.32	Ex	No Meter
3 Mile Cr 3	4/24/2013	37	2.32	Ex	94
3 Mile Cr 4	4/24/2013	45	2.36	Ex	73
Ball Cr 1	10/3/2012	18	1.35	Ex	7
Ball Cr 2	10/3/2012	23	2.08	Ex	8
Ball Cr 3	10/3/2012	20	2.78	Ex	10
Ball Cr 4	10/3/2012	34	2.44	Ex	11
Ball Cr 1	6/18/2012	24	2.18	Ex	8
Ball Cr 2	6/18/2012	32	2	Ex	11
Ball Cr 3	6/18/2012	31	2.17	Ex	13

Ball Cr 4	6/18/2012	41	2.32	Ex	9
Ball Cr 1	3/20/2013	28	2.03	Ex	7
Ball Cr 2	3/20/2013	37	2.1	Ex	9
Ball Cr 3	3/20/2013	34	2.27	Ex	9
Ball Cr 4	3/20/2013	35	2.67	Ex	10
Beaverdam 1	6/20/2012	17	2.43	Ex	No Meter
Beaverdam 2	6/20/2012	27	3.14	Ex	No Meter
Beaverdam 4	6/20/2012	21	4.32	Good	No Meter
Duncan Cr 1	1/28/2013	9	3.44	Ex	41
Duncan Cr 2	1/28/2013	15	3.63	Ex	46
Duncan Cr 3	1/28/2013	26	3.79	Good	31
Duncan Cr 4	1/28/2013	26	3.95	Good	34
Duncan Cr 1	5/30/2013	14	2.93	Ex	46
Duncan Cr 2	5/30/2013	23	2.95	Ex	48
Duncan Cr 3	5/30/2013	20	3.94	Good	42
Duncan Cr 4	5/30/2013	26	3.7	Ex	37
Duncan Cr 1	7/31/2012	11	3.51	Ex	59
Duncan Cr 2	7/31/2012	15	3.24	Ex	54
Duncan Cr 3	7/31/2012	14	3.61	Ex	49
Duncan Cr 4	7/31/2012	20	5.02	Good-Fair	36
L Buck Cr 1	10/4/2012	21	2.77	Ex	19
L Buck Cr 2	10/4/2012	24	2.11	Ex	20
Buck Cr 4	10/4/2012	29	2.39	Ex	11
L Buck Cr 1	6/19/2012	19	2.12	Ex	too shallow
L Buck Cr 2	6/19/2012	35	2.68	Ex	21
Buck Cr 4	6/19/2012	40	2.17	Ex	16
L Buck Cr 1	3/21/2013	24	2.24	Ex	13
L Buck Cr 2	3/21/2013	34	2.71	Ex	15
Buck Cr 4	3/21/2013	47	2.11	Ex	10
Rocky Cr 1	5/29/2012	21	2.8	Ex	22
Rocky Cr 2	5/29/2012	38	2.89	Ex	43
Rocky Cr 3	5/29/2012	33	2.92	Ex	36
Rocky Cr 4	5/29/2012	37	4.01	Good	36
Rocky Cr 1	5/9/2013	27	3.02	Ex	23
Rocky Cr 2	5/9/2013	40	2.75	Ex	32
Rocky Cr 3	5/9/2013	44	2.45	Ex	30
Rocky Cr 4	5/9/2013	51	3.14	Ex	31
Rocky Cr 1	12/19/2012	21	2.86	Ex	No Meter
Rocky Cr 2	12/19/2012	41	3.3	Ex	No Meter
Rocky Cr 4	12/19/2012	40	3.56	Ex	No Meter
Spring Cr 1	4/23/2013	31	1.79	Ex	37
Spring Cr 2	4/23/2013	26	1.98	Ex	38
Spring Cr 3	4/23/2013	28	2.15	Ex	32

Spring Cr 4	4/23/2013	37	2.52	Ex	37
Spring Cr 1	11/26/2012	22	2.25	Ex	38
Spring Cr 2	11/26/2012	22	1.86	Ex	39
Spring Cr 3	11/26/2012	24	2.72	Ex	36
Spring Cr 4	11/26/2012	23	2.55	Ex	42
Spring Cr 2	5/30/2012	25	1.97	Ex	37
Spring Cr 3	5/30/2012	38	1.94	Ex	35
Spring Cr 4	5/30/2012	33	2.07	Ex	39
Big Br 1	12/9/2011	2	7.15	Poor	
Big Br 2	12/9/2011	3	7.01	Poor	66
Big Br 3	12/9/2011	5	7.67	Poor	71
Big Br 4	12/9/2011	5	7.01	Poor	109
Big Br 1	6/11/2012	2	5.78	Good-Fair	46
Big Br 2	6/11/2012	3	6.58	Fair	73
Big Br 3	6/11/2012	7	7.12	Poor	78
Big Br 4	6/11/2012	8	6.66	Fair	116
Big Br 1	11/8/2012	1	5.93	Good-Fair	77
Big Br 2	11/8/2012	4	6.13	Fair	69
Big Br 3	11/8/2012	6	6.52	Fair	76
Big Br 4	11/8/2012	6	6.9	Poor	110
Bolin Cr 2	4/27/2012	5	5.64	Good-Fair	59
Bolin Cr 4	4/27/2012	9	6.05	Fair	131
Bolin 4-13	4/15/2013	6	5.28	Good	No Meter
Bolin Cr 3	4/15/2013	13	6.08	Fair	No Meter
Bolin Cr 4	4/15/2013	14	5.93	Good-Fair	No Meter
Bolin Cr 4	6/12/2012	9	6.09	Fair	144
Bolin Cr 3	10/23/2012	6	6.54	Fair	92
Bolin Cr 4	10/23/2012	7	6.08	Fair	146
Crooked 1	12/4/2012	6	6.22	Fair	59
Crooked 3	12/4/2012	10	5.72	Good-Fair	No Meter
Crooked 4	12/4/2012	12	5.24	Fair	No Meter
Crooked 2	5/14/2012	7	6.09	Fair	No Meter
Crooked 3	5/14/2012	9	5.55	Good-Fair	No Meter
Crooked 4	5/14/2012	10	4.87	Fair	No Meter
Flat Rock 1	5/15/2012	2	7.28	Poor	No Meter
Flat Rock 3	5/15/2012	9	6.56	Fair	No Meter
Flat Rock 4	6/6/2012	10	6.24	Fair	70
Flat Rock 1	9/5/2012	0	7.23	Poor	104
Flat Rock 3	9/5/2012	9	5.89	Good	81
Flat Rock 4	9/5/2012	10	6.39	Fair	88
Flat Rock 1	3/27/2013	0	7.84	Poor	187
Flat Rock 3	3/27/2013	16	5.36	Good	70
Flat Rock 4	3/27/2013	9	6.29	Fair	64

Poison Fk 1	12/10/2012	16	4.36	Ex	54
Poison Fk 2	12/10/2012	25	4.54	Good	61
Poison Fk 3	12/10/2012	25	4.17	Ex	67
Poison Fk 4	12/10/2012	25	4.58	Good	61
Poison Fk 1	6/13/2012	12	4.02	Ex	43
Poison Fk 2	6/13/2012	17	4.18	Ex	83
Poison Fk 3	6/13/2012	17	3.8	Ex	62
Poison Fk 4	6/13/2012	19	4.55	Good-Fair	62
Poison Fk 1	2/18/2013	15	3.95	Ex	41
Poison Fk 2	2/18/2013	24	4.58	Good	77
Poison Fk 3	2/18/2013	26	3.83	Ex	57
Poison Fk 4	2/18/2013	31	4.21	Ex	58
Shaddox 2	5/16/2012	0	6.67	Fair	No Meter
Shaddox 3	5/16/2012	3	6.76	Fair	No Meter
Shaddox 4	5/16/2012	0	7.57	Poor	No Meter
Shaddox 3	1/19/2013	0	7.51	Poor	64
Shaddox 4	1/19/2013	0	6.77	Poor	61

Appendix 3.Gale, S. 2011. Assessment of Conductivity and Biology in North Carolina
To be appended for final report