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ORIGINAL RESEARCH

Riparian Habitat Dissimilarities in Restored and Reference Streams are Associated with Differences in Turtle Communities in the Southeastern Piedmont

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Abstract Few studies have assessed whether restored streams and riparian floodplains support reference communities of certain groups of freshwater organisms, such as turtles. This exploratory study compared turtle assemblages in six reference and six restored streams in the North Carolina Piedmont, which were assessed using standard trapping practices with baited hoop nets. We also quantified turtle-relevant habitat characteristics (structure, water quality, vegetation) through reach-scale surveys to assess potential differences in turtle composition. Turtle abundance at restored sites was more than twice that of references sites and trends existed in the distribution of turtle species, but neither abundance nor composition was found to be statistically different. Habitat characteristics that affect turtle communities were not equivalent between sites, with reference streams having higher canopy cover, and lower total phosphorus, dissolved oxygen and total suspended solids than restored streams. Mantel's test and non-metric multidimensional scaling plots indicated that turtle composition was significantly correlated with habitat and vegetation, and that turtle communities were generally separated between restored and reference streams. These findings suggest a pattern that restored streams with riparian wetlands may provide more suitable habitat than reference streams for most southeastern Piedmont turtle species, but further studies are required to fully examine these patterns.

Keywords Restoration · Turtle · Stream · Riparian · Ecosystem

Introduction

Despite having ecosystem-based objectives, the impact of restoration on many components of stream ecosystems remains unknown due to a severe lack of biological monitoring (Jähnig et al. 2011). Many stream restoration projects fail to monitor even the most abundant and important organismal groups to determine if their goals have been met (Richardson 2004). Such failure to monitor essential ecological parameters is based on the potentially erroneous assumption that establishing certain structural components and plant species at a stream restoration site will necessarily facilitate the re-establishment of other organisms in the ecosystem (e.g. "Field of Dreams" hypothesis, Hobbs and Cramer 2008; Sudduth et al. 2011). Other barriers, such as lack of funding, time and personnel, prevent comprehensive evaluations of the success of many restorations (Bash and Ryan 2002; Convertino et al. 2013). Furthermore, the US Army Corps of Engineers' (USACE) regulatory guidance for compensatory mitigation through stream restoration does not offer specific, quantitative monitoring parameters that would rigorously evaluate ecosystem function for restoration-based mitigation projects (USACE 2008). Important questions remain as to whether most restored streams contain all of the biotic components necessary for the restoration of full ecological function and diversity, particularly with respect to higher order

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organisms. Consequently, more studies are required to assess the appropriateness of the stream restoration "Field of Dreams" hypothesis to key aquatic and riparian organisms, including aquatic mammals (Brown et al. 2008), birds (Seavy 2012), non-game fish (Raborn and Schramm 2003), amphibians and reptiles.

Aquatic and semi-aquatic freshwater turtles are diverse, abundant (Iverson 1982) and essential organisms in freshwater ecosystems, particularly in the southeast U.S., but are seldom studied in restored stream and wetland sites (Palmer and Braswell 1995; Meyers and Pike 2006; Graham et al. 2010). 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, while turtles themselves vary widely in their dietary requirements (Bodie 2001; Aresco 2009). The roles of turtles in freshwater ecosystems are thought to include exchanging energy among aquatic, riparian and terrestrial ecosystems, altering nutrient cycling, and dispersing seeds for terrestrial plants (Cheung and Dudgeon 2006; Pearse et al. 2006; Conover and Klein 2010). Turtle assemblages may also serve as indicators of biotic and abiotic characteristics of freshwater habitats, including hydrology, turbidity and primary and secondary production (Bodie et al. 2000). Thus, studying how turtle communities differ in restored streams can provide valuable information about how successfully restoration replicates pre-degradation conditions.

Despite their importance to the ecological functioning of stream and riparian ecosystems, turtle communities are rarely quantified in restored stream or wetland sites, and there are no studies to our knowledge that look at how stream and riparian restoration through geomorphic alterations affect turtle assemblages. Yet stream restoration has the potential to significantly affect the composition of turtle assemblages. For example, restoration may improve turtle habitat by reducing the amount of canopy cover as a result of tree removal, altering the number of basking sites, and increasing wetland vegetation through better connection with the floodplain (Barrett and Guyer 2008). Alternatively, numerous studies have documented no improvement in other taxonomic groups (such as macroinvertebrates) in restored streams (Palmer et al. 2009; Ernst et al. 2012); this may indicate a failure to fully restore the ecology of a degraded stream and its adjacent riparian habitat, which may have negative consequences for turtles. Additionally, the process of restoration using geomorphic methodologies can be disruptive to higher order organisms (Heinrich et al. 2014), and native turtles may be displaced or killed during the process of restoration.

The North Carolina Piedmont offers an ideal setting for studying the effects of stream and riparian restoration on turtle communities. Forested and agricultural lands in the southeastern Piedmont are being rapidly cleared for development, as population growth burgeons (Napton et al. 2010), and degradation of stream water quality and ecosystem health is prevalent in urbanizing areas of the Piedmont of Georgia (Schnoonover and Lockaby 2006), South Carolina (Lewis et al. 2007), North Carolina (NC; Gage et al. 2004; Richardson et al. 2011), and Virginia and Maryland (Horwitz et al. 2008; Groffman et al. 2003). In response to rapid habitat degradation, restoration efforts have accelerated in the Piedmont of NC. Consequently this region offers a high number of restored reaches from which to select study sites, and streams within this area support turtle communities representative of the other states within the southeastern Piedmont, thus providing excellent locations for studying systems representative of the greater physiographic region (Conant and Collins 1998).

The southeastern Piedmont is home to a large variety of aquatic and semi-aquatic turtle species (Palmer and Braswell 1995). Within the central part of the Piedmont, there are ten species of turtle that can be found in stream ecosystems. *Clemmys guttata* (spotted turtle) prefers grassy wetlands and blackwater streams (Buhlmann et al. 2008; LeGrand et al. 2008), and it is a species of concern in Georgia, South Carolina, and North Carolina. *Chrysemys picta* (painted turtle) and *Chelydra serpentina* (common snapping turtle) are dietary generalists and live in a variety of freshwater habitats in the Piedmont (Buhlmann et al. 2008). Found in all southeastern Piedmont states, *Kinosternon subrubrum* (eastern mud turtle) prefers shallow aquatic habitats with suitable terrestrial habitats nearby for aestivation and hibernation (Semlitsch and Bodie 2003; Wilson et al. 2014b); *Kinosternon baurii* (striped mud turtle) can be found in streams, but are much less common in moving water (Wilson et al. 2014b). *Pseudemys floridana* (Florida cooter) and *Pseudemys concinna* (river cooter) are more common in larger water bodies, but can be found in smaller blackwater streams (Buhlmann et al. 2008). *Sternotherus odoratus* (common musk turtle) is highly aquatic, moving overland only if forced to do so by displacement or drought. Two distinguishable sub-species of *Trachemys scripta* have been identified in the Piedmont. *T. scripta scripta* (yellow-bellied slider) is a habitat generalist and commonly found in North Carolina, South Carolina and Georgia (Wilson et al. 2014a). The native range of *T. scripta elegans* (red-eared slider) is in the Mississippi River Basin of the US, and it has been introduced in a number of watersheds outside of this range within Maryland, Virginia, North Carolina, and South Carolina (Somma et al. 2014).

Our study aims to determine if recently restored stream and riparian ecosystems support turtle species assemblages equivalent to those in natural reference streams in the same physiographic region. We measured turtle assemblage characteristics and important stream and riparian habitat features in six reference and six restored streams. We addressed the following questions in this exploratory study: (1) do reference and restored sites differ by turtle abundance and/or turtle species composition?; (2) do ecologically important habitat characteristics differ between restored and reference streams?; and (3) do habitat characteristics correspond with turtle community composition?

Methods

Site Selection

Our study compared turtle species assemblages among six restored and six natural reference streams in the NC Piedmont (Fig. 1, Table 1). Three criteria for selection of restored sites were: (1) located within the NC Piedmont region; (2) included a stream channel restoration component; and (3) were between their second and fifth growing seasons since the completion of restoration. In addition, all six streams were restored using geomorphic-based restoration methodologies (primarily Natural Channel Design; Doll et al. 2003), with riparian vegetation planted at the completion of construction. Comparable reference streams were considered if they were within 12 km of at least one restored stream location and if their biological integrity was not known to be compromised, according to the North Carolina 303d list of impaired water bodies (NCDWQ 2008). Additional characteristics considered in reference stream site selection included similar size and stream order, predominantly forested land cover and riparian areas, and permission from property owners to access the streams.

Aquatic Turtle Sampling

Aquatic turtle sampling occurred via hoop-net turtle traps (0.76 m diameter hoop, 1.83 m long and 3.8 cm mesh net) (Memphis Net and Twine, Model TN215). Three traps were set within a 60-m reach according to standard methods (Steen and Gibbs 2004) and checked daily. Although species and sex biases have been documented with this trapping method (DonnerWright et al. 1999; Bodie and Semlitsch 2000; Tran et al. 2007), the use of aquatic hoop traps for freshwater community studies is common, widely accepted and effective in studies of semi-aquatic turtle communities (Conner et al. 2005; Gibbs and Steen 2005; Glorioso et al. 2010).

Trapping occurred during the summer of 2009 at three separate intervals: late May to early June, mid-June to early July, and mid- to late-July. Every stream was visited for the same number of nights during each interval, totaling 12 trap nights spent at each site. Because it was not possible to trap at all 12 locations simultaneously, sites were visited in groups of four (two restored and two reference streams) based on relative locations within the study area.

After removing any captured turtles for further measurements, the empty trap was returned to its original location. For each turtle captured, the species, sex, and location were recorded, and standard length (plastron) and mass measurements were made. Captured turtles were individually identified by making unique notching in the shell (Ernst 1971) or using photographs of natural scarring (for more aggressive species), and released on site.

Habitat Characterization

The stream reach was characterized by measuring habitat characteristics (structure and water quality) and riparian vegetation. Stream structure was defined by pool width, pool depth, bank slope, and canopy cover. Pool width was calculated as the mean baseflow maximum wetted width for each pool where a turtle trap was located. Pool depth was determined by taking the mean of five depth measurements within each pool. Mean bank slope (water surface to floodplain) was determined by taking three slope readings using a magnetic slope instrument at the beginning, middle, and end of the studied reach. Percent canopy cover served as a proxy for the amount of sunlight reaching the stream. A wide-angle photo was captured with a digital camera at chest height (~1.2 m) from the middle of the stream, and percent cover was calculated by determining the proportion of dark pixels in each photo using the ImageJ software program (Abramoff et al. 2004).

Water quality measurements were conducted at least 48 h after a rain event to minimize the occurrence of anomalies as a result of runoff. Dissolved oxygen concentration and specific conductivity were gathered at three sites within each reach with a calibrated YSI meter (Model 556 MPS, Yellow Spring Instruments, OH). Three surface water samples were taken from each stream site using an acid washed 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: total phosphorus (SM 4500 PE), chlorophyll a, total nitrogen (SM 4500-NO3-E), total solids (EPA 160.3), and turbidity (EPA 180.1) (http://www.standardmethods.org/).

To characterize the riparian vegetation, three 30-m line transects were established in the riparian area parallel to the studied stream reach. A weighted string was lowered every 20 cm along the transect, and the name of the first plant species touched was noted for each transect point (Richardson and King 2013).

Data Analysis

Turtle abundance was defined as the total number of all turtles captured at each site. Turtle abundance was compared between stream types using modified *t*-tests: instead of directly comparing each group using a standard *t*-test, we compared each mean difference with 999 bootstraps of the data.

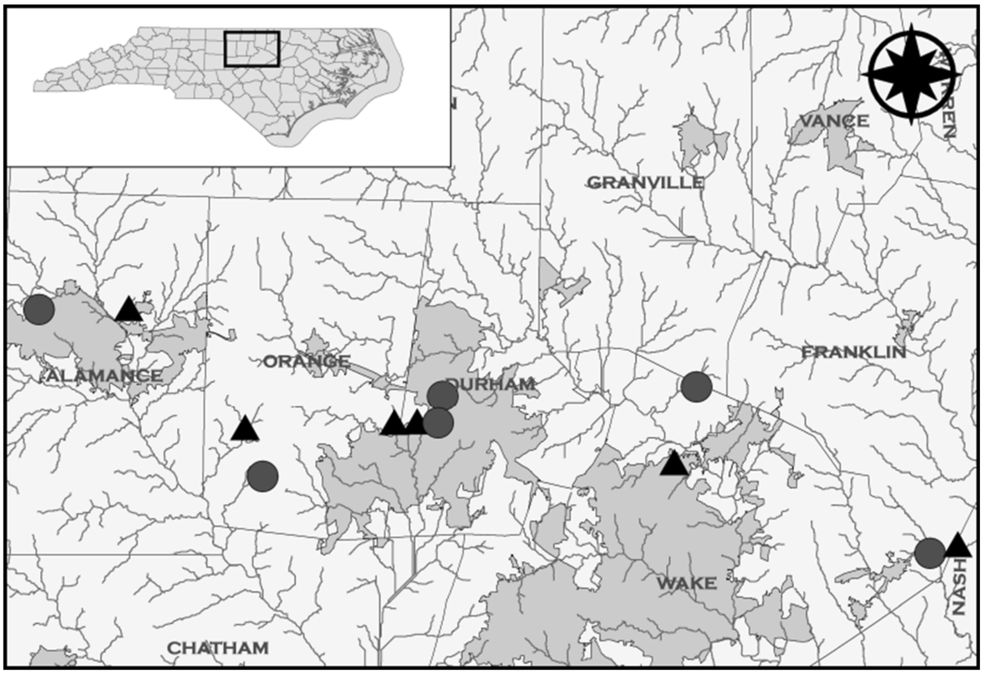

Fig. 1 Locations of reference (*triangles*) and restored (*circles*) stream sites sampled in this study in the Piedmont ecoregion of the southeastern U.S. The shaded regions show urban municipal boundaries within the study area

Reference and restored streams were compared for each character of interest (turtle community, habitat characteristics, and riparian plant community) using an Analysis of Similarities (ANOSIM) with the Paleontological Statistical (PAST) analytical software package (Harper et al. 2001) Similarity matrices for each of the three characters of interest were created using Chord distances. This distance metric was determined to be the most suitable for turtle and plant community data because it emphasizes differences in species proportions within each community and excludes joint absences (Anderson et al. 2011). It also provided a way to relativize the water quality and structural data. If reference and restored sites were found to be significantly different, a Similarity Analysis (SIMPER) was conducted to determine which components of the matrix contributed most to differences between site types.

Mantel's tests were used to calculate correlations between turtle species composition, and habitat and riparian plant characteristics to examine potential predictors of turtle assemblages. If the Mantel's test indicated that the correlation was significant, habitat and riparian plant matrices (developed with Chord distances) were plotted using non-metric multidimensional scaling (NMDS) techniques. Non-metric multidimensional scaling (NMDS) is a multivariate statistical method that

Table 1 Twelve stream study site codes (repeated in later tables and figures), locations, stream order, lentic habitat within 1 km radius, years since restoration (time restored), and restoration size

	Site	Code	Latitude	Longitude	Order	Lentic Habitat (m^2)	Age (year)	Restoration Size
Reference	Boyds Creek	BOY	36.1203°	−79.3683°	2	338,844	NA	NA
	Cane Creek	CAN	35.9863°	−79.2070°	1	66,800	NA	NA
	Cedar Creek	CED	35.9475°	−78.6191°	2	150,878	NA	NA
	Mud Creek	MUD	35.9932°	−78.9713°	2	22,480	NA	NA
	Piney Creek	PIN	35.9922°	−79.0025°	1	9,967	NA	NA
	Turkey Creek	TUR	35.8539°	−78.2316°	3	45,866	NA	NA
Restored	Bold Run Creek	BOL	36.0322°	−78.5588°	1	36,727	2	496.5 m stream
	Collins Creek	COL	35.9315°	−79.1829°	1	18,262	2	2881.27 m stream
	Ellerbe Creek	ELL	36.0228°	−78.9306°	2	57,270	5	1913.84 m stream
	Glen Raven Creek	GLE	36.1178°	−79.4903°	2	40,102	3	732.13 m stream
	Moccasin Creek	MOC	35.8430°	−78.2703°	1	75,376	4	54.86 m stream, 14,973 m^2 riparian buffer
	Sandy Creek	SAN	35.9912°	−78.9428°	2	26,823	3	14568.7 m^2 restoration and creation

More information on each restoration project can be found at portal.ncdenr.org/web/eep and clicking on the "Project Documents" link can be used to simplify complex species community and other ecological data by ordinating (systematically arranging) the information on a pre-determined number of axes in a way that reflects the ecological differences between samples (Kenkel and Orlóci 1986). Once data are ordinated on the axes in a way that captures the maximum amount of data variability, the data can be plotted to look for potential clustering of samples (e.g. by site type) and trends between species composition and environmental variables. NMDS offers an unbiased summary of ecological data in addition to providing a simplified technique for visualizing complex data. Once NMDS analyses were complete for habitat and riparian vegetation parameters, turtle community data were overlaid in the form of vectors to show relationships between the site characteristics and individual turtle species. Statistical significance for all statistical tests was set at an alpha value of 0.05.

Results

Turtle Community Characteristics

A total of 77 turtles were captured representing eight Piedmont turtle species; see Supplementary Materials (S1), Palmer and Braswell (1995), and Ernst and Lovich (2009) for greater details regarding the ecology and characteristics of these species. At the reference sites, 24 turtles representing five species were captured, while 53 turtles representing seven species were captured at the restored sites (Table 2). Although abundance was not significantly different between site types ($P=0.13$), mean turtle abundance at restored sites (≈9) was more than twice that of reference sites (≈4).

ANOSIM results indicate that turtle communities do not significantly differ between reference and restored sites ($P=0.31$), but within species abundance did not appear to be evenly distributed between site types. Of the eight species trapped, three were only found at restored streams (*C. guttata*, *K. subrubrum,* and *T. scripta elegans*), and more than double the number of *C. picta, C. serpentina,* and *T. scripta scripta* individuals were captured at restored streams than at reference streams. *P. floridana* was only captured at reference streams, and *S. odoratus* was found more frequently in reference streams.

Habitat Characteristics

Reference and restored stream sites differed significantly in terms of their habitat (structural and water quality) characteristics (ANOSIM analysis, $P=0.006$) (Table 3). The SIMPER analysis indicated that three water quality and one structural habitat quality contributed to the greatest difference between stream types (>85 % of difference explained). Compared with restored streams, reference streams had lower total phosphorus (44.8 vs. 94.8 μg/L), higher mean canopy cover (73.1 vs. 27.1 %), lower mean concentration of total solids (74.9 vs. 123.1 mg/L), and lower dissolved oxygen (49 vs. 58.2 % saturation)).

Riparian plant communities also differed significantly between restored and reference streams (ANOSIM analysis, $P=0.002$). Of the 141 plant species identified, 23 species were found at both site types, 65 were found only at restored sites, and 53 were found only at reference sites (Supplementary Materials S2). Of the 60 species included in the SIMPER analysis (those that occurred at 2+ sites), five plant species were identified that contribute the most to differences between site types. Three species were more representative of reference sites (*Microstegium vimineum, Smilax rotundifolia,* and *Carpinus caroliniana,*). Two species were only found in restored streams and had relatively high abundance at these sites: *Juncus effusus* and *Schedonorus arundinaceus.*

Turtle Community and Habitat Correlations

The Mantel's test indicated that turtle community composition was significantly correlated with habitat parameters (water quality and structural) that separate the two stream types ($P=0.015$, $r=0.342$) (Fig. 2). *S. odoratus* and *P. floridana* were more frequently associated with habitat characteristics of reference streams. *S. odoratus* in particular was more frequently associated with lower order reference streams. All other turtle species were more frequently associated with the habitat characteristics of restored streams. Within the restored stream group, *T. scripta elegans* and *C. serpentina* were more highly correlated with the habitat conditions of Ellerbe Creek and Sandy Creek. *T. scripta scripta* fell in the middle of the restoration habitat conditions, while *C. guttata, K. subrubrum,* and *C. picta* were more highly correlated with the remaining restored streams.

Turtle community composition was also correlated with riparian plant community data ($P=0.041$, $r=0.274$). However, only two turtle species appeared to separate between riparian communities of restored streams and those of reference streams. *C. serpentina* was most highly associated with the riparian communities of restored streams, while *P. floridana* was most highly associated with the riparian community of reference streams.

Discussion

This exploratory study addresses a crucial yet largely unanswered question of how stream restoration affects turtle community composition and whether differences in turtle habitat reflect observed differences in turtle composition. Our

Table 2 Number of turtles captured at each of the twelve stream sties for each of the following species: *C. guttata* (CG), *C. picta* (CP), *C. serpentina* (CS), *K. subrubrum* (KS), *P. floridana* (PF), *S. odoratus* (SO), *T. scripta elegans* (TE) and *T. scripta scripta* (TS)

Site	CG	CP	CS	KS	PF	SO	TE	TS	Total # Turtles	# Species/ Site
Reference sites										
BOY	0	0	0	0	0	0	0	0	0	0
CAN	0	1	1	0	0	3	0	1	6	4
CED	0	0	2	0	0	0	0	1	3	2
MUD	0	0	2	0	0	1	0	1	4	3
PIN	0	0	1	0	0	1	0	3	5	3
TUR	0	1	1	0	1	3	0	0	6	3
Total reference	0	2	7	0	1	8	0	6	24	5
Restored sites										
BOL	0	0	3	0	0	0	0	0	3	1
COL	0	1	3	0	0	3	0	0	7	3
ELL	0	0	6	0	0	0	0	2	8	2
GLE	0	0	2	1	0	0	0	0	3	2
MOC	2	5	0	4	0	2	0	9	22	5
SAN	0	1	2	0	0	0	4	3	10	5
Total restored	2	7	16	5	0	5	4	14	53	7

research of turtle communities in the southeastern Piedmont documented twice the mean abundance of turtles in restored streams than reference streams. While not statistically significant, these findings suggest a trend that may have biological significance and deserves additional study. The ANOSIM analysis indicated that turtle community composition did not statistically differ between reference and restored streams, but we did observe trends in species distribution based on the life history traits of the turtles. Additionally, habitat characteristics important to turtles were significantly different between restored and reference streams, and these habitat characteristics were correlated with trends in turtle community composition that showed separation between restored and reference streams.

Our results show important differences in turtle habitat characteristics (structural and water quality) between reference and restored streams that suggest that restored streams are more suitable habitat for most aquatic and semi-aquatic turtles of the Piedmont. Reference streams were more typical of forested headwater streams within the Piedmont, including higher canopy cover, lower total suspended solids, and lower primary production (lower total phosphorus and lower daytime dissolved oxygen). In contrast, restored streams were characterized by habitat and water quality features of more open water systems: lower canopy cover, higher total suspended solids, and higher primary productivity (due to higher nutrients and increased light) (Hladyz et al. 2011). Differences in canopy cover between stream types are partially a function of the process by which streams are typically restored, and partially due to the age of restored streams. Larger trees might be removed purposely, if the restoration incorporates channel reconfiguration, or incidentally to make

Table 3 Mean differences between reference and restored streams for structural and water quality characteristics, and percent contribution of variable to differences between restored and reference sites using SIMPER analysis

Variable	Reference mean ±1 SE	Restored mean ±1 SE	Contribution
Total Phosphorus (μg/L)	44.8±7.0	94.8±28.2	29.1 %
Canopy (%)	73.1±4.4	27.2±7.3	24.4 %
Total Solids (mg/L)	74.9±9.7	123.1±18.8	20.3 %
Dissolved Oxygen (%)	49.0±10.1	58.2±12.8	13.2 %
Depth (cm)	49.3±8.3	38.0±2.7	6.2 %
Bank Slope (°)	39.5±5.2	22.4±6.1	5.1 %
Turbidity (NTU)	9.32±3.40	11.13±4.91	1.1 %
Total Nitrogen (μg/L)	1087±36	1275±175	0.2 %
Chlorophyll a (μg/L)	1.73±0.51	4.37±2.33	0.2 %
Baseflow Width (m)	5.7±0.9	3.4±0.5	0.1 %
Specific Electrical Conductivity (mS/cm)	0.14±0.03	0.18±0.04	<0.1 %

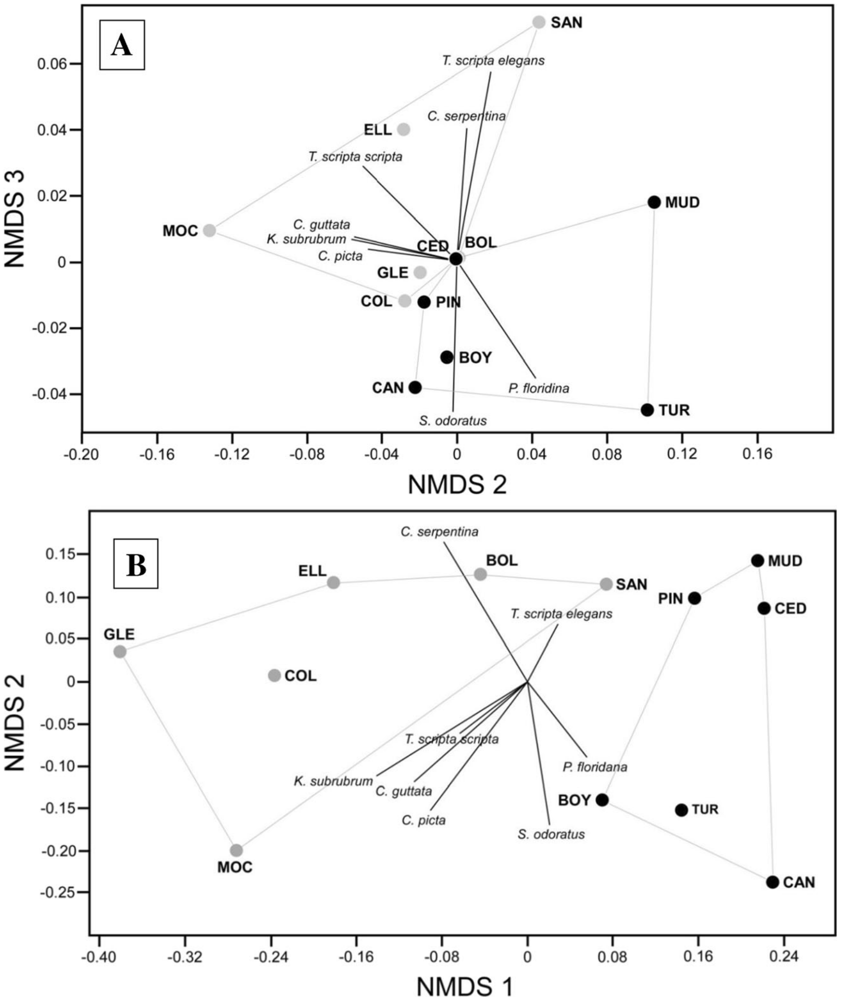

Fig. 2 Plot of the twelve study streams based on an NMDS three-axis analysis of the (**a**) habitat (structure and water quality) and (**b**) riparian vegetation dissimilarity matrices constructed using Chord distances. The two axes selected for display represent the two with the greatest degree of separation between reference and restored sites. The *gray circles* represent the restored sites and the *black circles* represent the reference sites. The *arrows* show the correlation vectors for the turtle species associated with the NMDS axes

way for larger machinery. Differences in shading of streams may contribute to the disparity in turtle species composition between site types both directly and indirectly. Shading of streams directly affects turtles by reducing the number of available basking sites, an important habitat requirement of many turtle species (Bulté and Blouin-Demers 2010). In their study of urban vs. reference streams in the southeastern Piedmont, Barrett and Guyer (2008) documented an increase in the number of aquatic turtles in urban streams, which they attributed to the presence of open canopy and warmer waters. Studies of Piedmont turtles in human-altered lentic environments also suggests high light environments are of importance to turtles (Guzy et al. 2013).

Light attenuation through increased canopy cover both reduces in-stream primary productivity and alters the composition of understory vegetation. Differences in in-stream productivity between restored and reference sites may have bottom-up effects on turtle abundance (Aresco 2009). In their study on human-modified ponds, Failey et al. (2007) argue that turtles benefit from human activities that maintain or increase open-canopy habitats, and restored streams in the Piedmont may offer important habitat for semi-aquatic turtles as natural open-canopy wetlands continue to be lost. Higher total suspended solids in restored streams indicate the presence of high sediment load and are likely responsible for the higher turbidity at these sites. It is possible that turtles prefer the more turbid water of restored streams as well; Glorioso et al. (2010) found that certain turtle species preferentially live in murky waters.

Our results also indicate that riparian plant community composition is an important habitat variable separating reference and restored streams, and restored streams have plants indicative of better turtle habitat. Two plant species characteristic of reference sites, *C. caroliniana* and *S. rotundifolia,* are native, woody understory species that are common in forested areas of the Piedmont. The dominance of these species further supports the idea that reference streams are more typical forested headwater streams. Another plant species ubiquitous in the reference sites is *M. vimineum*, a highly invasive grass species. Despite their close proximity to the stream, none of these species is an obligate or facultative wetland plant species; this may suggest that reference streams may not be hydrologically well-connected with their floodplain due to increased channel incision. Reference streams were also characterized by steeper slopes and deeper pools than restored streams, further suggesting some degree of stream incision at these sites. Additionally, the high mean abundance of *M. vimineum* at all of the reference streams provides further evidence of some degradation at reference sites and a lack of continued riparian flooding (DeMeester and Richter 2010; Ho and Richardson 2013). The reference sites in this study were carefully selected for maximum stream quality and minimum degradation. Evidence of channel and riparian degradation in the selected reference sites further suggests that stream degradation is unavoidable across the Piedmont area as a remnant of post-settlement, widespread farming (Walter and Merritts 2008) and rapid development across the region (Napton et al. 2010). Restored streams were characterized by a different invasive grass species, *S. arundinaceus*, which is more prevalent in high light environments more typical of this stream type. However, *J. effusus* was also prevalent at restored stream sites. *J. effuses* is a facultative wetland species commonly found in shallow emergent freshwater wetlands (Ervin and Wetzel 2002; USDA 2014), and likely indicates high connectivity between the stream and its floodplain. While no direct connection between turtles and any of these important plant species could be found in the literature, we speculate that the presence of *J. effusus* is indicative of the type of habitat (wetland or non-wetland) historically available to turtle species. Thus, stream channels that are highly connected with their floodplains can create the backwater areas necessary for *J. effuses'* survival as well as increasing the amount and variability of aquatic habitat available for turtle communities. Other studies also document changes in turtle composition due to reduced riparian food sources and habitat as a result of stream incision (Bodie 2001).

Differences in habitat and vegetation characteristics between sites may also explain the differences observed in the distribution of turtle species between reference and restored sites. Of the eight turtle species documented in this study, six turtle species were more prevalent or only captured at restored sites. *C. guttata* was only captured at the restored stream location (Moccasin Creek) that most closely met its habitat preference for higher abundance of aquatic vegetation and slower moving water (Buhlmann et al. 2008). Documentation of *C. guttata* is noteworthy, given its elusive nature and its conservation status in three southeastern states (LeGrand et al. 2008). *K. subrubrum* (a widespread Piedmont species) was captured exclusively at two restored sites, possibly reflecting its preference for the dense riparian ground vegetation more prevalent in open canopy conditions (Buhlmann et al. 2008). *T. scripta elegans* was only captured at one highly urban stream restoration site. This sub-species of *T. scripta* is a particularly invasive turtle species in some parts of the U.S. and in most of Europe, with the Invasive Species Specialist Group naming it in the top 100 invasive species in the world (Cadi and Joly 2004; Somma et al. 2014). *T. scripta elegans* is frequently found outside of its native range because individuals are often released as unwanted pets, possibly explaining its occurrence in the most urban restored stream.

The three species captured at both types of streams (but more commonly in restored sites), *C. picta, C. serpentina,* and *T. scripta scripta*, are widespread and common habitat generalists in the southeastern Piedmont (Buhlmann et al. 2008; Ernst and Lovich 2009; Graham et al. 2010). The literature suggests that these species may also be better adapted to human-modified aquatic environments, characterized by restored streams. Eskew et al. (2010b) found that survivorship and recruitment of *T. scripta scripta* was unaffected by development surrounding a Piedmont pond, and *C. serpentina* survival rates in developed ponds exceeded those of natural habitats. A study by Failey et al. (2007) found that these same three species, and to a lesser extent *K. subrubrum,* were common in farm and golf course ponds highly impacted by human disturbance. Interestingly, this same study found that *P. concinna* and *S. odoratus* were not as common in these highly modified habitats (see below).

The two remaining species were either captured only or more frequently at reference sites. *P. floridana* was captured only once in a reference stream at the eastern border of the Piedmont, which may be attributed more to the stream's proximity to the Coastal Plain ecoregion and the order of the stream (third), and less to the type of site. Only *S. odoratus* was captured more frequently at reference sites. *S. odoratus* does not readily move between aquatic habitats, and therefore may not have had enough time or reason to recolonize restored stream locations (Ernst and Lovich 2009).

Two additional site characteristics were beyond the scope of this study, but may influence turtle abundance and composition in restored and reference streams. First, the quality and size of the surrounding habitat with respect to its suitability for turtles was not examined. These characteristics can significantly affect the successful habitation and reproduction of many freshwater turtle species (Bodie and Semlitsch 2000; Attum et al. 2008; Guzy et al. 2013). Currently, the US Army Corps of Engineers and US Environmental Protection Agency compensatory mitigation requirements do not necessarily require the permitee to conserve or protect associated terrestrial components (USOFR 2008) 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 (Harden et al. 2009) and may have significant implications for successful use of restored stream sites by turtles to maintain their populations. Thus, surrounding suitable nesting habitat and reduction of proximity to roads may be particularly important when restoration projects are conducted in residential areas (Price et al. 2013).

The second factor not considered in this study was the degree of connectivity of the restored streams with other locations that might affect turtle distribution and re-colonization, and which has been found to affect rare species of reptiles. Bodie and Semlitsch (2000) documented turtle colonization in newly formed wetlands within 5 years of their creation, and Bowers et al. (2000) found low level re-colonization of most species of reptiles and amphibians in a stream system in South Carolina, 2 to 3 years after hot water from a nuclear facility devastated local flora and fauna. Thus colonization of restored streams within 2 to 4 years post-restoration is not unexpected, especially given the high number of open water habitats within one km radius of each stream (Table 1) that could serve as potential source populations.

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. A study by Eskew et al. (2010a) suggested that there may be a substantial lag time between habitat modification and the effect on adult turtle populations for *C. picta*, and Eskew et al. (2010b) indicated that *C. serpentina* had low recruitment in developing sites. We suggest that collection of age distribution data will be necessary to more thoroughly assess whether turtle populations are sustainable in both reference and restored stream systems.

Conclusion and Implications

This study takes a first step towards determining if restored stream ecosystems can support the native freshwater turtle populations that are critical components of these systems in the southeastern Piedmont. Given their integral role in stream ecosystems, turtles are uniquely situated to offer understanding of the success of restoration efforts. Our findings have two important implications regarding stream restoration in the Piedmont and consequently, for the conservation of native turtle species in the region. First, the habitat analyses indicate that the reference streams examined in this study were more characteristic of typical shaded forest headwater streams in the Piedmont, with some evidence that channel incision and degradation from the abundance of invasive riparian plants may be widespread in this region, thus providing less turtle habitat. In contrast, restored sites' characteristics were more similar to high light, open water habitats, more highly connected with their floodplain, which have been found to be preferable to many turtle species in studies of lentic habitats in this region (Guzy et al. 2013). Second, our study suggests that there is a trend towards higher turtle abundance, and possibly different turtle communities, at restored streams due to differences in habitat characteristics. Monitoring turtle species populations at restoration sites in the future is 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 (Meyers and Pike 2006; Barrett and Guyer 2008), ecologically sound restored habitats may serve as critical habitat resources for long-term turtle conservation.

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