The Effect of Stream Restoration on Turtle Species Assemblages in the Piedmont Region of North Carolina, USA

by

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ABSTRACT

In response to the negative impact of urban and agricultural development on freshwater systems, stream restoration efforts often attempt to return degraded streams to a natural ecosystem structure and function. However, few attempts have been made to monitor the effectiveness of restored streams in supporting certain important groups of organisms found in native aquatic ecosystems, such as freshwater turtles. The purpose of this study was to compare six natural and six restored streams in the North Carolina Piedmont by quantifying habitat characteristics that might drive differences in turtle assemblages and by directly capturing turtles at each site. Stream habitat was characterized by water quality analyses, structural measurements of each stream (width, depth, etc.) and floodplain vegetation surveys. Three baited hoop nets were set at each location for a total of 36 trap-nights at each stream, which were used to collect turtle population data from mid-May to late July 2009. In total 77 turtles were captured comprising eight species. At the natural sites, 24 turtles were captured representing five species (*C. picta, C. serpentina, P. floridana, S. odoratus,* and *T. scripta scripta*), while 53 turtles were captured at the restored sites representing seven species (*C. guttata, C. picta, C. serpentina, K. subrubrum, S. odoratus, T. scripta elegans* and *T. scripta scripta*). Modified t-tests, based on randomized permutation tests, suggest that natural and restored sites differ in turtle abundance (p=0.13), but are not different in species richness (p>0.99) or gender ratios (p=0.80). A species community index suggests that natural and restored turtle assemblages overlap by 50%. Non-metric multidimensional scaling (NMS) analyses of habitat characteristics indicate that natural and restored streams differ in channel structure, vegetation, and some water quality variables. Using Mantel's test to compare turtle species composition with the most important variables separating natural and restored streams, canopy, slope, total phosphorus, chlorophyll A, and abundance of *Juncus effuses* were found to be most strongly correlated with patterns in turtle assemblage composition. This is one of the first studies to address the possible impact of stream restoration on turtle assemblages, and the findings suggest that restored streams may be better habitat for turtles in the Piedmont of North Carolina.

INTRODUCTION

As urban development, agricultural practices, and timber harvesting continue to threaten stream ecosystem quality and function, stream restoration is increasingly utilized by resource managers and state governments to mitigate stream degrading activities (Hashisaki 1996, Bash and Ryan 2002, Saunders et al. 2002, Tran et al. 2007). While restoration efforts can vary widely in their objectives, these projects often focus on renewing ecosystem health and function to either pre-degradation quality or to similar habitats in the same region through the use of reference sites (Ehrenfeld 2000, Hobbs and Cramer 2008). In North Carolina, the Wetlands Restoration Program was established in part to prioritize the restoration of functioning ecosystems in streams used for compensatory mitigation, so that functions lost to stream degradation and destruction could be effectively replaced (NCEEP 1997). Considering the wide range of ecological functions provided by streams and their associated riparian habitats, as well as the diverse and often threatened number of species involved in these functions, restoring all components of stream ecosystems is a formidable task (Groffman et al. 2003, Saunders et al. 2002).

One way in which successful stream ecosystem functioning can be confirmed is by quantifying the diversity and abundance of species assemblages that are important components of natural stream ecosystems (Gawlik 2006). Although many stream restoration projects aspire to restore ecosystem health and function, including those managed by the state of North Carolina, many projects do not monitor certain critical organismal groups in the ecosystem to determine if their goal has been met (Richardson 2004). Failure to monitor additional ecosystem parameters is based on the potentially erroneous assumption that if the appropriate structural components and plant species are established at a stream restoration site, other organisms in the ecosystem will follow (Hobbs and Cramer 2008). Additionally, there are a number of barriers to conducting complete evaluations of project success for many restorations, such as lack of funding, time and personnel (Bash and Ryan 2002). In North Carolina, mitigation projects managed by the NCEEP require only that plant and channel structural criteria for restoration projects be monitored for five years following restoration (NCEEP 2010). Questions remain as to whether the restored streams contain all of the biotic components necessary for the restoration of full ecological function.

One organismal group that has rarely been studied in restored systems is freshwater turtles. Particularly in the southeast United States, turtles are diverse and important organisms in stream ecosystems, especially in creating a link between wetland and upland habitats (Bodie and Semlitch 2000, Meyers and Pike 2006, Tran et al. 2007). Turtle biomass in freshwater ecosystems is at least one order of magnitude higher than endotherms, and the highest among reptile organism groups (Iverson 1982). Freshwater turtles are an important part of the food webs in which they live; turtle eggs and hatchlings provide a food source for organisms from varying trophic levels, and the variation in their dietary requirements results in their consumption of many other plants and animals in the system (Bodie 2001). The role of turtles in freshwater ecosystems are thought to include changing energy flow of the system, altering nutrient cycling, and even dispersing seeds for terrestrial plants in some systems (Cheung and Dudgeon 2006, Pearse et al. 2006). Not only can turtle assemblages provide information about the health of the ecosystem, but they can also serve as indicators of the abiotic factors present in a restored stream (Bodie et al. 2000).

Because of the integral role that freshwater turtles play in stream ecosystems, understanding the success of stream restoration, particularly ecosystem-focused restoration, is incomplete without quantifying the turtle assemblages present in these systems. Through this study, we aimed to determine if recently restored stream ecosystems support equivalent turtle species assemblages as competently as natural streams in the same physiographic region. To meet the study objective, we tested three hypotheses: 1) there would be no difference in turtle abundance, richness or gender ratios between natural and restored sites; 2) turtle species composition would not vary between the site types; 3) habitat characteristics that are ecologically important to turtles would be equivalent between natural and restored stream sites.

METHODS

Site Selection

The Piedmont of North Carolina is a rapidly changing region of the country as a result of heightened population growth and development. In one decade (1990-2000), the Piedmont experienced a nearly 40% increase in population, increasing to a total of 1.5 million people in the Triangle region alone (McDonald and Urban 2006). Consequently, natural forest and wetland areas are being cleared to make way for development. Pfiefer and Kaiser (1995) reported that of the 1,702 wetlands permits distributed by the state of North Carolina, which affected 2,152 acres of vegetated wetlands, only 40% of the permanent impacts were offset by wetland creation, restoration, or enhancement. These disappearing and degraded freshwater habitats are home to one of the greatest diversities of reptiles and amphibians, whose conservation may soon come to rely on restored streams providing new habitat (Meyers and Pike 2006).

In this study, comparisons of turtle species assemblages were made between six restored streams and six natural streams found in five counties in the North Carolina Piedmont (Figure 1). Stream restoration sites were chosen from a comprehensive list of wetland restoration activities in North Carolina that is managed by the North Carolina Ecosystem and Enhancement Program (NCEEP)(Appendix 1). Three criteria were used to select streams from among the numerous restoration locations. Only restoration sites located within the North Carolina Piedmont physiographic region were chosen to minimize existing differences in turtle biodiversity with other regions of the state. Restoration projects were selected only if they included a stream channel restoration component, and excluded sites in which a stream was present but remained essentially unaltered. Finally, age of the restoration site was considered, with all streams having between two and four growing seasons since the completion of restoration.

Separate criteria were used to choose comparable natural streams. A natural stream was only considered if it was geographically close (within 11.2 km) to at least one of the restored stream locations and if the biological integrity of the stream was not known to be compromised according to the North Carolina 303d list of impaired water bodies (NCDWQ 2006). Additional characteristics considered in natural stream site selection included similar size to restored streams, forested land cover surrounding the stream, and the ability to receive permission from property owners to access the streams.

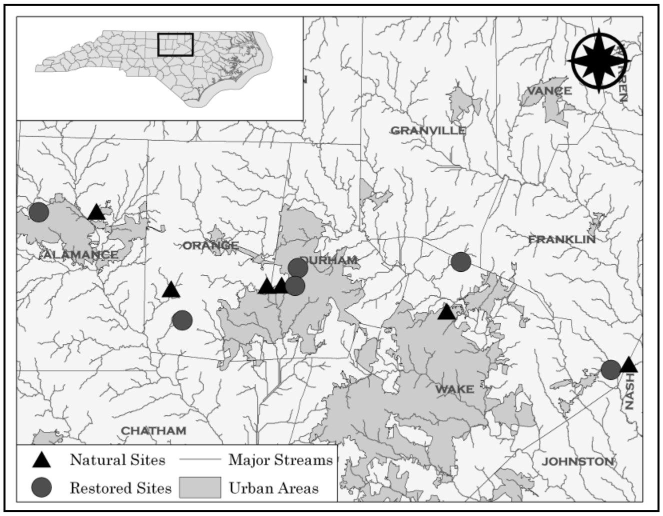


Figure 1. Locations of natural and restored stream sites sampled in this study in the Piedmont ecoregion

Turtle Trapping

Turtle trapping was conducted during the summer of 2009 between late May and late July. Because it was not possible to trap at all twelve locations simultaneously, two restored streams and two natural streams were selected for one of 3 trapping groups based on their relative locations in the study area. Each trapping group was visited at three separate intervals during the research period. The first round of trapping occurred between late May and early June, and traps were set for three consecutive nights at each of the three groups of sites. The second round of trapping was conducted between mid-June and early July, and traps were set for five consecutive nights at each group. The last round was conducted in mid- to late-July, with traps set for four consecutive nights.

On the first day of a trapping period, three hoop-net turtle traps (0.76m diameter hoop, 1.83m long and 3.8cm mesh net) were set at each of the four streams in that group (Memphis Net and Twine, Model TN215). Although several studies suggest this method of trapping is biased in both the species and gender of turtles captured (Bodie and Semlitsch 2000, DonnerWright et al. 1999, Tran et al. 2007), it was assumed that these biases were consistent across all sites. All three traps were set within a 60m stretch of the stream, and they were anchored to the bank through attachment to trees or tent stakes. The location of all traps remained constant if possible throughout the research period; shifts in location only took place if the original pool became too shallow in later trapping rounds to effectively set the trap. Traps were baited with one can of tuna, which was poked with several holes to allow the smell to permeate the surrounding water, and was hung by a string at the back of each trap. Because the second round of trapping was longer, an additional tuna can was added to each trap after the third day in order to ensure that the bait remained fresh. One empty one-gallon plastic bottle was also placed in each net to ensure that the turtles had a place to surface for air within the net (Steen and Gibbs 2004).

Traps were checked once daily during the trapping period at approximately the same time of day. If no turtle was caught, the empty trap was returned to its original location. When a turtle was captured, the net was relocated to the nearest bank to conduct measurements of the turtles. The species, gender, and location of each turtle were recorded, and length (plastron) and mass measurements were made. For smaller species, turtles were placed in a cloth bag and mass measurements were made on a spring scale. The size and temperament of *C. serpentina* prohibited the use of this methodology for determining the mass. Instead, *C. serpentina* individuals were tied using a nylon rope (the rope ran through the mouth and under the shell to prevent extension of the neck during measurements), and then placed on a ground field scale.

Before release, turtles were marked so that all potential recaptured turtles could be distinguished from new individuals. Identification of individual turtles was made by notching specific scutes of the carapace, with each individual of a species having a unique notch combination (Ernst 1971). *C. serpentina* were an exception to this marking scheme due to the difficulty of making notches near the front of the carapace. Instead, preexisting pockmarks and other scars in the turtle carapace that were unique to each individual were noted and used to identify potential recaptures of these animals. Photographs were taken of all turtles for future reference. Upon completion of measurements and markings, all turtles were released on site.

Habitat Characterization

Several assessments were made to characterize the section of stream in which the turtle traps were located, including stream structure, water quality, and riparian vegetation. Stream structure was characterized by taking three measurements of the stream channel. Average pool width was calculated as the mean of the maximum width values at each pool where a turtle trap was located. The depth of each pool was determined by making five depth measurements around each trap and averaging the resulting values. The mean slope (water surface to floodplain) for the entire stream section was determined by taking three slope readings using a magnetic slope instrument at the beginning, middle, and end of the trapped stream section. The amount of sunlight reaching the stream was also estimated as a structural component of the stream, and canopy cover was measured as a proxy for this characteristic. Canopy cover was estimated using a wide angle digital camera, and pictures were taken at chest height from the middle of the stream. Percent cover was then determined by calculating the proportion of dark pixels in each photo using the Image J software program (Abramoff et al. 2004).

All water quality measurements were conducted at least 48 hours after a rain event to minimize the occurrence of anomalies as a result of weather and subsequent runoff conditions. A water quality meter was used to gather information on dissolved oxygen concentration and specific conductivity (Model 556 MPS, Yellow Spring Instruments, OH). Prior to recording data, the YSI meter was first calibrated in the lab, and was also allowed to acclimate in the stream for several minutes in the field. In addition, three surface water samples were taken from each stream site using a dip bucket. To reduce the possibility of contamination, sampling was conducted first at the most downstream site and then proceeding upstream. Six tests of water quality were conducted using Standard Methods and EPA protocols. The following characteristics were measured: total phosphorus (SM 4500 PE), chlorophyll A, total nitrogen (EPA 350.2), nitrate (EPA 350.1), total suspended solids (EPA 160.3), and turbidity (EPA 180.1) (See Appendix II for complete information on water quality tests).

To characterize the riparian vegetation, three 30-meter transects were established along the floodplain closest to the stream channel within the stretch that the traps were located. A weighted string was lowered every 2 cm along the transect, and the name of the plant species was noted if it was the first to be touched by the weight at each transect point.

Data Analysis

Modified t-tests were conducted to compare basic turtle population characteristics between natural and restored stream groups, including turtle abundance, species richness, and gender ratio. In each t-test, the mean difference between the two site types was compared with 999 randomized permutations of the data. Turtle abundance for each site was calculated by summing the number of turtles captured regardless of species type (recaptures were not counted in abundance values). Species richness of each site was determined by counting the number of species captured at a particular site. A number of streams did not have both male and female turtle captures, so typical gender ratio calculations could not be made (unable to divide by 0). Instead, the gender ratio was calculated by subtracting the number of females from the number of males, and dividing by the total number of turtles captured at that site. Gender ratio values varied from -1 to 1, where -1 indicated only females were captured and 1 indicated only males were captured at the site. Overall turtle assemblage similarity between natural and restored communities was estimated using a community similarity index that takes into account both the type of species present and the abundance of each species (Odum 1950). The resulting values from this calculation could range from 0 (two communities do not share any species in common) to 1 (two communities have the same species in the same abundances).

Non-metric multidimensional scaling (NMS) was conducted using the PC-Ord software package (McCune and Mefford 2006) to determine if the habitat characteristics of natural and restored sites differed in ways meaningful to many turtle species. NMS ordinates samples based explicitly on their ecological distances (Kenkel and Orlóci 1986). Therefore, when sample scores are plotted in ordination space, the measured distances between each set of two points is directly related to the ecological distances of those points. In this case, vegetation composition was used as the basis for developing three ordination axes. Based on their vegetation characteristics, each of the twelve sites could then also be plotted in ordination space.

Using the results of the NMS, the most important habitat characteristics separating natural and restored streams were estimated among all of the measured environmental variables. To assess which plant species were most important in separating natural and restored streams, an Indicator Species Analysis (ISA) was conducted by site type. ISA calculates two metrics for each species by group. The first is the relative abundance of the species in a group, which indicates the percentage of the total number of individuals found in that group. The second is relative frequency, which indicates the percentage of samples from a group that contain that particular species. The observed indicator value is then calculated by multiplying these two metrics together. By comparing the indicator value with a matrix of randomly permuted values in a Monte Carlo fashion, it was determined if a species is a significant indicator of the compositional group in which it was most consistently and exclusively found. To determine the relative importance of stream structural and water quality variables in separating natural and restored streams, Pearson correlations between each of these variables and the ordination axes were conducted.

A series of Mantel's tests, statistical tests that are used to compare distance matrices, were used to estimate the relative importance of the habitat characteristics in driving differences in turtle species composition among the sites. A matrix of turtle community compositional differences was created by calculating Bray-Curtis distances in a statistical package called Ecodist (Goslee and Urban 2007) that was conducted using R statistical software (R Core Development Team 2009). Bray-Curtis distances were used because this method has been found to be a robust method for estimating ecological distances (Faith et al. 1987). This dissimilarity matrix was then tested for its correlation with the three habitat variable groups (vegetation composition, stream structure, and water quality). Vegetation composition distances were calculated using the same Bray-Curtis method for the turtle species composition described above. Structure and water quality distance matrices were created using Mahalanobis distances, due to the high degree of correlation among variables within a habitat group. Mantel's tests were also conducted between the turtle species composition dissimilarity matrix and individual habitat variables that were deemed to be most important in the NMS analysis. These same habitat variables were also used to examine correlations with turtle abundances for more common species (captured at more than three sites). For the individual habitat variables and individual turtle species abundances, Euclidean distance matrices were derived for comparison. Statistical significance was set at an alpha value of 0.1.

RESULTS

Turtle Assemblage Characteristics

Seventy-seven turtles were captured in total at the twelve stream sites, representing eight turtle species (*Clemmys guttata, Chrysemys picta, Chelydra serpentina, Kinosternon subrubrum, Pseudemys floridana, Sternotherus odoratus, Trachemys scripta elegans* and *Trachemys scripta scripta*). *C. guttata* prefers grassy wetlands and blackwater streams, and is a species of concern (S3 status: vulnerable) in the state of North Carolina (Buhlmann et al. 2008, LeGrand et al. 2008). *C. picta* and *C. serpentina* are generalists both in what they eat and where they live, and are therefore commonly found in a wide variety of aquatic habitats in North Carolina (DonnerWright et al. 1999, Buhlmann et al. 2008). A common species in North Carolina, *K. subrubrum* prefers aquatic habitats that are shallow, and use surrounding terrestrial habitats for estivation and hibernation during most of the year (Semlitsch and Bodie 2003, Wilson et al. 2009b). *P. floridana* are more common in larger waterbodies, but can be found in blackwater streams (Buhlmann et al. 2008). *S. odoratus* is highly aquatic, and does not move overland unless forced to do so by displacement or drought. For the species *T. scripta*, two distinguishable sub-species were captured, and they were treated as two different species because of differences in their native range. *T. scripta scripta* is a habitat generalist and commonly found across the Piedmont of North Carolina (Wilson et al. 2009a). The native range of *T. scripta elegans* is in the Mississippi River Basin of the US, and has been introduced in a few urban watersheds in North Carolina (USGS 2009).

At the natural sites, a total of 24 turtles were captured representing five species, while a total of 53 turtles were captured at the restored sites representing seven species (Table 1). Restored sites showed almost twice the mean turtle abundance (8.88 turtles) of natural sites (4.8 turtles), and turtle abundance was found to be significantly different between these site types (p=0.13). There was no significant difference found between site type for either species richness (p>0.99) or gender ratios (p=0.80).

Table 1. Turtle abundance and species richness at each of the twelve stream sites. The code for each stream name is shown in parentheses.

Natural Sites			**Restored Sites**		
Site	**Turtles (n)**	**Species (n)**	**Site**	**Turtles (n)**	**Species (n)**
Boyds (BOY)	0	0	Bold Run (BHR)	3	1
Cane (CAN)	6	4	Collins (COL)	7	3
Cedar (CED)	3	2	Ellerbe (ELL)	8	2
Mud (MUD)	4	3	Glen Raven (GLR)	3	2
Piney (PIN)	5	3	Moccasin (MOC)	22	5
Turkey (TUR)	6	4	Sandy (SAN)	10	4
Total	**24**	**5**	**Total**	**53**	**7**

Although species richness did not differ between natural and restored streams, the type of turtle found at each location did not appear to be evenly distributed between each type of stream (Table 2). Of the eight species trapped, three species were only found at restored stream sites (*C. guttata*, *K. subrubrum,* and *T. scripta elegans*), and one species was only captured natural sites (*P. floridana*). The remaining four species did not show equivalent numbers of individuals between restored and natural sites. *C. picta, C. serpentina,* and *T. scripta scripta* each had more than double the number of individuals at restored streams as at natural streams. Only *S. odoratus* was found more frequently in natural sites. The community similarity index yielded a value of 0.52, suggesting that there is only a 50% overlap between in the natural and restored stream turtle communities.

Table 2. Number of individuals of each species captured for all natural and all restored streams.

Species	**Natural**	**Restored**
C. guttata	0	2
C. picta	2	7
C. serpentina	7	16
K. subrubrum	0	5
P. floridana	1	0
S. odoratus	8	5
T. scripta elegans	0	4
T. scripta scripta	6	14

Habitat Characterization

***Structural Characteristics*:** Natural and restored streams appeared to differ in all four structural characteristics (Table 3). Natural streams had consistently higher canopy cover than restored streams. There was no overlap in the range of calculated canopy values; the natural stream with the least cover was 58% and the restored stream with the highest canopy cover was 45.1%. While the mean bank slope was smaller for restored streams than for natural streams, there was a large amount of overlap between the two ranges. Natural streams also tended to be wider and deeper than restored streams, but the high degree of variability in both characteristics led to some overlap on this variable.

Table 3. Summary of structural characteristics for natural and restored streams

	Natural	**Restored**	**Natural**	**Restored**
Variable	*Mean Values for Site Type*		*Range of Measured Values*	
Canopy (%)	73.1	27.2	58.0-84.2	0-45.1
Slope (°)	39.5	22.4	20.0-55.7	4.0-46.3
Width (m)	5.7	3.4	3.6-9.4	1.8-5.0
Depth (cm)	49.3	38.0	29.7-82.0	31.9-47.7

Water Quality Measurements: There was a high degree of variability in all water quality characteristics among the twelve stream sites (Table 4). For all water quality parameters, the range of values overlapped between natural and restored streams, and in many cases the mean values were similar between the site types. Total phosphorus, chlorophyll A and total suspended solids appeared to have the greatest difference in mean values between the site types. All three of these water quality characteristics had higher mean values in restored streams than in natural streams.

Table 4. Summary of water quality characteristics for natural and restored streams

	Natural	**Restored**	**Natural**	**Restored**
Variable	*Range of Measured Values*		*Mean Values for Site Type*	
Conductivity (mS/cm)	0.08-0.27	0.08-0.38	0.14	0.18
Dissolved Oxygen (mg/L)	9.57-70.87	6.27-86.37	48.97	58.19
Turbidity (NTU)	1.87-23.63	1.77-34.33	9.32	11.23
Total Suspended Solids (g/100 mL)	58.00-121.33	72.67-195.33	74.89	123.06
Total Nitrogen (ug/L)	928.9-1199.9	976.0-2130.6	1086.89	1274.61
Total Phosphorus (ug/L)	23.21-65.90	29.54-201.53	44.80	94.77
Chlorophyll A (ug/L)	0.28-3.51	0.53-14.87	1.73	4.37

Vegetation Characteristics: A total of 141 plant species were identified in surveying the twelve stream locations (Appendix III). Twenty-three species were found at both natural and restored stream sites; 65 were found only at restored sites and 53 were found only at natural sites. The ISA was conducted only for the 57 plant species that occurred at more than one site (restored or natural). When the observed indicator values were compared with indicator values from randomized permutations, only six species had a p-value of <0.1. Three of these species most accurately represented the natural sites (*Carpinus caroliniana*, *Microstegium vimineum,* and mosses in family Bryophyta). *C. caroliniana* is a native plant that is equally likely to be found in wetland and non-wetland habitat. *M. vimineum* is a highly invasive grass species that is commonly found in disturbed habitats, and can be equally found in wetland or non-wetland ecosystems. Because all mosses were only identified to family, the particular characteristics of the species that were present at natural sites cannot be determined. The other three species were good indicators of restored sites (*Juncus effusus, Solidago altissima,* and *Symphyotrichum pilosum*). A native plant in North Carolina, *J. effuses* is a facultative wetland species. *Solidago altissima* is a native plant to this region, but is more commonly found in upland habitats than as a part of riparian vegetation. *Symphyotrichum pilosum* is equally likely to be found in upland or wetland ecosystems, and is a native plant in this area.

NMS Analysis: Only the 57 plant species that occurred in more than one location were used in the species composition dissimilarity matrix, from which the three NMS ordination axes were developed. The final iteration produced axes with a stress of 7.10 and an instability of 0.0427. The Pearson correlation coefficients between the ordination axes and the structural and water quality variables were developed to examine patterns in environmental data (Table 5).

Table 5. Correlation coefficients between stream variables and three NMS axes by Pearson's method.

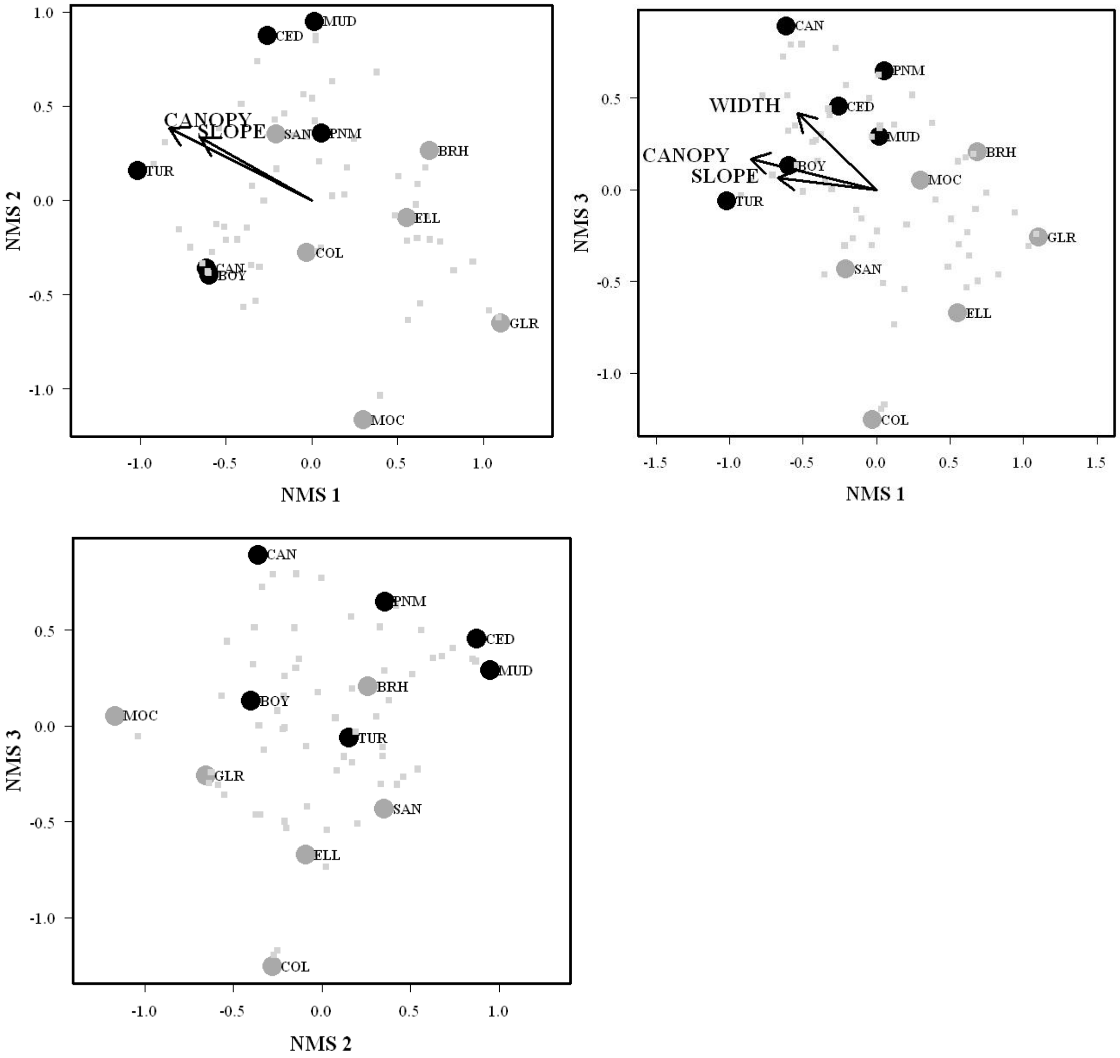
Variable	**Axis 1**	**Axis 2**	**Axis 3**
Canopy	*-0.819	*0.516	0.353
Slope	*-0.643	*0.430	0.223
Width	*-0.557	0.035	*0.474
Depth	*-0.533	0.241	0.069
Conductivity	0.003	0.001	-0.274
Dissolved Oxygen	0.290	0.021	-0.168
Turbidity	-0.042	-0.092	0.041
Total Suspended Solids	*0.400	0.182	-0.227
Total Nitrogen	-0.003	-0.364	-0.316
Total Phosphorus	-0.176	0.115	-0.283
Chlorophyll A	0.079	*-0.518	-0.205

*= p<0.1

High correlation values with all three ordination axes indicated that canopy was a dominant variable. In Axis 1, the other three stream structure variables (slope, width, and depth) were also highly correlated with the axis, as well as total suspended solids. Chlorophyll A concentrations were more strongly correlated with Axis 2, as well as slope and canopy variables. Axis 3 was most tightly correlated with width, canopy, total nitrogen and conductivity, but only width was significantly related. Turbidity, dissolved oxygen, and conductivity contributed relatively little in all three axes in determining vegetation and stream site location in ordination space.

Each axis was plotted with the other two axes to create three plots in two-dimensional space (Figure 2). The dashed line in each plot represents an artificial separation between the location of natural and restored sites in each of the plots to indicate how they group in ordination space. In two of the plots (Axis 1 vs. Axis 2 and Axis 2 vs. Axis 3), there is not a clean separation between the two types of sites: in each plot, one restored site is grouped with the natural sites. However, in the plot of Axis 1 vs. Axis 3, there is a clean separation in ordination space between natural and restored sites.

Figure 2. Stream sites and vegetation plotted in ordination space based on three axes developed in the NMS data analysis.



Legend: The black circles represent the natural sites, the gray circles represent the restored sites, and the light gray squares represent the plant species in ordination space. The arrows show the maximum correlation vectors for those variables that have a p-value<0.1 when the correlation is compared with a permutation test.

Turtle Composition vs. Habitat Characteristics

The results of the Mantel's tests (Table 6) indicate the total and partial correlations between turtle species composition and the dissimilarity matrices of each of the habitat characteristic groups (structural, water quality, and vegetation). Structural characteristics as a group did not appear to significantly correlate with turtle species composition. Water quality and vegetation differences were both significantly correlated with turtle species differences, and the significant partial Mantel's tests suggest that these two habitat groups correlate with turtle species composition in different ways.

Table 6. Explanatory power of each group of habitat characteristics with respect to turtle species composition by Mantel's test. Note that "WQ" signifies water quality.

Test	**Mantel R**	**P-value**	**Lower Limit 5%**	**Upper Limit 95%**
Species vs. Structure	-0.201	0.836	-0.282	-0.091
Species vs. WQ	0.327	*0.040	0.191	0.406
Species vs. WQ │Plants	0.418	*0.006	0.284	0.526
Species vs. Plants	0.426	*0.004	0.262	0.536
Species vs. Plants │WQ	0.317	*0.053	0.124	0.421

**= p-value <0.1*

Based on the habitat qualities that were most important in separating natural and restored streams from the NMS and exploratory data analysis, three structure, three water quality and six plant indicator variables were tested individually to determine if their differences were correlated with turtle compositional dissimilarity (Table 7). Five habitat characteristics were found to be significantly correlated with turtle species composition. Of the stream structural characteristics, canopy and slope were the most highly correlated with turtle composition. Total phosphorus and chlorophyll A were the two water quality characteristics that were related to turtle assemblage composition. Of all six indicator plant species, only differences in the abundance of *J. effusus* seem to be related to turtle composition dissimilarity.

Table 7. Mantel's tests to look at explanatory power individual habitat variables with respect to turtle species composition.

Test	**Mantel R**	**P-value**	**Lower Limit 5%**	**Upper Limit 95%**
Species vs. Canopy	0.214	*0.100	0.116	0.289
Species vs. Slope	0.275	*0.040	0.230	0.353
Species vs. Width	-0.019	0.493	-0.135	0.138
Species vs. Depth	0.044	0.346	-0.122	0.196
Species vs. Total Suspended Solids	0.004	0.427	-0.161	0.134
Species vs. Total Phosphorus	0.510	*0.011	0.163	0.611
Species vs. Chlorophyll A	0.435	*0.079	-0.223	0.571
Species vs. *C. caroliniana*	-0.145	0.717	-0.261	-0.030
Species vs. *J. effusus*	0.556	*0.033	0.115	0.652
Species vs. *M. vimineum*	-0.195	0.878	-0.307	-0.075
Species vs. Bryophyta	-0.106	0.692	-0.234	0.026
Species vs. *S. altissima*	0.105	0.186	-0.002	0.208
Species vs. *S. pilosum*	0.084	0.205	0.006	0.200

**= p-value <0.1*

The five habitat variables found to be significantly correlated with turtle species composition did not provide an indication of how individual turtle species abundances were correlated with these factors, or if individual turtle responses were driving the overall patterns in composition as it related to environmental variables. Additional Mantel's tests were conducted to assess how strongly correlated the most important variables were to the four species captured at three or more sites: *C. serpentina, C. picta, S. odoratus,* and *T. scripta scripta. C. serpentina* was not found to be strongly correlated with any of the factors important in species composition as a whole. Instead, this turtle species was most strongly associated with two plant species that were indicators of restored stream sites: *S. altissima* and *S. pilosum* (Table 8). All habitat variables that were strongly associated with overal turtle composition were also correlated with *C. picta* abundance with the exception of canopy cover (Table 9). No habitat variables were significantly correlated with the abundance of *S. odoratus* (Table 10). *T. scripta scripta* was highly correlated with chlorophyll A, total phosphorus, and abundance of *J. effusus* (Table 11).

Table 8. *Mantel's tests to look at explanatory power individual habitat variables with respect to* C. serpentina *presence.*

Test	**Mantel R**	**P-value**	**Lower Limit 5%**	**Upper Limit 95%**
Species vs. Canopy	-0.128	0.712	-0.209	0.008
Species vs. Slope	-0.046	0.533	-0.107	0.107
Species vs. Width	-0.073	0.482	-0.130	0.019
Species vs. Depth	-0.083	0.477	-0.163	0.023
Species vs. Total Suspended Solids	-0.206	0.911	-0.297	-0.068
Species vs. Total Phosphorus	0.020	0.302	-0.217	0.271
Species vs. Chlorophyll A	0.140	0.183	-0.103	0.487
Species vs. *C. caroliniana*	-0.099	0.581	-0.220	-0.040
Species vs. *J. effusus*	0.188	0.137	-0.038	0.481
Species vs. *M. vimineum*	-0.233	0.976	-0.272	-0.202
Species vs. Bryophyta	-0.119	0.583	-0.195	-0.024
Species vs. *S. altissima*	0.760	*0.032	-0.065	0.864
Species vs. *S. pilosum*	0.824	*0.031	-0.024	0.877

**= p-value <0.1*

Table 9. *Mantel's tests to look at explanatory power individual habitat variables with respect to* C. picta *presence.*

Test	**Mantel R**	**P-value**	**Lower Limit 5%**	**Upper Limit 95%**
Species vs. Canopy	0.085	0.295	-0.136	0.311
Species vs. Slope	0.345	*0.032	0.197	0.438
Species vs. Width	-0.066	0.398	-0.125	0.007
Species vs. Depth	-0.089	0.426	-0.134	0.049
Species vs. Total Suspended Solids	-0.172	0.926	-0.220	0.009
Species vs. Total Phosphorus	0.770	*0.003	0.244	0.940
Species vs. Chlorophyll A	0.880	*0.015	0.094	0.942
Species vs. *C. caroliniana*	-0.088	0.499	-0.148	0.121
Species vs. *J. effusus*	0.935	*0.091	-0.112	0.953
Species vs. *M. vimineum*	-0.071	0.398	-0.127	0.110
Species vs. Bryophyta	-0.156	1	-0.188	-0.115
Species vs. *S. altissima*	-0.128	0.680	-0.180	-0.070
Species vs. *S. pilosum*	-0.114	0.614	-0.150	-0.065

**= p-value <0.1*

Table 10. *Mantel's tests to look at explanatory power individual habitat variables with respect to* S. odoratus *presence.*

Test	**Mantel R**	**P-value**	**Lower Limit 5%**	**Upper Limit 95%**
Species vs. Canopy	-0.063	0.613	-0.184	0.056
Species vs. Slope	0.068	0.241	-0.089	0.209
Species vs. Width	0.084	0.269	-0.211	0.236
Species vs. Depth	0.105	0.153	-0.166	0.254
Species vs. Total Suspended Solids	0.037	0.303	-0.091	0.242
Species vs. Total Phosphorus	-0.074	0.694	-0.145	0.025
Species vs. Chlorophyll A	0.100	0.281	-0.026	0.265
Species vs. *C. caroliniana*	0.197	0.267	-0.149	0.369
Species vs. *J. effusus*	-0.017	0.356	-0.122	0.056
Species vs. *M. vimineum*	-0.085	0.709	-0.164	0.010
Species vs. Bryophyta	-0.053	0.457	-0.158	0.092
Species vs. *S. altissima*	-0.047	0.459	-0.134	0.040
Species vs. *S. pilosum*	-0.071	0.510	-0.150	-0.009

**= p-value <0.1*

Table 11. *Mantel's tests to look at explanatory power individual habitat variables with respect to* T. scripta scripta *presence.*

Test	**Mantel R**	**P-value**	**Lower Limit 5%**	**Upper Limit 95%**
Species vs. Canopy	0.088	0.279	-0.067	0.311
Species vs. Slope	0.268	0.120	-0.078	0.374
Species vs. Width	-0.078	0.444	-0.136	0.052
Species vs. Depth	-0.086	0.467	-0.139	-0.016
Species vs. Total Suspended Solids	-0.139	0.745	-0.226	0.099
Species vs. Total Phosphorus	0.771	*0.010	0.325	0.903
Species vs. Chlorophyll A	0.814	*0.060	-0.074	0.910
Species vs. *C. caroliniana*	-0.154	0.971	-0.205	-0.152
Species vs. *J. effusus*	0.906	*0.054	-0.077	0.929
Species vs. *M. vimineum*	-0.189	0.985	-0.221	-0.174
Species vs. Bryophyta	-0.092	0.409	-0.184	0.242
Species vs. *S. altissima*	-0.131	0.639	-0.169	-0.035
Species vs. *S. pilosum*	-0.109	0.544	-0.162	0.026

**= p-value <0.1*

DISCUSSION

Turtle Population Characteristics

This is one of the first studies to document the effects of restoration on the abundance and composition of turtles in the North Carolina Piedmont. The results suggest that turtle species abundance was significantly greater in restored sites than natural sites, but that species richness among sites was similar. Bodie and Semlitch (2000) found that turtles colonized wetlands that were formed five years previously as a result of water scouring. This suggests that even if turtles are displaced from stream habitats during the restoration process, it would not be unexpected to see recolonization (barring the presence of distribution barriers) of these habitats within 2-4 years since restoration. Another study, by Bowers et al. (2000), examined the restoration of a single stream system 2-3 years after hot water from a nuclear facility devastated local flora and fauna. While that study showed significant colonization of reptiles and amphibians in less than three years, albeit with diminished density of most species, our research of streams 2-4 years post-restoration exhibited different findings. While stream restoration can be extremely disruptive to the stream channel and riparian areas, it may be that the effects of restoration are not quite as devastating or extensive as those that occurred in the nuclear facility restoration example. In comparison with these two other studies, it may be easier for turtles to either remain at the stream during restoration or to move more readily from source populations.

When examining the distribution of the eight species captured in this study, the composition of turtles at restored and natural sites does not seem to be equivalent. Three species were only caught at restored sites: *C. guttata*, *K. subrubrum,* and *T. scripta elegans*. *C. guttata* was only captured at one restored stream location (Moccasin Creek, MOC), which most closely met the habitat preferences of this species (Buhlmann et al. 2008). The capture of this species is noteworthy, given that it is typically difficult to find and is of conservational interest in North Carolina (LeGrand et al. 2008). *T. scripta elegans* was also only captured at one restored site, which was a more highly urban restored stream. This sub-species of *T. scripta* is a particularly invasive turtle species in some parts of the US and in most of Europe, with the Invasive Species Specialist Group naming it in the top 100 invasive species in the world (Lowe et al. 2000, Cadi and Joly 2004, USGS 2009). The USGS has documented capture of this species in the most urban counties in North Carolina: Durham, Mecklenburg, and Wake counties (USGS 2009). *T. scripta elegans* are popular as pet turtles, and the occurrence of this species in urban restored streams may be explained by unwanted pets being released into this environment. *K. subrubrum* was captured at only two restored stream locations: Moccasin Creek and Glen Raven Creek. This species is common in North Carolina, and may have been found at these sites because of its preference for riparian vegetation, which was less thick and prevalent at some of the natural sites (Buhlmann et al. 2008). Only one individual of *P. floridana* was captured in a natural site. It was captured at the stream site that was closest to the coastal plain physiographic region, and contained slower, dark-colored water that is more characteristic of this region. Although typically found in larger rivers, *P. floridana* prefers this type of stream with a sandy or silty bottom (Buhlmann et al. 2008). Four species of turtles captured in this study were found at both natural and restored sites (*C. picta, C. serpentina, S. odoratus,* and *T. scripta scripta*). All of these species are more common in North Carolina; they usually inhabit a variety of aquatic habitats (although most prefer lentic habitats to streams), and none of them is a species of conservational concern in the state (Bodie et al. 2000, Buhlmann et al. 2008, Ernst and Lovich 2009). One possible explanation for the greater number of *S. odoratus* captures in natural sites is that this species does not readily move from one aquatic habitat to the other, and therefore may not have had enough time or reason to recolonize restored stream locations (Ernst and Lovich 2009).

The community similarity index value for individuals in restored and natural streams was 0.52. This suggests that the turtle communities at natural and restored sites only overlap by about 50%. The cohabitation patterns and drivers of turtle species composition are affected by direct interaction with other turtle species and habitat characteristics (Bodie et al. 2000). Given the observed differences in habitat characteristics between the stream types, it seems plausible that the habitat features of these stream locations might be driving differences in turtle species assemblages.

The modified t-test results comparing gender ratios also indicated no detectable difference in the proportion of males and females captured at natural and restored sites. Studies on overland movement of turtles to new habitats are somewhat conflicting. In general, female turtles are more likely to venture onto land than male turtles, as they do so for both nesting and emigration to new habitats (Bodie and Semlitch 2000, Attum et al. 2008). Other studies suggest that dispersal to new locations is primarily achieved by male turtles (Semlitsch and Bodie 2000). Better documentation of gender ratios at restored stream locations, particularly as a function of restoration age, will provide improved understanding of turtle population dynamics in these systems and their sustainability in maintaining turtle species at restored sites.

Habitat Characterization and Effect on Turtles

Natural and restored stream sites showed differences in vegetation, structure and water quality characteristics. Structural characteristics appeared to more strongly correlate with the NMS axes, and were therefore more likely to differ between natural and restored sites. Natural sites tended to have greater canopy cover, steeper bank slopes, and deeper and wider pools than the corresponding restored stream locations. These structural characteristics suggest a number of things about the restored streams and their natural counterparts. Steep slopes, wide pools, and deep pools are generally features associated with stream incision and channel degradation. Given that natural streams were selected based on the surrounding land cover to maximize the likelihood of selecting streams that were not degraded, it was surprising to find increased degradation in natural channels. Brinson and Rheinhardt (1996) state that the use of degraded streams as a model for restoration efforts is misusing it as a reference. However, because natural sites were selected carefully to maximize stream quality, the results of the habitat analysis may suggest that stream degradation is a reality in the entire Piedmont area as a remnant of post-settlement, widespread farming practices across the region. While pool width and depth were not significantly correlated with turtle species dissimilarity, the steepness of the stream slopes was strongly correlated with general turtle composition. In particular, *C. picta* and *T. scripta scripta* abundances were also strongly correlated with the slope of the bank. Other studies have shown that stream incision can have a negative effect on resident turtle species and change species composition by reducing riparian food sources and habitat (DonnerWright et al. 1999, Bodie 2001). The species captured in the natural (incised) streams of our study were the most common species, and are consistent with the type of turtle captured in a study conducted in the Midwest (*C. picta, C. serpentina, S. odoratus*)(DonnerWright et al. 1999). It may be that generalist turtle species can more successfully occupy these degraded natural stream habitats than other turtle species. Yet the Mantel's tests of individual turtle abundance suggest that even some of these more generalist species are more common in sites that are less incised - in this case, the restored streams.

Differences in canopy cover between natural and restored streams are likely a function of the process by which streams are typically restored. If major channel modifications are required as part of the goals for a restoration project, larger trees might be removed if they are located where the new channel will be placed, or they may also be incidentally taken to make way for larger machinery. In any case, the consequences of reduced shade from larger trees in restored streams could be another factor contributing to the disparity in turtle species composition between site types. Because the ability to bask in aquatic habitats is important to many turtle species (DonnerWright et al. 1999), the higher light intensity in restored stream systems might be preferable for basking habits of resident turtles. The Mantel's test seems to support these predictions because canopy was found to be strongly related to turtle composition among the twelve sites. However, none of the individual species' abundances showed a strong correlation with canopy cover, even those with strong basking habits (such as *C. picta* and *T. scripta scripta*). This finding may also indicate that canopy cover is a good indicator of site type (natural or restored), and therefore is only good at predicting overall turtle composition dissimilarity.

The relative unimportance of water quality characteristics, when compared with structural characteristics, in separating natural and restored streams in ordination space may be due to the high degree of variability among the samples. While water quality samples were taken from each stream within a short period of time and when samples were less likely to be biased by recent weather events, water quality is typically highly variable on a number of time scales. As a result, the water quality measurements taken in this analysis may not have provided a complete picture of the quality of each stream on average. But two of these measurements seemed to have higher consistency within site type and ultimately were more closely tied to the

NMS axes: total phosphorus and chlorophyll A. Both of these tended to be higher in restored streams than in corresponding natural streams. The Mantel's tests suggest that both of these water quality parameters may also be important in dictating turtle species composition as they were highly correlated, especially for *C. picta and T. scripta scripta.* Higher phosphorus loading and evidence of higher productivity in the stream ecosystem can ultimately have bottom-up effects on the types and abundance of turtle species found in an aquatic habitat (Bodie et al. 2000). *C. serpentina* abundance was not significantly correlated with either of these two variables, but there did appear to be a positive correlation between *C. serpentina* abundance dissimilarity and differences in chlorophyll A. This is consistent with the findings of other studies that have linked higher habitat productivity with greater *C. serpentina* density (DonnerWright et al. 1999, Ernst and Lovich 2009). The relationship between *C. serpentina* and chlorophyll A may not have been as strong in this study due to the high degree of water quality variability among sites, as well as the generalist nature of this turtle species.

The results of the NMS indicate that plant species composition is an important habitat variable in separating natural and restored streams. Six species turned out to be particularly important in identifying site type, as determined by the ISA (*Carpinus caroliniana, Microstegium vimineum,* family Bryophyta, *Juncus effusus, Solidago altissima,* and *Symphyotrichum pilosum*). The Mantel's test comparing overall turtle composition dissimilarity with plant composition dissimilarity indicates that plant composition overall may be an important variable in separating turtle communities. But only the species *J. effusus* was significantly correlated with turtle species composition overall, as well as abundances of *C. picta* and *T. scripta scripta*. No direct connection between turtles and this plant species was evident from the literature reviewed for this study. It may be, however, that *J. effusus* is correlated with turtle composition and some species abundances because it is an indicator of other habitat conditions that might be favorable for turtle species. *J. effusus* is a facultative wetland species commonly found in shallow emergent freshwater wetlands (Ervin and Wetzel 2002, USDA 2010). Because of its habitat requirements, *J. effusus* may be indicative of stream channels that are highly connected with their floodplains to create the backwater swamp areas necessary for this plant species' survival. This extension of wetland areas beyond the stream channel may also increase the amount and variability of aquatic habitat available for turtle communities. Two other plant species, *S. altissima* and *S. pilosum,* were highly correlated with *C. serpentina* abundance. Both of these species are not necessarily associated with riparian areas, and *S. altissima* is a common species in North Carolina. Cohabitation of *C. serpentina* and *S. altissima* may simply mean that one generalist species is correlated with another generalist.

Unaddressed Factors in Study

Two additional site characteristics were beyond the scope of this study, but may influence turtle abundance and composition in restored streams. First, the quality and size of the surrounding habitat was not examined. The characteristics of the surrounding terrestrial habitat can have a significant effect on the successful habitation and reproduction of many freshwater turtle species (Iverson 1982, Bodie and Semlitsch 2000, Attum et al. 2004). Some species, like *K. subrubrum,* will leave aquatic sites for terrestrial habitation in late spring, and do not return again until the following spring (Semlitsch and Bodie 2003). Currently, the wetland permit review and associated compensatory mitigation requirements do not necessitate that conservation or mitigation projects incorporate an associated terrestrial component whose size is of significance to turtles (Joyal et al. 2001). If restoration efforts do not consider the importance of preserving or restoring terrestrial habitat surrounding the streams, most of the nesting and hibernation sites for turtles will be outside of the restored wetland boundary (Burke and Gibbons 1995). Failure to account for use of territory surrounding the stream could have significant implications for how successfully turtles use restored stream sites.

The second factor that was not considered in this study was the degree of connectivity of the restored stream with other locations that might affect turtle distribution and recolonization. Barriers, such as roads, can be a source of high mortality to turtles that are moving between sites (Conner et al. 2005). Although connectivity is less a consideration in a hydrologically connected stream network, this may have implications for other wetland restoration projects that are more isolated from other freshwater bodies. Attum et al. (2004) found that rare species of reptiles were particularly affected by the quality of connecting terrestrial habitat.

Moreover, this study only considered adult turtle captures at each of the stream sites, but did not quantify signs of turtle reproduction or the presence of other life stages. Collection of these data will be necessary to more thoroughly assess whether turtle populations are sustainable in both natural and restored stream systems.

CONCLUSIONS AND IMPLICATIONS

This study takes a first step in determining if restored stream ecosystems can support the native freshwater turtle populations that are critical components of natural stream ecosystems. Given integral role of freshwater turtles in stream ecosystems, understanding how turtles respond to restoration is necessary to assess whether restoration efforts effectively restore streams to the desired level of ecosystem functioning. The findings of this research have two important implications regarding stream restoration in the North Carolina Piedmont and consequently, for the conservation of native turtle species in the region. First, the habitat analyses indicate that the natural streams examined in this study have more characteristics indicative of stream incision and degradation than restored streams in the same area. These findings suggest that stream degradation may be a reality in the Piedmont as a result of widespread farming in the eighteenth and nineteenth centuries, and restoration may be an appropriate method to counter these effects. Second, monitoring turtle species populations at restoration sites is also critical for the conservation of these organisms in an increasingly managed network of freshwater systems (Bodie 2001, Hobbs and Cramer 2008). As habitat loss and degradation continue to contribute to turtle population declines worldwide and the number of restored streams increases on the landscape (Conner et al. 2005, Meyers and Pike 2006), ecologically-sound restored habitats may serve as critical habitat resources for long-term turtle conservation.

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APPENDICES

Appendix I: Additional Information on the NCEEP Program

NCEEP is part of the North Carolina Department of the Environment and Natural Resources (NCDENR) and is dedicated to **“**restor[ing], enhance[ing], preserve[ing] and protect[ing] the functions associated with wetlands, streams, and riparian areas, including but not limited to those necessary for the restoration, maintenance and protection of water quality and riparian habitats throughout North Carolina**”**(NCEEP 2009). After the incorporation of the NC Wetlands Restoration Program (NCWRP) into NCEEP, many wetland and stream restoration and enhancement projects have been turned over to the NCEEP for mitigation of development across the state, and therefore the NCEEP provides the most complete listing of restoration initiatives.

Appendix II: Detailed information about water quality tests

Name	**Source**	**Test**	**Type**	**Precision (%RSD)**	**Calibration Range**	**Accuracy (% R)**	**Concentration Range**	**MDL**	**Unit**
Total Phosphorus	SM 4500 PE	Colorimetric	SW	13	Middle	70-130	Middle	0.002	µg/L
Total Nitrogen	EPA 350.2	Colorimetric	SW	10	Middle	70-130	Low	0.004	µg/L
Total Suspended Solids	EPA 160.3	Gravimetric	SW	NA	10-20,000	90-110	High	0.5	mg/L
Turbidity	EPA 180.1	Turbidimeter	SW	2	0-100	90-110	Low	0.1	NTU

Appendix III: List of plant species sampled at all twelve stream locations.

Species	**Code**	**# Restored**	**# Natural**	**N/I**	**Wetland?**
Acer floridanum	ACFL	0	20	N	NA
Acer rubrum	ACRU	11	22	N	FAC
Agrostis gigantea	AGGI	9	0	I	FAC
Amphicarpaea bracteata	AMBR	8	22	N	FAC
Anthoxanthum odoratum	ANOD	2	0	I	FACU
Arisaema triphyllum	ARTR	0	2	N	FACW-
Arthraxon hispidus	ARHI	2	0	I	FACU+
Arundinaria gigantea	ARGI	0	3	N	FACW
Asimina triloba	ASTR	0	2	N	FAC
Baccharis halimifolia	BAHA	2	0	N	FAC
Betula nigra	BENI	1	0	N	FACW
Bidens aristosa	BIAR	1	0	N	FACW
Boehmeria cylindrica	BOCY	1	0	N	FACW+
Bromus **sp.**	BRSP	1	0	NA	NA
BRYOPHYTA	MOSS	0	13	NA	NA
Carex **sp.**	CASP	0	2	NA	NA
Carex annectens	CAAN	2	0	N	FACW
Carex grayi	CAGR	0	3	N	FACW
Carex lupulina	CALP	36	0	N	OBL
Carex lurida	CALR	5	0	N	OBL
Carex scoparia	CASC	4	14	N	FACW
Carex squarrosa	CASQ	0	12	N	FACW
Carex vulpinoidea	CAVU	3	0	N	OBL
Carpinus caroliniana	CACA	0	64	N	FAC
Carya cordiformis	CACO	4	0	N	FAC
Celastrus orbiculatus	CEOR	9	0	I	NA
Cercis canadensis	CECA	0	4	N	FACU
Chasmanthium latifolium	CHLT	0	37	N	FAC-
Chasmanthium laxum	CHLX	0	14	N	FACW-
Cimicifuga racemosa	CIRA	0	4	N	NA
Cinna arundinacea	CIAR	3	0	N	FACW
Circaea lutetiana **ssp.** ***canadensis***	CILC	0	1	N	FACU
Clematis terniflora	CLTE	1	0	I	FAC-
Clematis virginiana	CLVI	2	0	N	FAC+
Clethra alnifolia	CLAL	0	14	N	FACW
Commelina virginica	COVI	7	0	N	FACW
Conyza canadensis	COCA	4	0	N	FACU
Cornus florida	COFL	0	6	N	FACU
Corylus americana	COAM	6	18	N	FACU
Cryptotaenia canadensis	CRCA	0	1	N	FAC+
Cyperus erythrorhizos	CYER	2	0	N	OBL
Dactylis glomerata	DAGL	31	0	I	FACU
Desmodium laevigatum	DELA	6	1	N	NA
Dichanthelium boscii	DIBO	0	16	N	NA
Dichanthelium dichotomum	DIDI	0	34	N	FAC
Dichanthelium laxiflorum	DILA	0	18	N	FAC
Dichanthelium scabriusculum	DISB	0	2	N	OBL
Dichanthelium scoparium	DISP	27	8	N	FACW

Diospyros virginiana	DIVI	3	4	N	FAC
Elaeagnus umbellata	ELUM	1	2	I	NA
***Eleocharis* sp.**	ELSP	2	0	NA	NA
Eleocharis obtusa	ELOB	2	0	N	OBL
Elephantopus carolinianus	ELCA	0	8	N	FAC
Elymus hystrix	ELHY	1	3	N	NA
Elymus virginicus	ELVI	1	0	N	FAC
Erigeron strigosus	ERST	5	0	N	FAC
Euonymus americanus	EUAM	0	5	N	FAC-
Eupatorium capillifolium	EUPA	7	0	N	FACU
Eupatorium serotinum	EUSE	2	0	N	FAC
Fagus grandifolia	FAGR	0	5	N	FACU
Galium tinctorium	GATI	0	1	N	FACW
Glechoma hederacea	GLHE	3	0	I	FACU
Hexastylis arifolia	HEAR	0	1	N	FAC-
Hibiscus moscheutos	HIMO	5	0	N	OBL
Holcus lanatus	HOLA	3	0	I	FACU-
Hypericum punctatum	HYPU	0	1	N	FAC
Ilex opaca	ILOP	0	1	N	FAC-
Impatiens capensis	IMCA	61	0	N	FACW
Itea virginica	ITVI	0	6	N	FACW+
Juncus acuminatus	JUAC	1	0	N	OBL
Juncus effusus	JUEF	92	0	N	FACW+
Juncus tenuis	JUTE	0	2	N	FAC
Juniperus virginiana	JUVI	0	7	N	FACU-
Leersia oryzoides	LEOR	32	0	N	OBL
Lespedeza cuneata	LECU	16	0	I	NI
Ligustrum sinense	LISI	8	6	I	FAC
Lindera benzoin	LIBE	0	4	N	FACW
Liquidambar styraciflua	LIST	2	7	N	FAC+
Liriodendron tulipifera	LITU	3	0	N	FAC
Lobelia cardinalis	LOCA	2	0	N	FACW+
Lolium perenne	LOPE	9	0	I	FACU
Lonicera japonica	LOJA	39	15	I	FAC-
Lonicera maackii	LOMA	14	0	I	NA
Lotus corniculatus	LOCO	3	0	I	FACU
Ludwigia alternifolia	LUAL	1	0	N	OBL
Ludwigia palustris	LUPA	1	0	N	OBL
Menispermum canadense	MECA	0	2	N	NI
Mentha x piperita	MEPI	1	0	N	FACW
Microstegium vimineum	MIVI	35	160	I	FAC+
Mitchella repens	MIRE	0	1	N	FACU+
Muhlenbergia schreberi	MUSC	0	2	N	FAC
Murdannia keisak	MUKE	10	0	I	OBL
Oxalis stricta	OXST	1	2	N	UPL
***Panicum* sp.**	PASP	4	6	NA	NA
Panicum virgatum	PAVI	38	0	N	FAC+
Parthenocissus quinquefolia	PAQU	3	3	N	FAC
Paspalum urvillei	PAUR	5	0	I	FAC
Penthorum sedoides	PESE	1	0	N	OBL

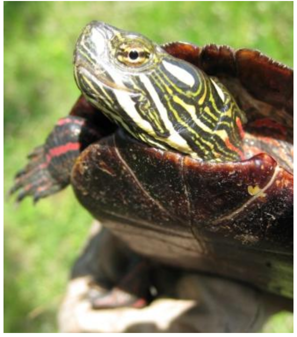
Persicaria hydropiperoides	PEHY	2	0	N	OBL
Persicaria longiseta	PELO	3	7	I	NA
Persicaria sagittata	PESA	11	0	N	OBL
Photinia pyrifolia	PHPY	1	0	N	FACW
Phytolacca americana	PHAM	1	0	N	FACU+
Pilea pumila	PIPU	0	1	N	FACW
Pinus taeda	PITA	1	11	N	FAC
Platanus occidentalis	PLOC	3	0	N	FACW-
Poa pratensis	POPR	5	0	N	FACU+
Polystichum acrostichoides	POAC	0	5	N	FAC
Prunus **sp.**	PRSP	0	1	NA	NA
Quercus alba	QUAL	0	15	N	FACU
Quercus falcata	QUFA	0	2	N	FACU-
Quercus phellos	QUPH	1	0	N	FACW-
Quercus rubra	QURU	0	2	N	FACU
Ranunculus abortivus	RAAB	0	1	N	FAC
Rhododendron periclymenoides	RHPE	0	3	N	FAC
Rubus argutus	RUAR	5	0	N	FACU+
Rudbeckia laciniata	RULA	0	2	N	FACW
Salix caroliniana	SACA	4	2	N	OBL
Salix nigra	SANI	57	0	N	OBL
Sambucus nigra ssp. canadensis	SANC	15	2	N	FACW-
Schedonorus phoenix	SCPH	56	0	I	FAC-
Sisyrinchium angustifolium	SIAN	0	1	N	FAC
Smilax rotundifolia	SMRO	3	62	N	FAC
Solanum carolinense	SOCA	1	0	N	FACU
Solidago altissima	SOAL	31	0	N	FACU+
Solidago bicolor	SOBI	0	6	N	NA
Solidago rugosa	SORU	4	0	N	FAC
Symphyotrichum pilosum	SYPI	26	0	N	FAC-
Tiarella cordifolia	TICO	0	2	N	FAC-
Toxicodendron radicans	TORA	13	2	N	FAC
Trifolium pratense	TRPR	1	0	I	FACU-
Trifolium repens	TRRE	4	0	I	FACU
Tripsacum dactyloides	TRDA	26	0	N	FAC+
Ulmus alata	ULAL	0	2	N	FACU+
Uvularia perfoliata	UVPE	0	4	N	FACU
Vaccinium **sp.**	VASP	0	5	NA	NA
Verbesina occidentalis	VEOC	5	1	N	FACU
Viburnum rafinesqueanum	VIRA	0	6	N	NA
Viola sororia	VISO	0	8	N	FAC-
Vitis cinerea var. baileyana	VICB	10	0	N	FAC+
Vitis rotundifolia	VIRO	0	24	N	FAC

Appendix IV: Pictures of each of the turtle species captured in this study.

Clemmys guttata

Pseudemys floridana

Chrysemys picta



Sternotherus odoratus

Chelydra serpentina

Trachemys scripta elegans

Kinosternon subrubrum

Trachmys scripta scripta