Creating False Images: Stream Restoration in an Urban Setting

Authors: **Kristan Cockerill** and William P. Anderson, Jr.

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Creating False Images:
Stream Restoration in an Urban Setting

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ABSTRACT:
Stream restoration has become a multibillion dollar business with mixed results as to its efficacy. This case study utilizes pre- and post-monitoring data from restoration projects on an urban stream to assess how well stream conditions, publicly stated project goals, and project implementation align. Our research confirms previous studies showing little communication among academic researchers and restoration practitioners as well as provides further evidence that restoration efforts tend to focus on small-scale, specific sites without considering broader land use patterns. This study advances our understanding of restoration by documenting that although improving ecological conditions is a stated goal for restoration projects, the implemented measures are not always focused on those issues that are the most ecologically salient. What these projects have accomplished is to protect the built environment and promote positive public perception. We argue that these disconnects among publicized goals for restoration, the implemented features, and actual stream conditions may create a false image of what an ecologically stable stream looks like and therefore perpetuate a false sense of optimism about the feasibility of restoring urban streams.

(KEY TERMS: stream restoration; pre and post monitoring; thermal pollution; urban streams; public perception.)

INTRODUCTION

The idea of "restoring" waterways has a long and varied history. In 1871, British Parliament heard calls to restore rivers polluted by discharge from woolen manufacturers (Royal Commission on River Pollution, 1871). Restoration was also promoted as a necessary component of fisheries management in prominent 19th Century journals (Ffennell, 1872; "The Naturalist", 1872). This attention focused largely on the economic ramifications of poor water quality and what was being "restored" was economic vitality. By the early 20th Century restoration was being promoted as necessary for flood control. For example, in the 1940s the Schuylkill River was "restored" to remove accumulated culm deposited by the numerous regional coal mines and to reshape the river to improve flood control (Pitkin, 1956). With the advent of the modern environmental movement mid-20th Century, the idea of restoring rivers increasingly reflected growing awareness of our dependence on healthy ecosystems and the negative ecological impacts caused by industrialization and urbanization. Stream restoration is now a multibillion dollar industry touted as a necessary approach to alleviate impacts from historical damage and to improve ecological conditions.

This growth in activity and shift in focus aligns with the rise of environmental ethics and the idea that Homo sapiens has an obligation to repair the damage it has wrought on ecosystems and to avoid future damage. Guilt and concern about our ability to sustain ourselves, along with a prevailing sense of optimism and hubris that it is possible to repair past damage have helped to build the ecological restoration bandwagon (Elliot, 1997; Hilderbrand et al., 2005). A hope for redemption is reflected in most definitions of restoration, including the widely cited National Research Council (1992) report that defines stream restoration as, "reestablishment of predisturbance aquatic functions and related physical, chemical, and biological characteristics." As scholars well recognize, especially in urbanized settings, meeting this definition is not feasible. First, because in most places it is difficult to know what a "predisturbance" stream looked like and how it functioned (Rhoads et al., 1999). Second, even if that knowledge were well established, in many settings it is not physically possible to recreate those conditions. In addition, recent research shows that uncertainty about prehuman disturbance characteristics have resulted in restoring streams to an earlier condition, but still reflecting post-human disturbance (Walter and Merritts, 2008). Finally, streams are dynamic systems and would have experienced change even without human manipulation. These realities have contributed to a glossary of terms (e.g., rehabilitation, mitigation, enhancement) that refine characteristics of the diverse activities that in practice tend to be lumped into "restoration" (see Shields et al., 2003 for a summary table). As Wohl et al. (2005) note, "Various perceptions of what is meant by 'restoration' reflect the wide disparities in stakeholder interests, scientific knowledge, scales of interest, and system constraints encountered in practice. In the parlance of stream and river management, 'restoration' describes activities ranging from 'quick fixes' involving bank stabilization, fencing, or engineering fish habitat at the reach scale, to river-basin-scale manipulations of ecosystem processes and biota over decades."

Partially because of this diverse mix of intention and activity, until very recently, there was little attention paid in assessing or monitoring stream restoration projects. There is now a growing body of literature reporting results from such projects, but these studies do not yet offer any consensus on the ecological value of stream restoration or on whether the expenditure has been worthwhile. Instead, there is rather a broad mix of findings including continued debate over Natural Channel Design as an effective approach to classify and manipulate waterways (Jennings, 2003; Kondolf, 2006; Lave, 2009); mixed assessments of the effects and effectiveness of geomorphologic or hydromorphologic driven restoration (Hilderbrand et al., 2005; Jahnig et al., 2010; Miller and Kochel, 2010); evidence that macroinvertebrate populations may or may not be recovered through restoration (Sudduth and Meyer, 2006; Jahnig et al., 2010; Palmer et al., 2010; Selvakumar et al., 2010); and that even well-planned experimental research on stream restoration (or any ecological restoration) delivers ambiguous results (Shields et al., 2003; Cabin, 2007). Half or fewer of the projects included in the National River

Restoration Science Synthesis database can be deemed successful when assessed against Palmer et al. (2005) criteria for restoration projects, which include having a guiding image of a more dynamic, healthy river; ecologic condition is measurably improved; river system is resilient with minimal maintenance needed; no lasting harm inflicted during implementation; and pre- and post-assessment completed (Alexander and Allan, 2007; Bernhardt et al., 2007).

Studies have demonstrated that restoration projects are often site-specific, small-scale, and opportunistic (i.e., they occur when funding, land, and landowner support are present) rather than implemented as part of a broader effort to address watershed scale land and water use impacts (Bernhardt et al., 2005; Wohl et al., 2005; Alexander and Allan, 2007; Christian-Smith and Merenlender, 2010). Additional studies focus on the importance of aesthetics in restoration activities and that aesthetic values and ecological values sometimes align and sometimes do not (Larned et al., 2006; Gobster et al., 2007; Chin et al., 2008; Junker and Buchecker, 2008; Westling et al., 2009; Wyzga et al., 2009). Finally, there is strong evidence that practitioners do not seek information from the academic literature and that there is a general lack of communication between researchers and those who implement restoration projects (Rhoads et al., 1999; Wohl et al., 2005; Wheaton et al., 2006; Bernhardt et al., 2007; O'Donnell and Galat, 2008). This disconnect is well represented in research showing that despite the less than overwhelming evidence that ecological conditions can be improved, especially on urban streams (Violin et al., 2011), stream restoration project managers do report that their projects are successful (Alexander and Allan, 2007; Bernhardt et al., 2007; Jahnig et al., 2011). In these cases, success is based on receiving positive public response and general observations of the restored site rather than on specific monitoring data about ecological conditions.

Contemporary academic literature clearly connects restoration efforts with improving ecological systems. Those seeking funding or other support for restoration projects often use the potential for ecological remediation as a rationale. The starting conditions on the waterway and the implemented restoration measures, however, are often not directly conducive to affecting ecological change. Rather, the effective rationale has been to protect the built environment. As Kondolf and Micheli (1995) have written, many restoration projects are really "environmentally friendly flood control" while Shields et al. (2003) note that many projects are "essentially landscaping efforts." In addition, Sudduth et al. (2007) report that although environmental degradation does motivate restoration, land availability is often the driving factor for site selection rather than choosing sites most likely to benefit ecologically from being restored. Finally, Wohl et al. (2005) write that the potential for restoring ecological conditions on urban streams is especially limited and the benefits from projects are largely social. In their review of daylighting projects, Wild et al. (2011) note that social benefits have not been well studied.

In this case study of Boone Creek in North Carolina, we explore the idea that, as has historically been the case, there are diverse reasons to implement a restoration project. Modern rationales include maintaining structural integrity to protect the built environment, improving recreational opportunities, developing a desirable aesthetic, as well as promoting ecological health. As Westling et al. (2009) note, however, there is little evidence that multiple benefits are realized from restoration projects. Our findings provide specific support for previous work suggesting a lack of coordination among researchers and funders or their contractors in planning, implementing, or monitoring stream restoration projects. Our experience with Boone Creek also provides further evidence of a tendency for restoration projects to focus on small scale, specific sites without considering broader land use patterns in the basin (Bernhardt and Palmer, 2011). In addition, as others have done, we document that restoration does not always improve ecological conditions and can potentially further degrade stream conditions (Tullos et al., 2009). Our study offers a new perspective by suggesting that evidence from the literature combined with the specific example of Boone Creek show that a continued emphasis on ecology as the only or primary purpose of stream restoration may often set projects up to fail and denies the importance of other benefits from stream restoration in an urban setting. Key to this study is the idea that urban stream restoration can provide valuable services that are not ecological. In addition, we argue that promoting restoration under the imprimatur of ecology when the implementation and management are not ecologically possible creates false images about what ecological restoration does look like and perpetuates a false sense of optimism about the feasibility of ecologically restoring an urban or any degraded stream.

BOONE CREEK BACKGROUND AND MONITORING PROJECT

Boone Creek is a headwaters tributary of the South Fork New River, which drains a portion of the Blue Ridge Mountains in northwest North Carolina. Although this is a mountainous region with a total relief of nearly 500 m, the stream has only a moderate gradient that averages approximately 2%. There are several nonurbanized tributaries, however, that have gradients of approximately 20%. The catchment of the section of the stream reported on here has an area of approximately 5.2 km2.

The 1.8 km reach of Boone Creek discussed here flows through the Town of Boone (population of ~15,000) and Appalachian State University (ASU) (student population of ~17,000) and is heavily urbanized. A stream survey in 2005 revealed more than 70 outfall pipes, deeply incised reaches, minimal riparian vegetation, and in some locations direct drainage from pavement to the stream. A detrimental feature to the habitat and ultimate health of Boone Creek are a series of culverts that the stream flows through, one of which is 700 m long (Figure 1).

A 2004 planning class evaluated Boone Creek and made recommendations regarding its future use. Because hydrologic and water-quality data were not collected for the class study, a group of scientists on campus began a monitoring project with goals of (1) collecting baseline hydrologic and water-quality data,

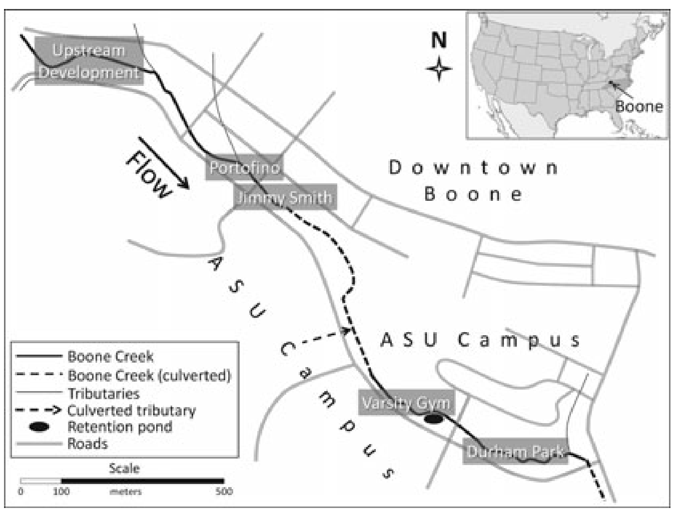

FIGURE 1. Map of Study Area.

(2) developing monitoring schemes for high-gradient, urbanized streams, and (3) determining modifications to morphology-based remediation protocols for high gradient, urbanized streams (Anderson et al., 2007). In 2006, a research team (including author Anderson) installed three stilling wells. In-Situ Troll 9,500 multiparameter probes (In-Situ, Inc., Fort Collins, Colorado) placed in each stilling well measured water levels, temperature, electrical conductivity, pH, turbidity, and dissolved oxygen (DO). Stream discharge vs. stage data enabled rating curves to be produced for each site, ultimately leading to hydrographs at each location.

Initial monitoring results indicated that discharge, electrical conductivity, and temperature were the most critical stream parameters (Anderson et al., 2007). Although turbidity increases during high discharge events, the amount of suspended sediment in the stream is relatively low when compared to other streams in North Carolina and was not deemed a critical parameter. Likewise, pH and DO values were not of critical concern. Flashy discharge was expected due to the stream's headwaters location and the abundance of impervious surface in the catchment; however, the level of flashiness exceeded expectations, sometimes increasing stream discharge by two orders of magnitude during storm events. Electrical conductivity values, which are an analog for the salinity of the stream, were also high, sometimes exceeding water-quality standards by a factor of six. The cause for this is liberal salt use to de-ice roads and sidewalks from October through April. High temperatures were not expected because of the stream's location at relatively high elevation (~1,000 m ASL) and its cool climate; however, temperatures higher than those suggested for trout habitat were regularly exceeded, sometimes in the form of temperature surges (Nelson and Palmer, 2007; Anderson et al., 2011).

The interesting temperature signals measured in the initial study of Anderson et al. (2007) prompted more detailed measurement of stream temperatures along the study reach. A total of 10 monitoring sites were added to Boone Creek in 2007 and these sites measured stream temperatures at 15-min intervals using HOBO Water Temperature Pro v2 (Onset Computer Corp., Cape Cod, Massachusetts). In addition, 18 streambed piezometer nests, also outfitted with HOBO Water Temperature Pro v2 dataloggers, were installed in the vicinity of one of the stream gauging stations. The streambed temperature time series were combined with the method of Hatch et al. (2006) to estimate base flow. These additional temperature data contributed to an energy balance study (Anderson et al., 2010) that examined the potential thermal impacts of culvert removal from Boone Creek. Using an energy balance made up of groundwater, atmospheric, and stream components coupled with associated temperatures, the modeling study suggested that culvert removal would reduce daily-averaged stream temperatures along the study reach by up to 1.35°C.

A 2012 report from the U.S. Geologic Survey found that the negative impacts from urbanization are not uniform across regions (Coles et al., 2012). Therefore, it is important to assess the specific conditions at any stream site. Rice et al. (2011) analyzed the level of urbanization in the Boone Creek catchment and found that the impermeable surface coverage (ISC) in the catchment increases from approximately 13.7% at the upper end of the study catchment to approximately 24.3% at the end of the study catchment. Following this increasing trend in ISC, mean summer temperatures along the study stream reach increase 4-5°C. These trends correlate with air temperatures at daily-, weekly-, and monthly-averaged time scales. Analysis of a 25-m buffer zone along individual reaches of the stream showed that ISC ranges from 1% in the upper reaches of the stream to nearly 75% in the heavily urbanized reaches that flow through the town and campus. The buffer ISC correlates with temperature surges in the catchment, with temperature-surge amplitudes ranging from a mean of 1.90°C in areas of low buffer ISC to 3.27°C in areas of high buffer ISC.

Anderson et al. (2011) further examined the role of temperature surges in Boone Creek with a numerical modeling study of flood waves influenced by temperature-surge events. Flood waves cause a reverse gradient between the stream and riparian groundwater, temporarily changing Boone Creek from a gaining to a losing stream. This reversal in groundwater flow also causes the relatively hot groundwater to exchange heat with the cooler riparian sediments, thereby naturally remediating some of the heat prompted by the temperature surge. Temperature surges in Boone Creek over a four-year period, during which 71 temperature-surge events occurred, averaged a change of 2.39°C (maximum of 6.36°C) within 15 min of monitoring. These surges were also detected in the streambed piezometer nests at depths of up to 0.50 m. Although Anderson et al. (2011) model a generic stream, the conditions of the model are based on data collected from Boone Creek. The modeling results suggest that the influence of the flood wave extends to a depth of 2 m into the streambed and persists for days. They also suggest that the streambed may store approximately 72% of the storm-induced heat stored in the stream itself;

thus, the streambed may act as a buffer to some of the thermal signal of temperature surges.

Although the first restoration effort on Boone Creek was completed in 1998, since 2005 there has been increasing emphasis on campus and in the town to further restore the creek. In 2007, the ASU Provost chartered a Water Resources Planning Committee and asked this group to develop recommendations for managing Boone Creek on campus. The committee's report did provide specific suggestions, including not mowing to the creek's edge to promote a riparian buffer and using less salt on campus during the winter. The broader recommendation, however, was that focusing on the creek was insufficient and that the campus needed to consider land use impacts when thinking about managing water on campus, and more broadly in the town (Thaxton and Cockerill, 2007). The campus and the town have subsequently embarked on several discreet restoration projects on the creek with multiple stated goals. There has not been any concerted effort to consider land use issues that contribute to the negative conditions on the creek. As this study shows, the restoration efforts are not meeting ecologically oriented goals and land use decisions are potentially offsetting positive impacts from the restoration efforts.

BOONE CREEK RESTORATION PROJECTS

An explicit rationale for implementing the four restoration projects described in this article included improving water quality and stream health. More specifically, proponents of the restoration projects have noted a need to reduce sediment and improve habitat. The measures implemented, however, are not always aligned with these goals, although they may achieve other, nonecological goals. In addition, although the academic research team has been monitoring the hydrology and chemistry of the creek since 2006, these data have not been directly applied to planning or implementing restoration efforts. There has been little communication between the researchers and the teams that actually implemented the projects. The restoration teams are not actively monitoring these sites and have not requested data from the researchers. These projects are described in the chronological order of implementation and site locations are indicated on Figure 1. These projects were not linked or coordinated with each other, but were proposed and implemented as opportunities arose.

Durham Park

In the mid-1990s ASU embarked on a $30 million project that included upgrading the boiler plant, moving a baseball field, and constructing an 18,500 m2 Convocation Center in the 100-year floodplain. To provide flood mitigation and stormwater retention for the new construction, Boone Creek was daylighted from its culvert under the baseball field. Initial plans showed the creek running through several small ponds where the baseball field had been. As finalized in 1998, the project did not include any ponds, but did feature several meanders with pool and riffle sequences. It also included banks heavily armored with boulders of nonlocal rock, which acted much like pavement to heat runoff (Figure 2). Manicured native plants, nonnative ornamentals and sod were planted above the armoring. This landscaping provided no shade to the creek and no habitat for riparian fauna. In recent years, the riparian area has been maintained in a less manicured state and the boulders have accumulated enough soil in places to support vegetation. This vegetation, however, is mowed at least once a year and there is still no shade on the water.

a b

FIGURE 2. Durham Park Restoration Site. The Durham Park site in 2005 (a) and same location in 2012 (b). Note the lack of shade on the stream and the heat generating boulders (a) as well as the increased vegetation due to soil accumulation on the boulders (b)

Portofino Site

In 2008, the North Carolina Clean Water Management Trust Fund (CWMTF) provided $36,000 to a regional nonprofit organization to restore a 90-m segment of the creek. The State of North Carolina established the CWMTF in 1996 to fund projects that (1) enhance or restore degraded waters, (2) protect unpolluted waters, and/or (3) contribute toward a network of riparian buffers and greenways for environmental, educational, and recreational benefits. At this location, the creek runs under a local restaurant and along a parking lot that was being undercut. Stabilizing the parking lot required significant armoring as there was no room to re-slope the bank (Figure 3). Efforts on the restaurant side included restructuring the bank and planting native vegetation right to the water's edge to create a small floodplain/wetland area, which improved habitat and provided significant shade to that creek segment.

a b

FIGURE 3. Portofino Restoration Site. The Portofino site in 2005 (a) before restoration and in 2008 (b) post restoration. The arrow marks the parking lot that was a focal point of this project.

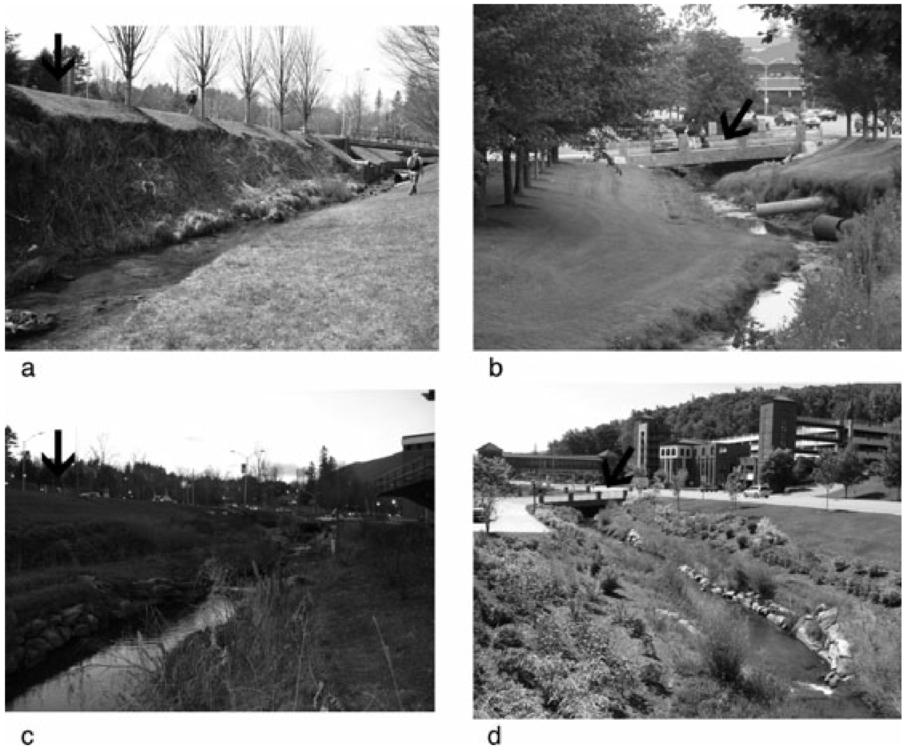

FIGURE 4. Varsity Gym Restoration Site. The Varsity Gym site in 2005 (a and b) before restoration and in 2012 post restoration (c and d). The arrows in a and c mark the primary street that the restoration was intended to protect. The arrows in b and d mark a bridge as a point for common reference.

FIGURE 5. Jimmy Smith Park Restoration Site. The Jimmy Smith Park site in 2005 (a and b) before restoration and in 2012 post restoration (c-e). The arrows in a and c mark the parking lot that was a focal point of this project. In a and c, even given the winter *vs.* summer conditions note that the canopy over the creek has been reduced. The arrows in b and d mark a primary street that runs parallel to the stream. This street is just out of the shot in e.

Varsity Gym

In 2010, the University began a $1 million restoration project in front of the newly renovated Varsity Gym. At this site, the stream runs between the building and the primary road through campus, which was being undercut. This project was funded through the Department of Transportation and the CWMTF and covered about 170 m. It eliminated several of the outfall pipes that drained directly into the creek. To address the undercutting the street-side bank was heavily armored and several mature trees were removed from the top of the bank (Figure 4). To the extent possible, the bank opposite the street was resloped to provide a bit of a floodplain and the creek was realigned to flow closer to the gym building and farther from the street. The upper banks were landscaped with native plants. The lower banks were seeded with general low cover mix, which did cover the banks by the second growing season. This does provide potential habitat, but will not provide any shade to the creek even when the plants are mature. In 2011, a storm event washed seed mats downstream and damaged a segment of the restoration requiring additional armoring to be added to the street-side bank. In 2012, a high water event created a new scour on the street-side bank, which has deepened during rain events in 2013.

This project also included constructing a rain garden on the upstream portion of the restored segment, as well as storm drain diversions and a retention area to capture storm flow at the downstream end of the segment. The retention system has a capacity of approximately 515 m3.

Jimmy Smith Park

The most recent project was completed in 2011 at Jimmy Smith Park and included about 60 m of stream at a cost of $73,000. Prior to being restored this “pocket park” featured one of the most well shaded sections of Boone Creek. This project was sponsored by a regional nonprofit and funded through CWMTF. The restoration included removing nonnative, senescing trees and re-sloping both banks to create a small floodplain (Figure 5). In addition, a shallow, linear catchment at the top of the bank that abuts a parking lot was installed to slow and filter water before it drains to the creek. The banks were revegetated with native plants and seeded with a general mix. Within several months of completion, clover and grass had taken hold throughout the area, but this section was subsequently mowed, reducing its habitat value and this low cover provides no shade to the water surface. At the downstream end of this segment the stream enters a 700-m culvert, resurfacing at the top of the Varsity Gym segment.

RESULTS FROM RESTORATION PROJECTS

Biology

Biologic indicators such as macro- or microinvertebrate populations have not been included in ongoing monitoring efforts on Boone Creek, but data presented in a 2007 report to the ASU Provost show a significantly depleted stream (Thaxton and Cockerill, 2007). Subsequent informal reports to the authors from ASU instructors and others who use the creek as an outdoor laboratory note that the creek continues to have limited aquatic populations. Given the lack of sufficient or appropriate vegetation in places, the lack of shade, and the sections that remain culverted, these conditions are not likely to greatly improve. This reflects disconnects among available data, stated restoration goals to improve ecological conditions, and the actual restoration implementation. The Water Resources Planning Committee conducted a small-scale study showing that simply not mowing the grass along a section of creek tripled species richness and doubled the diversity compared to an adjacent mowed section (Thaxton and Cockerill, 2007). Yet three of the four restored segments provide minimal vegetation at the creek's edge and these segments have been mowed on a routine basis. If biologic conditions are considered part of ecological improvement, the implemented efforts are not promoting this.

Sediment

In all but the Durham Park project, reducing erosion and subsequent sediment was indicated as an ecological benefit of the project. Pre-restoration monitoring data, however, indicated that sediment has not been an issue on Boone Creek, demonstrating another disconnect between available data, stated goals, and project implementation. Reducing erosion to protect infrastructure has been achieved at these sites, but that is a separate issue from reducing sediment to improve stream quality. Interestingly, the restoration at Jimmy Smith Park may have created a sediment issue as the bank re-sloping has shifted the creek from sitting on a gravel layer to sitting directly on a clay layer that may be more susceptible to erosion. Because the restoration team is not routinely monitoring their efforts, and sediment is not regularly included in the research team's monitoring, any increase in sediment may go undetected.

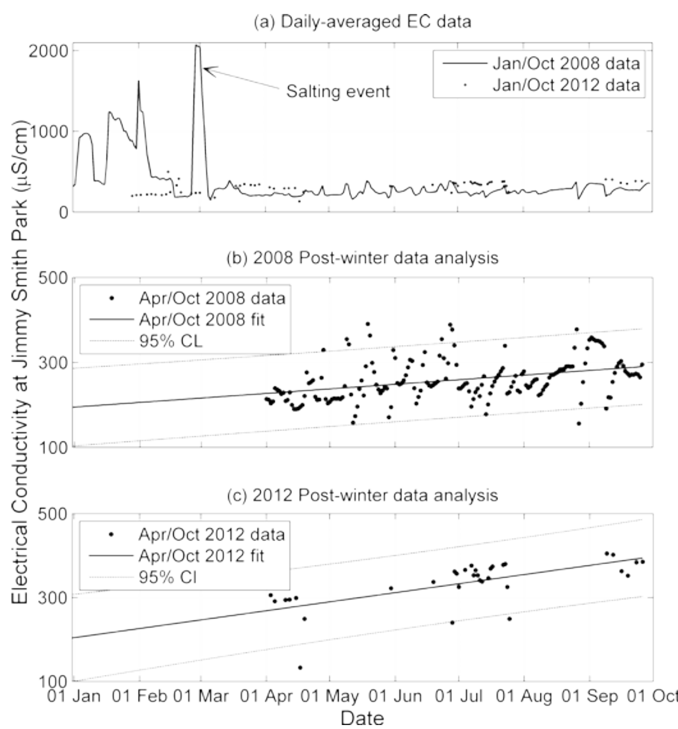

FIGURE 6. Electrical Conductivity. Electrical conductivity measurements in 2008 and 2012. (a) Time series of electrical conductivity measurements showing daily-averaged values for 15-min data in 2008 and once-daily measurements in 2012. (b) Post-winter data analysis for 2008. (c) Post-winter data analysis for 2012.

Discharge, Conductivity, Temperature

The discharge on the creek has not been impacted by the restoration projects. The stream continues to be flashy, which has affected restoration efforts as high water has washed out seed mats and scoured behind armoring.

Chemically, the creek remains in good condition, with the exception of high conductivity values. As Figure 6 shows, the restoration efforts have not decreased the average conductivity values in the stream. Figure 6a shows time series of electrical conductivity pre-restoration (2008) and post restoration (2012). It should be noted that the 2008 data are daily averages from data collected at 15-min intervals; the 2012 data represent single measurements and likely miss salinity surges in the stream. The input of salt to the system will vary with the severity of the winter season. The sharp rises in electrical conductivity represent high-salinity runoff during and after winter storm events, when the campus and town liberally apply road salt to roads and sidewalks. The spikes in 2012 were significantly lower due to a very mild winter with less salt use on roads and sidewalks. Given the lack of vegetation along much of the riparian corridor and the high percentage of impervious surface surrounding the creek, these measurements are not surprising. Of course, as vegetation matures along the riparian corridor, there is still the potential for these restored sites to reduce salt flow into the creek.

The time series in Figure 6 (b and c) display post winter salinity levels. Figure 6b shows pre-restoration data in which electrical conductivity values average 260 lS/cm between April and October. Figure 6c shows post-restoration data that averaged 307 lS/cm between April and October. Confidence limits are shown in both panels. The pre- and post-restoration datasets display an increasing trend through the summer, which likely occurs due to the arrival of saline base flow that has recharged throughout the winter combined with typically low flows during August and September. The higher slope to the 2012 data is likely in response to the lower discharge rates that occurred during the dry summer of 2012. It is clear from these figures that restoration has not reduced the salinity levels in Boone Creek.

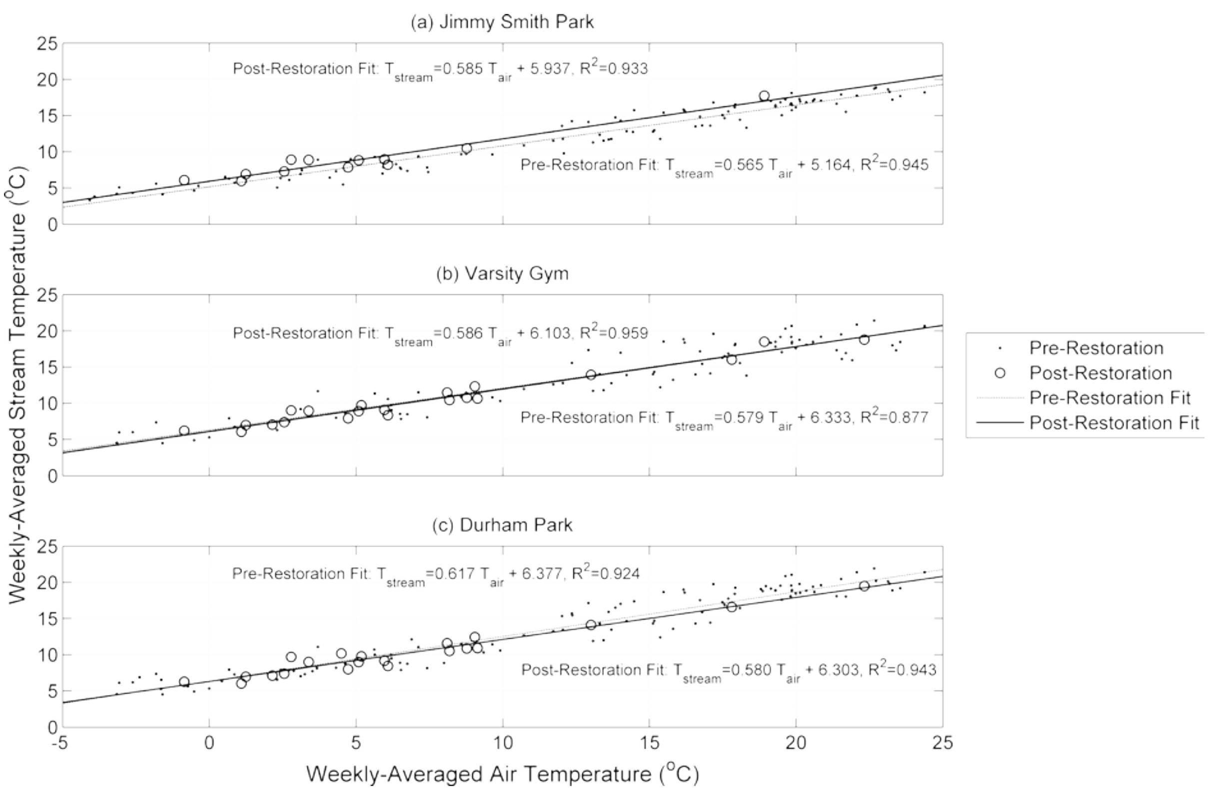

FIGURE 7. Temperature. Weekly averaged air and stream temperature measurements from January 2007 through September 2012. The post-restoration data are from August 2011 through September 2012. These trends hold when calculated at daily and monthly scales. ANCOVA results reveal that the change at Jimmy Smith Park is significant, [$F(1, 116) = 6.81$, MSE = 1.12, $p = 0.01$] and there is no change at Varsity Gym [$F(1, 106) = 0.19$, MSE = 2.36, $p = 0.66$]. Durham Park shows a downward trend at warmer temperatures, but this is not significant [$F(1, 130) = 0.99$, MSE = 1.86, $p = 0.32$].

Hydrologically, temperature has been the most significant ecological issue on Boone Creek and these restoration projects have done little to address this. Removing some of the outfall pipes has likely helped reduce negative impacts from runoff. The Jimmy Smith project included a filter strip to help control runoff from the parking lot, but this represents another gap between the existing data and restoration plans, as the pre-restoration monitoring data offer no evidence that runoff from the gravel parking lot was an issue at this site.

Despite the millions of dollars spent on restoration projects, thermal pollution remains a key concern on this stream. As Figure 7 shows, temperatures actually increased following the restoration at the Jimmy Smith Park site, likely because large trees that had been providing shade were removed. The mean stream temperature shows an increase across the air temperature gradient post restoration (0.77° higher at 0°C; 0.97° higher at 10°C; 1.17° higher at 20°C), which ANCOVA results show is significant [$F(1, 116) = 6.81$, $MSE = 1.12$, $p = 0.01$]. Conditions at the Varsity Gym site have stayed constant since the restoration, as there was no shade prior to or after the project was implemented. The downstream site at Durham Park does show a trend toward decrease in stream temperature suggesting that fewer outfall pipes, the retention pond, and perhaps the increased vegetation on the bank armoring may be helping to reduce water temperatures. At this time, however, this change in temperature is not statistically significant.

Impact on the Built Environment

All of these projects included measures that have provided positive results for protecting the built environment. Since its implementation, Durham Park has prevented floodwaters from reaching the adjacent road, despite several hurricane driven rain events on campus. The Jimmy Smith Park project likely pre vented flooding on the adjacent roadway during a high water event in January 2013. The Varsity Gym site has also helped to reduce flooding as water is funneled through the retention pond. In addition, the undercutting along the road has been eliminated, although there have been several failures along the armoring suggesting that this project will require consistent monitoring and maintenance to continue to protect the road. The Portofino site has stabilized the adjacent parking lot, which is a significant concern in this region as parking areas are extremely limited. In the short term, the Jimmy Smith project does seem to have slowed the loss of parking spaces on its adjacent lot as well.

DISCUSSION/CONCLUSION

The experience on Boone Creek echoes much of the existing knowledge about stream restoration. Our case study demonstrates, as Palmer and Allan (2006) found, that "there is little coordination among restoration plans and projects in most watersheds." Even though all of these projects were on one small creek, they were not coordinated. In addition, these projects showed disconnects among what pre-restoration monitoring data suggested were the problems on Boone Creek, what the stated restoration goals have been, and what has been implemented. All four projects did note that they were addressing issues with the built environment, but they were also promoted as efforts to improve ecological conditions. Media coverage and official documents about the Durham Park project declared that it would return Boone Creek to a "natural mountain stream" (Nicholson, 1995). A press release about the Portofino project noted that there was tremendous erosion at this site and that goals included stabilizing property along the creek and to create habitat for fish, amphibians, and birds (ASU News, 2008a). Emphasizing an ecological rationale, campus media coverage of the Varsity Gym project noted that "The design features rock structures that will mimic natural stream flow" and quoted a project promoter as saying, "we would love to see trout in the creek again" (ASU News, 2008b).

The Boone Creek case offers evidence for Shields et al.'s (2003) supposition that "… few channel modification projects lack environmental restoration or enhancement as a stated goal, if only for political reasons." Three of the four projects on Boone Creek received funding through the CWMTF because the sponsors indicated that the restoration efforts would improve water quality. Yet, according to pre-restoration monitoring, the primary ecological issue on Boone Creek is thermal pollution and none of the restoration projects included a stated goal to lower stream temperatures. A second key concern is salt, yet there was no program in the restoration projects to focus on the reduction of salt entering the waterway. This shortcoming well matches other's experience with a lack of communication between researchers and those who implement restoration efforts (Rhoads et al., 1999; Wohl et al., 2005; Wheaton et al., 2006;

FIGURE 8. Portofino Site 2012. The Portofino site in 2008 immediately post restoration (a) and in 2012 (b). The arrows point to the same structure, but the new campus building that was constructed on the restored site prevents duplicating this shot with the same perspective.

Bernhardt et al., 2007; O'Donnell and Galat, 2008). Had the existing monitoring data been consulted and these specific conditions been the focal point, the restoration projects should have included more, and more appropriate, riparian vegetation as opposed to "landscaping." Projects could have emphasized salt loving plants as part of the re-vegetation plan. The reality of all of these projects is that their primary goals were to protect the built environment, and in that they have succeeded.

This study also further supports previous work demonstrating that many, maybe even most, of the issues on an urban stream can never be addressed by focusing on the creek itself (Niezgoda and Johnson, 2005; Palmer and Allan, 2006; Christian-Smith and Merenlender, 2010). In the Boone Creek case, land use changes throughout the watershed continue to affect conditions on the creek. The high conductivity is a function of a need to keep roads and sidewalks ice-free throughout campus and the town. Although Boone Creek was daylighted through Durham Park, large segments of the creek remain culverted under parking lots and buildings. A section of the wetland at the restored Portofino site was paved in 2012 as part of a campus construction project (Figure 8). At the Jimmy Smith site, one goal was to protect a parking lot. Researcher observations of flow patterns suggest that runoff from upslope, which has not changed, may have contributed as much to the collapse of a parking space as the erosion from the creek bank below and therefore, the parking lot may still be in jeopardy. Further upstream from the sites described here, the segment of the creek that had historically shown the coldest temperatures is increasingly being surrounded with pavement as that property is developed. Water temperature averages have increased between 2007 and 2012 (1.8° at air temperature 0°C; 1.6° at 10°C; 1.4° at 20°C), which is significant [$F(1, 558) = 112$, $MSE = 1.45$, $p \leq 0.001$]. It is important to note, however, that there have not been any extreme low air temperatures since this site was developed (Figure 9). This development will, of course, have downstream impacts and undoubtedly already contributes to the temperature results shown for the restored reaches.

As noted in the Results, what the Boone Creek restoration projects have accomplished is to protect specific elements of the built environment. The newly sloped bank at the Jimmy Smith site has offered floodwater storage capacity, easing the creek's entrance into a culvert at the downstream end of the restored segment. The Varsity Gym project with its rain gardens and retention system offers similar flood storage for small storm events and has reduced the immediate threat of the stream undercutting a primary street. This retention feature may also be contributing to decreased temperatures downstream. Durham Park has successfully kept the adjacent street from flooding, even during intense storm events. In an urbanized setting these are important and positive results.

These projects have also changed the aesthetics of the creek, and anecdotally, have received public support. Qualitative evidence gathered from students on field trips along the creek and casual conversation with others walking along the creek suggests that the projects have "improved" the stream in the eyes of the public. They make comments like, "it looks better than it used to" and "this has reduced the erosion" which is perceived as a good thing. On one hand, this is encouraging as it perhaps reflects that water education has worked in making people aware that erosion can be a problem. On the other hand, there is a lack of sophistication in understanding that some erosion is normal, especially on a mountain, headwaters stream. To the public and those implementing projects, visible erosion led to the conclusion that sediment was a problem. At the Jimmy Smith and the Varsity Gym sites, despite data to the contrary, project personnel told the authors that sediment was a serious problem for creek quality. The erosion was a very real problem for the built environment and it was not pretty by most standards, but resolving this erosion issue has not generated ecological benefits to the stream.

As several studies have noted, what people perceive to be "natural" is what they respond positively to in viewing stream conditions (Nassauer et al., 2001; Junker and Buchecker, 2008; Petursdottir et al., 2013). Therefore, because the Boone Creek projects have been promoted as providing ecological restoration, the public hears or reads that these are ecologically driven projects and what they see looks pretty and therefore those two ideas become linked for them. The data, however, clearly indicate that these restoration projects have not convincingly made ecological improvements and they are unlikely to do so in the future. The public wants to see "natural" conditions and they are told that restoration will generate those conditions. This potentially creates a barrier to protecting high quality streams because the perception of what such a stream looks like is skewed. Boone Creek projects have been promoted as recreating a "natural mountain stream," yet no segment of this creek looks like or behaves like a "natural mountain stream." Reference streams in the area

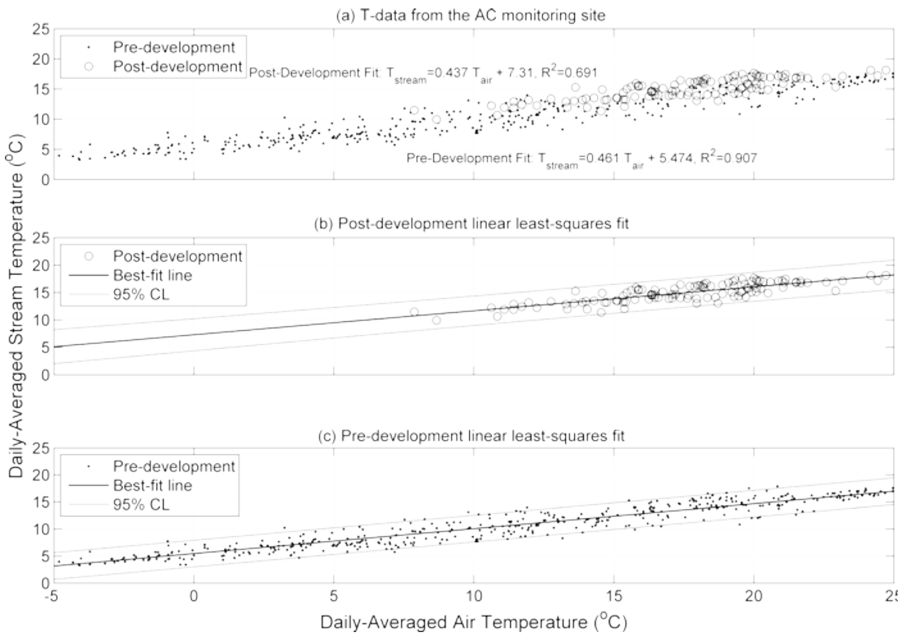

FIGURE 9. Upstream Temperature. Daily-averaged air and stream temperatures from January 2007 through September 2012. The post-development data are from August 2011 through September 2012. ANCOVA results show a significant upward trend in stream temperature [$F(1, 558) = 112$, MSE = 1.45, $p \leq 0.001$].

FIGURE 10. Mountain Stream in Southern Appalachia.

are characterized by extensive bank-top vegetation that completely shades the water; cold water; significant woody debris and cobbles that contribute to higher hydraulic roughness and hence wider channels (Leigh, 2010; Kaase and Katz, 2012). See Figure 10 for an example of what a reference stream looks like. Therefore, the public perception of an ecologically sound “mountain stream” as represented by Boone Creek is not well aligned with what characterizes an actual mountain headwaters stream. One impact of this is that when a site does offer a more ecologically sound implementation, but does not conform to the public’s sense of what constitutes “natural,” there can be tension. This was experienced at the Portofino site, when project managers received calls from the public asking when they were going to “mow the weeds” at the site. The native (and intentional) vegetation did not conform to public expectations or preferences, but it did provide some of the best potential habitat and shade of all the restored sites. This tension between what is perceived as aesthetically pleasing compared to what is ecologically beneficial is well established (Hilderbrand et al., 2005; Larned et al., 2006; Gobster et al., 2007). In addition, Lewis and Popp (2013) found significant disparity between public perceptions of ecosystem integrity and the results of a field assessment of ecosystem quality. On Boone Creek, although the stream is perceived to look better, as long as there are 700 m of culverted water, weirs, and high temperatures, this stream will not host trout or demonstrate other indicators of excellent ecological conditions.

Despite the growing evidence that ecologically restoring urban streams is problematic, the literature continues to emphasize ecology and promote ways to improve the ecologically based efforts. As our Introduction documents, there is significant debate and discussion concerning restoration projects and their success in improving ecological conditions. This is in part because there remains a dearth of studies that utilize pre- and post-monitoring data. In addition, what constitutes “success” is a contentious topic. As Jahnig et al. (2011) note, subjective perceptions are as relevant as quantified parameters and this complicates assessing project success. Specific to the Boone Creek case, there are undoubtedly steps that could be taken to improve ecological conditions (e.g., encouraging more woody growth along the riparian corridor), but the reality is that this is an urbanized creek and it cannot be “restored” to some pre-urban state. As the literature well shows, this is not a condition unique to Boone Creek but is relevant to most urban streams (Bernhardt and Palmer, 2011; Violin et al., 2011). There are, however, many other advantages, besides ecological function, to restoring streams within an urban context. The Boone Creek projects have been successful in improving aesthetics, providing flood control, and protecting the built environment. We argue that restoration proponents should resist confusing or conflating restoration for ecological reasons with restoration for aesthetic or structural reasons. To continue to create false images about ecological restoration may have long-term ramifications for stream management. Most importantly, there could be reduced motivation to support protecting nondegraded waterways, if the prevailing public attitude is that they can simply be restored after they become degraded. As Hilderbrand et al. (2005) note, development policies already “assume the ability to mitigate ecosystem damage through the restoration of degraded land or creation of new habitats.” Such assumptions reject an opportunity to better link the ideas of urbanization and the built environment and the negative impacts on our waterways. Protecting the built environment is often a legitimate reason to manipulate an urban stream, but shrouding this relationship under the idea of improving the ecology perpetuates a problematic idea that we can “have it all” — our comfortable urban environment and ecologically healthy streams within that environment. The growing body of evidence would suggest that it is not that simple. Finally, the continued lack of attention to available data means that many projects, like some of those described here, are spending money that could perhaps be better spent protecting a nondegraded stream or addressing urbanization effects rather than attempting to ecologically restore an urbanized creek.

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LITERATURE CITED

Alexander, G.G. and J.D. Allan, 2007. Ecological Success in Stream Restoration: Cast Studies from the Midwestern United States. Environmental Management 40(2):245-255, doi: 10.1007/s00267006-0064-6.

Anderson, Jr., W.P., J.L. Anderson, C.S. Thaxton, and C.M. Babyak, 2010. Changes in Stream Temperatures in Response to Restoration of Groundwater Discharge and Solar Heating in a Culverted, Urban Stream. Journal of Hydrology 393(3-4):309-320.

Anderson, Jr., W.P., C.M. Babyak, and C.S. Thaxton, 2007. Baseline Monitoring Case Study of a High-Gradient Urbanized Stream: Boone Creek, Boone, NC. In: Proceedings of the 2nd National Low Impact Development Conference, Wilmington, North Carolina, March 2007.

Anderson, Jr., W.P., R.E. Storniolo, and J.S. Rice, 2011. Bank Thermal Storage as a Sink of Temperature Surges in Urbanized Streams. Journal of Hydrology 409(1-2):525-537.

ASU News, 2008a. Boone Creek Restoration Project Begins. 15 May. http://www.news.appstate.edu/2008/05/15/boone-creek-res toration-project-begins/, accessed September 17, 2013.

ASU News, 2008b. $1 Million Boone Creek Restoration Project Begins in April 2009. 24 November. http://www.news.appstate. edu/2008/11/24/boone-creek-restoration/, accessed September 17, 2013.

Bernhardt, E.S. and M. Palmer, 2011. River Restoration: The Fuzzy Logic of Repairing Reaches to Reverse Catchment Scale Degradation. Ecological Applications 21(6):1926-1931.

Bernhardt, E.S., M.A. Palmer, J.D. Allan, G. Alexander, K. Barnas,S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follstad-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G.M. Kondolf, P.S. Lake, R. Lave, J.L. Meyer, T.K. O'Donnell, L. Pagano, B. Powell, and E. Suddeth, 2005. Synthesizing U.S. River Restoration Efforts. Science 308:636-637.

Bernhardt, E.S., E.B. Sudduth, M.A. Palmer, J.D. Allan, J.L. Meyer, G. Alexander, J. Follastad-Shah, B. Hassett, R. Jenkinson, R. Lave, J. Rumps, and L. Pagano, 2007. Restoring Rivers One Reach at a Time: Results from a Survey of U.S. River Restoration Practitioners. Restoration Ecology 15(3):482-493.

Cabin, R.J., 2007. Science-Driven Restoration: A Square Grid on a Round Earth? Restoration Ecology 15(1):1-7.

Chin, A., M.D. Daniels, M.A. Urban, H. Piegay, K.J. Gregory, W. Bigler, A.Z. Butt, J.L. Grable, S.V. Gregory, M. Lafrenz, L.R. Laurencio, and E. Wohl, 2008. Perceptions of Wood in Rivers and Challenges for Stream Restoration in the United States. Environmental Management 41(6):893-903, doi: 10.1007/ s00267-008-9075-9.

Christian-Smith, J. and A.M. Merenlender, 2010. The Disconnect between Restoration Goals and Practices: A Case Study of Watershed Restoration in the Russian River Basin, California. Restoration Ecology 18(1):95-102.

Coles, J.F., G. McMahon, A.H. Bell, L.R. Brown, F.A. Fitzpatrick, B.C.S. Eikenberry, M.D. Woodside, T.F. Cuffney, W.L. Bryant, K. Cappiella, L. Fraley-McNeal, and W.P. Stack, 2012. Effects of Urban Development on Stream Ecosystems in Nine Metropolitan Study Areas Across the United States. U.S. Geological Survey Circular 1373.

Elliot, R., 1997. Faking Nature: The Ethics of Environmental Restoration. Routledge, London, United Kingdom.

Ffennell, H., 1872. Our Salmon Fisheries. The Food Journal July:258-263.

Gobster, P.H., J.I. Nassauer, T.C. Daniel, and G. Fry, 2007. The Shared Landscape: What Does Aesthetics Have to Do with Ecology? Landscape Ecology 22(7):959-972.

Hatch, C.E., A.T. Fisher, J.S. Revenaugh, J. Constantz, and C. Ruehl, 2006. Quantifying Surface Water–Groundwater Interactions Using Time Series Analysis of Streambed Thermal Records: Method Development. Water Resources Research 42: W10410, doi: 10.1029/2005WR004787.

Hilderbrand, R., A.C. Watts, and A.M. Randle, 2005. The Myths of Restoration Ecology. Ecology and Society 10(1):19. http://www. ecologyandsociety.org/vol10/iss1/art19/.

Jahnig, S.C., K. Brabed, A. Buffagni, S. Erba, A.W. Lorenz, T. Ofenbock, P.F.M. Verdonschot, and D. Hering, 2010. A Comparative Analysis of Restoration Measures and Their Effects on Hydromorphology and Benthic Invertebrates in 26 Central and Southern European Rivers. Journal of Applied Ecology 47(3):671-680.

Jahnig, S.C., A.W. Lorenz, D. Hering, C. Antons, A. Sundermann, E. Jedicke, and P. Haase, 2011. River Restoration Success: A Question of Perception. Ecological Applications 21(6):2007-2015.

Jennings, G.D., 2003. Stream Restoration Case Studies in North Carolina. Paper presented at the Georgia Water Resources Conference, April 23-24, Athens, Georgia.

Junker, B. and M. Buchecker, 2008. Aesthetic Preferences Versus Ecological Objectives in River Restorations. Landscape and Urban Planning 85(3-4):141-154.

Kaase, C.T. and G.L. Katz, 2012. Effects of Stream Restoration on Woody Riparian Vegetation of Southern Appalachian Mountain Streams, North Carolina, U.S.A. Restoration Ecology 20(5):647-655.

Kondolf, G.M., 2006. River Restoration and Meanders. Ecology and Society 11(2):42. http://www.ecologyandsociety.org/vol11/iss2/ art42/.

Kondolf, G.M. and E.R. Micheli, 1995. Evaluating Stream Restoration Projects. Environmental Management 19(1):1-15.

Larned, S.T., A.M. Suren, M. Flanagan, B.J. Biggs, and T. Riis, 2006. Macrophytes in Urban Stream Rehabilitation: Establishment, Ecological Effects, and Public Perception. Restoration Ecology 14(3):429-440.

Lave, R., 2009. The Controversy Over Natural Channel Design: Substantive Explanations and Potential Avenues for Resolution. Journal of the American Water Resources Association 45(6): 1519-1532.

Leigh, D.S., 2010. Morphology and Channel Evolution of Small Streams in the Southern Blue Ridge Mountains of Western North Carolina. Southeastern Geographer 50(4):397-421.

Lewis, S.E. and J.S. Popp, 2013. Public Perception of Ecosystem Integrity of an Ozark Watershed. Journal of Soil and Water Conservation 68(2):89-98.

Miller, J.R. and R.C. Kochel, 2010. Assessment of Channel Dynamics, In-Stream Structures and Post-Project Channel Adjustments in North Carolina and Its Implications to Effective Stream Restoration.

Environmental Earth Sciences 59(8):1681-1692.

Nassauer, J.I., S.E. Kosek, and R.C. Corry, 2001. Meeting Public Expectations with Ecological Innovation in Riparian Landscapes. Journal of the American Water Resources Association 37(6): 1439-1443.

National Research Council, 1992. Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy. Committee on Restoration of Aquatic Ecosystems: Science, Technology, and Public Policy, Washington, D.C., National Academies of Science. ISBN: 10: 0-309-09288-4.

Nelson, K.C. and M.A. Palmer, 2007. Stream Temperature Surges Under Urbanization and Climate Change: Data, Models, and Responses. Journal of the American Water Resources Association 43(2):440-452, doi: 10.1111/j.1752-1688.2007.00034.x.

Nicholson, J., 1995. Convocation Center Will Have Minimal Impact on Boone's Floodway. ASU News, Boone, North Carolina, Appalachian State University.

Niezgoda, S.L. and P. Johnson, 2005. Improving the Urban Stream Restoration Effort: Identifying Critical Form and Processes Relationships. Environmental Management 35(5):579-592.

O'Donnell, T.K. and D.L. Galat, 2008. Evaluating Success Criteria and Project Monitoring in River Enhancement within an Adaptive Management Framework. Environmental Management 41(1): 90-105, doi: 10.1007/s00267-007-9010-5.

Palmer, M.A. and J.D. Allan, 2006. Restoring Rivers. Issues in Science and Technology 23(2):40-48.

Palmer, M.A., H.L. Menninger, and E.S. Bernhardt, 2010. River Restoration, Habitat Heterogenity and Biodiversity: A Failure of Theory or Practice. Freshwater Biology 55(1):202-222.

Palmer, M.A., E.S. Bernhardt, J.D. Allan, P.S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C.N. Dahm, J. Follstad Shah, D.L. Galat, S.G. Loss, P. Goodwin, D.D. Hart, B. Hassett, R. Jenkinson, G.M. Kondolf, R. Lave, J.L. Meyer, T.K. O'Donnell, L. Pagano, and E. Sudduth, 2005. Standards for Ecologically Successful River Restoration. Journal of Applied Ecology 42:208-217.

Petursdottir, T., A.L. Aradottir, and K. Benediktsson, 2013. An Evaluation of the Short-Term Progress of Restoration Combining Ecological Assessment and Public Perception. Restoration Ecology 21(1):75-85.

Pitkin, F.A., 1956. Correction of a Fluviatile Delinquent: The Schuykill River. In: Water for Industry. Symposium presented at the Boston Meeting of the American Association for the Advancement of Science, J.B. Graham and M.F. Burrill (Editors), December 29, 1953. Washington, D.C., American Association for the Advancement of Science, pp. 88-104.

Rhoads, B.L., D. Wilson, M. Urban, and E.E. Herricks, 1999. Interaction between Scientists and Nonscientists in CommunityBased Watershed Management: Emergence of the Concept of Stream Naturalization. Environmental Management 24(3):297- 308.

Rice, J.S., W.P. Anderson, Jr., and C.S. Thaxton, 2011. Urbanization Influences on Stream Temperature Behavior within Low- Discharge Headwater Streams. Hydrological Research Letters 5:27-31.

Royal Commission on River Pollution, 1871. Third Report of the Commissioners – Appointed in 1868 to Inquire into the Best Means of Preventing the Pollution of Rivers; Pollution Arising from the Woollen Manufacture, and Processes Connected There- with Report, Plans, and Facsimiles, Great Britain.

Selvakumar, A., T. O'Connor, and S. Struck, 2010. Role of Stream Restoration on Improving Benthic

Macroinvertebrates and In-Stream Water Quality in an Urban Watershed: Case Study. Journal of Environmental Engineering 136(1):127-139, doi: 10. 1061/(ASCE)EE.1943-7870.0000116.

Shields, F.D., C.M.J. Cooper, S.S. Knight, and M.T. Moore, 2003. Stream Corridor Restoration Research: A Long and Winding Road. Ecological Engineering 20:441-454.

Sudduth, E.B. and J.L. Meyer, 2006. Effects of Bioengineered Streambank Stabilization on Bank Habitat and Macroinvertebrates in Urban Streams. Environmental Management 38(2): 218-226.

Sudduth, E.B., J.L. Meyer, and E.S. Bernhardt, 2007. Stream Restoration Practices in the Southeastern United States. Restoration Ecology 15(3):573-583.

Thaxton, C.S. and K. Cockerill, 2007. Water Resources Planning Committee Report: Assessment and Recommendations for Boone Creek and University Policy Regarding Impact on Water Resources (5 October), Boone, North Carolina, 52 pp.

"The Naturalist", 1872. English Salmon Fisheries. The Country Gentleman's Magazine 8:475-476.

Tullos, D.D., D.L. Penrose, G.D. Jennings, and W.G. Cope, 2009. Analysis of Functional Traits in Reconfigured Channels: Implications for the Bioassessment and Disturbance of River Restoration. Journal of the North American Benthological Society 28(1): 80-92.

Violin, C.R., P. Cada, E.B. Sudduth, B.A. Hassett, D.L. Penrose, and E.S. Bernhardt, 2011. Effects of Urbanization and Urban Stream Restoration on the Physical and Biological Structure of Stream Ecosystems. Ecological Applications 21(6):1932-1949.

Walter, R.C. and D.J. Merritts, 2008. Natural Streams and the Legacy of Water-Powered Mills. Science 319:299-304.

Westling, E.L., D.N. Lerner, and L. Sharp, 2009. Using Secondary Data to Analyse Socio-Economic Impacts of Water Management Actions. Journal of Environmental Management 91(2):411-422.

Wheaton, J.M., S.E. Darby, D.A. Sear, and J.A. Milne, 2006. Does Scientific Conjecture Accurately Describe Restoration Practice? Insight from an International River Restoration Survey. Area 38(2):128-142.

Wild, T.C., J.F. Bernet, E.L. Westling, and D.N. Lerner, 2011. Deculverting: Reviewing the Evidence on the 'Daylighting' and Restoration of Culverted Rivers. Water and Environment Journal 25:412-421.

Wohl, E., P.L. Angemeier, B. Bledsoe, G.M. Kondolf, L. MacDonnell, D.M. Merritt, M.A. Palmer, N.L. Poff, and D. Tarboton, 2005. River Restoration. Water Resources Research 41:W10301, doi: 10.1029/2005WR003985.

Wyzga, B., J. Zawiejska, and Y.-F. Le Lay, 2009. Influence of Academic Education on the Perception of Wood in Watercourses. Journal of Environmental Management 90(1):587-603, doi: 10. 1016/j.jenvman.2007.12.013.