Effects of Stream Restoration on Trout in Two Northwestern North Carolina Streams

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Abstract: Stream restoration projects in coldwater streams have become increasingly common in North Carolina. Many of these projects are undertaken to reduce streambank erosion; however, improving aquatic habitat for fish is often a secondary goal. In an effort to evaluate the impact of stream restoration work on trout, the North Carolina Wildlife Resources Commission monitored trout abundance and biomass within two North Carolina streams. Trout were monitored one year prior to and for four years following restoration with backpack electrofishing gear. The data collected from each restoration reach was compared with data collected from an un-restored upstream control reach. Annual variation in relative trout abundance was similar between the restoration and control reach on both streams, suggesting that the changes observed were a result of natural variability. Other changes, such as a decline in trout biomass and the loss of brook trout (*Salvelinus fontinalis*) within the Laurel Creek restoration reach may be due in part to the restoration work. Although improvements in trout abundance and biomass resulting from the restoration work were not detected, both restorations likely met the primary goal of improving water quality by reducing streambank erosion, reconnecting the streams to the floodplain, and establishing permanent riparian buffers.

Key words: trout, restoration, monitoring, Appalachians

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Worldwide, streams are experiencing severe anthropogenic degradation at a greater rate than at any other time in history (NRC 1992). Logging, agriculture, and development have contributed to increased sediment loads and subsequent aquatic habitat loss throughout the United States. In western North Carolina, wild trout populations reside on both public and private lands. Trout populations on public lands, such as national forests and state parks, are primarily in good condition due to protected riparian buffers and limited land disturbing activities and development. In contrast, streams located on private lands in western North Carolina are often impacted through the loss of riparian buffers, stormwater runoff, sedimentation, and increased water temperatures.

Stream restorations are often used as a mitigation tool for impacted stream segments (Roni et al. 2002), and have become increasingly common in western North Carolina during the past decade. These projects are primarily implemented to stabilize stream channels, modify stream locations, and to improve water quality; however, improvement of aquatic habitats for fish is a secondary objective. Trout are sensitive bioindicators and have the ability to provide information about water quality and habitat impairments (Lyons et al. 1996). Currently, assessments of the efficacy of stream restoration projects on trout and other fish species in North Carolina are lacking, as has been reported for other areas of the United States (Kondolf 1998, Roni et al. 2002, Moerke and Lamberti 2003, Palmer and Allan 2006). A review of instream habitat restorations on trout populations provided both positive (White 1975, Schular et al. 1994, Glover 1994, Quinn and Kwak 2000, Binns 2004) and negative results (Iversen et al. 1993, Frissell and Nawa 1992, Kondolf et al. 1996, Kondolf 1998, Pattenden et al. 1998).

The North Carolina Wildlife Resources Commission (NCWRC) received information that stream restoration activities were to occur on two streams known to contain wild trout in northwestern North Carolina. These stream restorations were to be completed by private firms funded through grants with no association to NCWRC. The primary goal of both restorations was to improve water quality by repairing eroding streambanks and to enhance instream habitat. Both restorations involved natural channel design (channel pattern, profile, and dimension were all modified) and permanent conservation easements to protect riparian habitat. The objective of this study was to determine the response of trout to these restoration actions.

Study Areas

Sharp Creek

Sharp Creek (3617N, 8146W) is a third order tributary of Cove Creek, Watauga County, North Carolina, and is in the Watauga River drainage. The study site on Sharp Creek had a mean stream width (wetted perimeter) of 2.1 m, a 9-km^2 drainage area, and ranged in elevation from 854–859 meters. The restoration reach was 317 m in length, low gradient (1%), and meandered through a grassy field. Prior to restoration work in spring 2002, the stream was characterized as having steep banks covered primarily with grasses and shrubs, with few trees. The stream was incised, limiting access to the flood plain. Areas of erosion were evident, primarily in the form of steep undercut banks <1 m in height. The stream was composed primarily of riffle and run habitat, with few pools.

During summer 2002, restoration activities were conducted on Sharp Creek, which included placement of instream structures (rootwads, *n* = 6; crossvanes, *n* = 8) and streambank modification to alter hydrology and enhance instream habitat. The majority of the undercut banks that were once prominent in the reach were removed during the restoration. Upon completion of the restoration work, erosion control fabric and live-stake plantings were used to stabilize the banks.

The 175-m control reach was located immediately upstream of the restoration reach and was characterized as low gradient (1%) with narrow, steep banks. In contrast to the restoration reach, the control reach had very limited undercut bank habitat and erosion. The main habitat types were riffle and run, with few pools, and much of the stream reach was covered in grasses and shrubs. The watershed land use upstream of the control is primarily agricultural (row crops and livestock) and residential with very little forest.

Laurel Creek

Laurel Creek, (3613N, 8150W) is a second order tributary to the Watauga River, Watauga County, North Carolina, and is in the Watauga River drainage. The study site on Laurel Creek had a mean stream width (wetted perimeter) of 3.6 m, a 6-km^2 drainage area, and ranged in elevation from 1,042–1,065 m. The restoration reach was 433 m in length, moderate gradient (3%), and bordered by a large grassy field on one side and forest on the other. Evidence of historical sand and gravel mining operations was visible with much of the floodplain restricted by large berms and frequent eroding banks on each side of the stream. Unlike Sharp Creek, Laurel Creek had few undercut banks and a good diversity of riffle, run, and pool habitat.

The Laurel Creek restoration took place during the summer 2003. The restoration involved streambank modification and the placement of instream structures (rootwads, *n* = 2; crossvanes, *n* = 2; j-hooks, *n* = 2) to alter hydrology and enhance instream habitat. Erosion control matting and live-stakes were used to help stabilize the newly excavated banks.

The 200-m control reach was located immediately upstream of the restoration reach, and was characterized as moderate gradient (3%), with multiple 1–2 m falls. The reach had little to no erosion and good floodplain access, and the riparian area was entirely forested. A good diversity of riffle, pool, and run habitats was present. The watershed above the control is primarily forest and field, with limited agricultural (primarily livestock) and residential land use.

During September 2004, flooding associated with Hurricane Ivan and Hurricane Francis (approximately 51 cm of rain received in 10 days) caused extensive damage to the Laurel Creek watershed. The floods displaced nearly all of the instream structures constructed during the restoration; however, annual monitoring continued within the restoration reach.

Methods

Trout surveys were conducted in the restoration and control reaches prior to restoration work in Sharp Creek (June 2002) and Laurel Creek (April 2003), during June for four consecutive years following the completion of the restoration work. Three sites, 50–70 m in length within the restoration and control reaches of each stream, were selected. All sites contained a representation of the available habitats and were completely wadeable (<1 m maximum depth).

Backpack electrofishing units (Smith Root Model 12-B) set at a frequency of 70 Hz and a pulsed DC output of 8 ms were used to sample trout. Voltage output was adjusted between 600 and 900 volts depending on stream conductivity. Three passes were made through each site, and all trout were collected, weighed (g), and measured for total length (TL, mm).

Relative trout abundance (*n*/ha) and biomass (kg/ha) was determined annually for each of the three sites within each stream reach by summing the total number and weight of trout captured during the three passes. Age 0 trout, determined by length-frequency analysis, were excluded from all abundance and biomass estimates because their numbers often fluctuate widely from year to year (Borawa et al. 2001) and have lower capture efficiencies compared to larger trout (Peterson et al. 2004, Rosenberger and Dunham 2005). The annual mean relative trout abundance and biomass values from the restoration and control reach of each stream was obtained by averaging the three sites sampled in each reach. Standard errors (SE) of the annual mean abundance and biomass values were calculated. Confidence intervals (95%) for annual abundance and biomass values were compared between the restoration and control reach each year for each stream. Finally, Pearson correlation coefficients (r) were calculated to determine the relationship in annual variability between the restoration and control reaches for trout abundance and biomass.

Results

Abundance

Brown trout (*Salmo trutta*) were the only salmonid encountered in Sharp Creek, while Laurel Creek had both brown and brook trout (*Salvelinus fontinalis*). Trout abundance prior to the restoration work in Sharp Creek (restoration = 978 fish/ha, SE = 445; control = 1,184 fish/ha, SE = 594) exceeded the overall mean abundance estimate of trout obtained from 16 wild trout streams in North Carolina (611 fish/ha) monitored from 1989 to1996 (Borawa et al. 2001). Laurel Creek trout abundance prior to restoration work (restoration = 566 fish/ha, SE = 121; control = 506 fish/ha, SE = 85) was slightly less than the long-term average reported by Borawa et al. (2001).

Overlapping 95% confidence intervals indicated that mean trout abundance did not differ significantly between the restoration and control reach over all sample dates for Sharp Creek or Laurel Creek. Trout abundance declined within both the restoration and control reaches of Sharp Creek during this study (Figure 1). In contrast, trout abundance increased in both the restoration and control reaches within Laurel Creek. The Pearson correlation coefficient showed a strong relationship in the number of trout captured from the two reaches of Sharp Creek (r = 0.73) and Laurel Creek (r = 0.79) over the five years of sampling, suggesting that the variability in trout abundance observed between years was more likely a result of natural variability rather than an effect of the restoration work.

In Laurel Creek, prior to restoration work, the trout assemblage was composed primarily of brook trout in the restoration (65%) and control reach (59%). By 2007, the trout assemblage in the control reach had shifted to primarily brown trout (83%) and brook trout were not observed within the restoration reach.

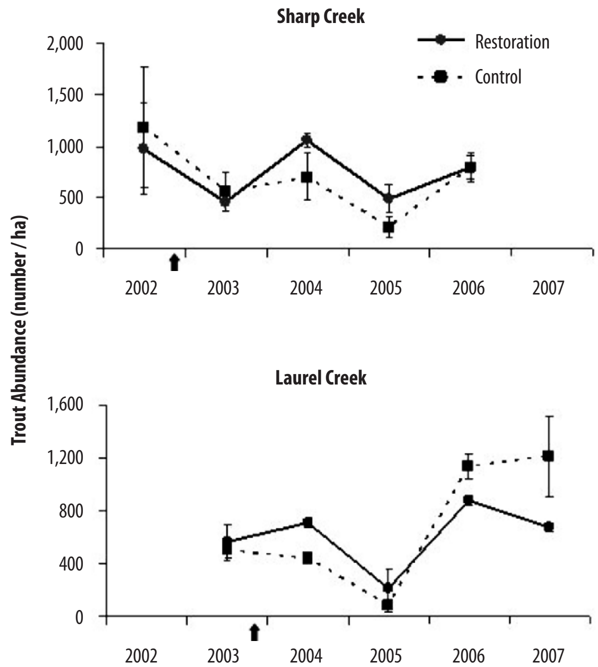

Figure 1. Mean trout abundance (±1 SE) in a restored and upstream control reach of Sharp Creek and Laurel Creek, Watauga County, North Carolina, from 2002 to 2007. The bold arrow on the *x*-axis indicates when the restoration work took place.

Biomass

Mean trout biomass for Sharp Creek (restoration = 143 kg/ha, SE = 61; control = 137 kg/ha, SE = 73) prior to restoration work exceeded the long-term average for trout biomass reported for other wild trout streams in North Carolina (Borawa et al. 2001) as well as the southern Appalachians (<34 kg/ha) (Durniak and England 1986, Bivens et al. 1995). Trout biomass in the restoration reach of Laurel Creek (69 kg/ha, SE = 52) prior to the restoration work also exceeded reported rates for southern Appalachian trout populations; however, biomass in the control reach (18 kg/ha, SE = 2) was much lower.

Comparison of 95% confidence intervals for mean trout biomass indicated that there was no significant difference between the restoration and control reach for Sharp Creek or Laurel Creek. Trout biomass declined 71% from 2002 (pre-restoration) to 2003

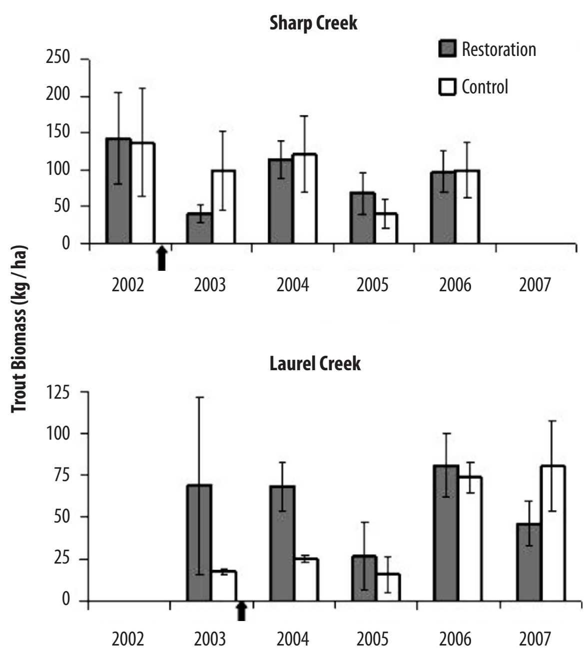

Figure 2. Mean trout biomass (±1 SE) in a restored and upstream control reach of Sharp Creek and Laurel Creek, Watauga County, North Carolina, from 2002 to 2007. The bold arrow on the *x*-axis indicates when the restoration work took place.

(1 year post-restoration) within the Sharp Creek restoration reach, while trout biomass in the control reach declined 28% (Figure 2). However, Sharp Creek trout biomass in the restoration reach (98 kg/ha, SE = 28) was nearly identical to the control reach (100 kg/ha, SE = 38) by the end of the study in 2006. Trout biomass in the restoration reach of Laurel Creek declined to 46 kg/ha (SE = 14) between 2003 and 2007, while the control reach improved to 80 kg/ha (SE = 27). The Pearson correlation coefficient for trout biomass within the Sharp Creek restoration and control reach revealed a moderately close association (r = 0.66), suggesting that most of the annual variation between the two reaches was due to natural variability. In contrast, variation observed between the restoration and control reach in Laurel Creek appeared to have very little association (r = 0.23), suggesting that the decline in trout biomass within the restoration site may be more likely a result of differences in stream habitat between the two reaches rather than natural variability.

Discussion

Sharp Creek

Trout populations in the southern Appalachians have been shown to be highly variable (Borowa et al. 2001, Kulp and Moore 2005). The cause of the decline in abundance and biomass within the Sharp Creek restoration is unclear, but the close association of annual variability within the restoration reach and the control reach suggests it was due primarily to natural variability within the watershed and not specifically the restoration work. However, undercut bank habitat was reduced during the Sharp Creek restoration, primarily as a result of bank modification in order to reduce erosion. The decline observed in trout biomass within the restoration, immediately following the completion of the project, may be a result of the removal of this habitat type. By 2004, trout biomass had improved, and likewise, undercut bank habitats had increased within the restoration reach as a result of new streambank erosion (NCSU WQG 2007a).

While undercut banks are often a source of erosion, the importance of overhead cover that undercut banks provide for trout has been well documented (Lewis 1969, White 1973, Devore and White 1978, Thorn 1988). As a result, the need to remove this feature from a stream reach should be evaluated with respect to the reduction in sediment that will occur (Thorn 1988). When the removal of undercut bank habitat is necessary, restoration designs should attempt to incorporate structures that provide overhead cover, such as woody debris installations, to offset the overall loss of this habitat type. In addition to the loss of undercut banks in Sharp Creek, pool habitat increased while riffle habitat decreased following the restoration (NCSU WQG 2007a). Although pools are a source of cover for trout, Wesche et al. (1978) reported that an increase in pool area did not improve the cover rating of small streams in Wyoming, and Thorn (1998) suggested that creating pool habitats that involved the loss of riffle habitats may actually reduce brown trout biomass.

Laurel Creek

Natural variability in trout populations in the southern Appalachians is commonly associated with droughts and floods (Kulp and Moore 2005). The substantial decline in trout biomass within the Laurel Creek restoration reach compared to the control reach suggests that habitat quality may have declined in the restored reach following the restoration work. While it is only possible to speculate on factors responsible for the shift in trout biomass between the Laurel Creek restoration and control reaches, the hurricane-related floods that occurred during fall 2004 are likely responsible. Within the Laurel Creek restoration reach, the 2004 floods removed practically all of the newly-created instream structures, and eroded much of the riparian vegetation along the streambanks, exposing large outcroppings of cobble (NCSU WQG 2007b). In contrast, the control reach of Laurel Creek experienced some shifting of riffle and pool habitat as large boulders were repositioned, but overall, the instream habitat and riparian vegetation remained intact.

Regardless of whether or not the observed changes in trout biomass within the Laurel Creek restoration are due to habitat alterations or natural variability, streams are dynamic systems and channel modifications by floods are natural. Given the expense and reported failure of instream restoration work (Frissell and Nawa 1992, Beschta et al. 1994, Roper et al. 1994, Pretty et al. 2003), the use of instream structures in moderate to high gradient streams such as Laurel Creek should be exercised with caution. Furthermore, recent studies suggest that riparian restoration alone, without the construction of instream structures, can produce more comprehensive, sustainable, and cost-effective habitat benefits for fish (Roni et al. 2002, Opperman and Merenlender 2004).

The loss of brook trout from the Laurel Creek restoration reach is a concern since brook trout are the only native salmonid to this region and are a high conservation priority for fish and game agencies in the eastern United States (NCWRC 1989, Hudy et al. 2005). It is unclear whether the change in the trout assemblage was due to the restoration, possibly altering habitat to conditions more favorable to brown trout, or if the loss of brook trout is due entirely to natural variability. In recent years, survey data has shown that many historical brook trout populations have been extirpated and current populations are dwindling (Hudy et al. 2005). Possible reasons for this loss include agriculture, loss of riparian forests, urbanization, acid precipitation, and competition with invasive species (Hudy et al. 2005) such as brown and rainbow trout (*Oncorhynchus mykiss*). However, studies have suggested that the distributional limits of brook trout in the southern Appalachians will often ebb and flow longitudinally in a stream over time when sympatric with other trout species (Larson et al. 1995, Strange and Habera 1998). Efforts to sample this section of Laurel Creek in future years will determine if brook trout have re-established in the restoration reach or if the sympatric brook and brown trout assemblage has shifted to an allopatric brown trout population.

Summary

The unusually high trout abundance and biomass observed in this study compared to data obtained from other southern Appalachian trout streams suggests that instream restoration work was not warranted at these sites if improving trout habitat was a primary goal. However, improving water quality by reducing streambank erosion was the primary objective of both restorations (NCSU WQG 2007a, NCSU WQG 2007b). Despite no measurable improvements in trout abundance and biomass, both restorations reduced erosion and included permanent conservation easements to protect riparian buffers within the restored reaches. The establishment of conservation easements should lead to trout habitat improvements in the future as vegetation further establishes along the streambanks, helping to prevent erosion during high flow events and providing shaded stream segments. As a result, future sampling of trout within these two restorations may reveal improvements.

The elevated trout abundance and biomass data obtained prior to restoration work in Sharp Creek and Laurel Creek reveals the importance of collecting fish assemblage data within proposed restorations before planning and implementing stream restoration work, especially if improved fish habitat and fish metrics are a goal of the restoration activities. Currently, there are few pre-construction requirements to sample biological data prior to implementing stream restoration projects. The requirement of fish or other biological survey data as a component of stream restoration grant applications, particularly when economically important species such as trout may be present, could help focus restoration activities where they are most beneficial.

Southern Appalachian streams are naturally nutrient poor (Kulp and Moore 2005) and estimates similar to the ones obtained for Sharp Creek and to a lesser extent Laurel Creek during this study suggest unnaturally high nutrient levels. While elevated abundance and biomass estimates for trout and other fish species are often viewed as a positive attribute by fish managers, they may indicate stream impairments such as nutrient enrichment (Lyons et al. 1996). Potential sources of nutrient enrichment were present in both watersheds, including livestock enclosures, agricultural fields, and residential developments. Given the naturally low levels of nutrients in southern Appalachian streams, streams that receive nutrient rich runoff may provide elevated abundance and biomass estimates for trout. Stream restorations that take place at the watershed scale, unlike the relatively small site-specific restorations monitored in this study, will likely involve a reduction in nutrients through livestock fencing, establishment of vegetated riparian buffers, and improved sewage and stormwater runoff from developed areas. These activities, while important for improving water quality parameters, may reduce the abundance and biomass of trout and other fish, as well as overall fish species diversity, in coldwater streams. This information is important if monitoring fish abundance and biomass estimates are part of a stream restoration evaluation.

Finally, a potential shortcoming of this study was the lack of information on the changes that occurred to stream features as a result of the restoration work. Neither the Laurel Creek or Sharp Creek restoration project required monitoring of the stream features following the restoration work. As a result, limited data was available on stream pattern and profile changes for either stream during this study. Inclusion of this data in future studies may be helpful in explaining the changes observed in the fish species of interest. As stream restoration activities increase, the use of multidisciplinary teams to evaluate physical and biological changes within restoration sites could help ensure the overall product will be more suitable for fish, while meeting the primary goals of sediment reduction and stream stability.

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Literature Cited

Beschta, R. L., W. S. Platts, J. B. Kauffman, and M. T. Hill. 1994. Artificial stream restoration-money well spent or an expensive failure? Pages 76–104 *in* Universities Council on Water Resources Annual Conference. University of Carbondale, Illinois.

Binns, N. A. 2004. Effectiveness of habitat manipulations for wild salmonids in Wyoming streams. North American Journal of fisheries Management 24:911–921.

Bivens, R. D., B. Carter, and C. E. Williams. 1995. Region IV trout fishery data collection report, 1994. Tennessee Wildlife Resources Agency, Nashville.

Borawa, J. C., J. H. Mickey, Jr., C. J. Goudreau, and M. M. Clemmons. 2001. Wild trout population monitoring summary, 1989–1996. North Carolina Wildlife Resources Commission, Division of Inland Fisheries, Raleigh.

Devore, P. W. and R. J. White. 1978. Daytime responses of brown trout (*Salmo trutta*) to cover stimuli in stream channels. Transactions of the American Fisheries Society 107:763–771.

Durniak, J. P. and R. H. England. 1986. Dynamics of rainbow trout populations in small headwater streams. Georgia Department of Natural Resources, Atlanta.

Frissell, C. A. and R. K. Nawa. 1992. Incidence and causes of physical failure of artificial habitat structures in streams of western Oregon and Washington. North American Journal of Fisheries Management 12:182–197.

Glover, R. D. 1994. Two decades of trout stream rehabilitation in the Black Hills of South Dakota. Pages 1–15 *in* J. G. Miller, J.A. Arway, and R. F. Carline, editors. Proceedings of the Fifth Trout Stream Habitat Improvement Workshop. Pennsylvania Fish Commission, Harrisburg.

Hudy, M., T. M. Thieling, N. Gillespie, and E. P. Smith. 2005. Distribution, status, and threats to brook trout within the eastern United States. Report submitted to the Eastern Brook Trout Joint Venture, Association of Fish and Wildlife Agencies, Washington, D. C.

Iversen, T. M., B. Kronvang, B. L. Madsen, P. Markmann, and M. B. Nielsen. 1993. Re-establishment of Danish streams: restoration and maintenance measures. Aquatic Conservation – Marine and Freshwater Ecosystems 3:73–92.

Kondolf, G. M. 1998. Lessons learned from river restoration projects in California. Aquatic Conservation of Marine and Freshwater Sciences 8:39–52.

———, R. Kattelmann, M. Embury, and D. C. Erman. 1996. Status of riparian habitat. Pages 36-1–36-2 *in* Sierra Nevada ecosystem project: final report to Congress, II. Assessments and scientific basis for management options. Centers for Water and Wildlife Resources, University of California-Davis, Report 88, Davis, California.

Kulp, M. A. and S. E. Moore. 2005. A case history in fishing regulations in Great Smoky Mountains National Park: 1934–2004. North American Journal of Fisheries Management 25:510–524.

Larson, G. L., S. E. Moore, and B. Carter. 1995. Ebb and flow of encroachment by nonnative rainbow trout in a small stream in the southern Appalachian mountains. Transactions of the American Fisheries Society 124:613–622.

Lewis, S. L. 1969. Physical factors influencing fish populations in pools of a trout stream. Transactions of the American Fisheries Society 98:14–19.

Lyons, J., L. Wang, and T. D. Simonson. 1996. Development and validation of an index of biotic integrity for coldwater streams in Wisconsin. North American Journal of Fisheries Management 16:241–256.

Moerke, A. H. and G. A. Lamberti. 2003. Responses in fish community structure to restoration of two Indiana streams. North American Journal of Fisheries Management 23:748–759.

North Carolina State University Water Quality Group (NCSU WQG). 2007a. Evaluation of the stream restoration at Sharp Creek. Clean Water Management Trust Fund Project report, Project 1999B-402.

———. 2007b. Evaluation of the stream restoration at upper Laurel Creek. Clean Water Management Trust Fund Project report, Project 1999B-402.

North Carolina Wildlife Resources Commission (NCWRC). 1989. Casting the future of trout in North Carolina: a plan for management of North Carolina's trout resources. North Carolina Wildlife Resources Commission, Raleigh.

National Research Council (NRC). 1992. Restoration of Aquatic Ecosystems. National Academy Press, Washington, D.C.

Opperman, J. J. and A. M. Merenlender. 2004. The effectiveness of riparian restoration for improving instream fish habitat in four hardwood-dominated California streams. North American Journal of Fisheries Management 24:822–834.

Palmer, M. A. and J. D. Allan. 2006. Restoring Rivers. National Academy of Science Journal: Issues in Science and Technology, Winter 2006.

Pattenden, M. M., L. Fitch, G. Hartmann, and R. Kellerhals. 1998. Can instream structures effectively restore fisheries habitat? Pages 1–14 *in* M. K. Brewin and D. H. A. Monita, editors. Forest fish conference: land management practices affecting aquatic ecosystems. Natural Resources Canada, Canada Forest Service, Information Report, Edmonton, Alberta.

Peterson, J. T., R. F. Thurow, and J. W. Guzevich. 2004. An evaluation of multipass electrofishing for estimating the abundance of stream-dwelling salmonids. Transactions of the American Fisheries Society 113:462–475.

Pretty, J. L., S. S. C. Harrison, D. J. Sheperd, C. Smith, A. G. Hildrew, and R. D. Hey. 2003. River rehabilitation and fish populations: assessing the benefits of instream structures. Journal of Applied Ecology 40:251–256.

Quinn, J. W. and T. J. Kwak. 2000. Use of rehabilitated habitat by brown trout and rainbow trout in an Ozark tailwater river. North American Journal of Fisheries Management. 20:737–751.

Roni, P., T. J. Beechie, R. E. Bilby, F. E. Leonetti, M. M. Pollock, and G. R. Pess. 2002. A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds. North American Journal of Fisheries Management 22:1–20.

Roper, B. B., D. L. Scarnecchia, and T. L. L. Marr. 1994. Summer distribution of and habitat use by Chinook salmon and steelhead within a major basin of the South Umpque River, Oregon. Transactions of the American Fisheries Society 123:298–308.

Rosenberger, A. E. and J. B. Dunham. 2005. Validation of abundance estimates for mark-recapture and removal techniques for rainbow trout captured by electrofishing in a small stream. North American Journal of Fisheries Management 25:1395–1410.

Schular, S. W., R. B. Nehring, and K. Fausch. 1994. Diel habitat selection by brown trout in the Rio Grande River, Colorado, after placement of boulder structures. North American Journal of Fisheries Management 14:99–111.

Strange, R. J. and J. W. Habera. 1998. No net loss of brook trout distribution in areas with sympatry with rainbow trout in Tennessee streams. Transactions of the American Fisheries Society 127:434–440.

Thorn, W. C. 1988. Brown trout habitat use in southeastern Minnesota and its relationship to habitat improvement. Minnesota Department of Natural Resources, Section of Fisheries, Investigational Report 395, St. Paul.

Wesche, T. A., C. M. Goertler, and C. B. Frie. 1987. Contribution of riparian vegetation to trout cover in small streams. North American Journal of Fisheries Management 7:151–153.

White, R. J. 1973. Stream channel suitability for coldwater fish. Proceedings of the 28th Annual Meeting of the Soil Conservation Society of America 28:61–79.

———. 1975. Trout population responses to stream flow and habitat management in Big Roche-a-Cri Creek, Wisconsin. Proceedings of the International Association of Theoretical and Applied Limnology, Winnipeg, Manitoba, Canada 19:2429–2477.