Do Fish Benefit from Stream Restoration in the Catskill Mountains?

by Barry P. Baldigo and Anne G. Ernst

Many streams across North America have been modified or restored in order to stabilize channel banks and beds; however, the effects of stream restoration on fish assemblages and stream habitat are seldom monitored, evaluated, or published. Because the impacts on ecosystems are poorly understood, subsequent restoration projects cannot build upon known successes or failures.

Over the past decade, the New York City Department of Environmental Protection (NYCDEP) and local Soil and Water Conservation Districts implemented stream restoration demonstration projects in almost a dozen Catskill Mountain streams. Fish assemblages and habitat at six restored (treatment) reaches (sections of streams studied) and five control reaches in five streams were sampled three to six times from 1999 to 2007 to assess their response to natural channel design (NCD) methods of stream restoration. A Before-After Control-Impact (BACI) study design was used to quantify net changes in fish and habitat indices at treatment reaches relative to those at nearby control reaches. In general, the restorations produced more stable channels that were deeper and narrower, but with reduced shade. Fish community richness (the number of species), diversity, species and biomass equitability, and total biomass increased significantly, but total density decreased after restoration. The net biomass of three trout populations (brook, brown and rainbow) increased on average 105 percent, and net biomass of blacknose dace, longnose dace, and slimy sculpin populations decreased by 38 percent. Stream stability, habitat, and fish assemblages did not improve at two of the six restored reaches. Differences in fish indices from stable and unstable reaches point to several thresholds that may be indicative of poor habitat quality and could gauge the prospects for ecosystem improvement following restoration.

Although fish and habitat responses were sometimes inconsistent among streams, our results demonstrate that the overall health of fish communities and trout populations in unstable Catskill Mountain streams can benefit from NCD restorations. These changes are most evident where stability of streambeds and banks are positively affected. A more pertinent question may be: do we care enough about the effects that stream restorations have on local fish assemblages, habitat quality, water quality, and channel stability to fully document those impacts and disseminate findings so that others can learn from our successes and our failures?

Background on Stream Restoration and Catskill Region Studies

In the early 1990s, private and nonprofit organizations as well as public agencies began to base stream restoration programs and projects on natural stream-channel morphology and fluvial processes to re-create stable stream geometry. Common objectives for stream restoration efforts included the protection or enhancement of water quality, riparian vegetation, bank and channel stability, natural flow, in-stream habitat, fish populations, aesthetics, and recreation (Palmer et al. 2005; Bernhardt 2005). As of July 2004, only 10 percent of the 37,099 restoration projects completed in the United States did monitoring of any type, and what little information was available could not be used to assess ecological effects (Bernhardt et al. 2005). Aside from efforts described here and in related publications (Baldigo, Warren, Gallagher-Ernst et al. 2008; Baldigo, Warren, Ernst et al. 2008; Baldigo and Warren 2008; Baldigo et al. in press; Ernst et al. in press), very few results have been published that characterize the short- or long-term effects of restoration projects on channel morphology, stream habitat, local fish populations and communities, normal stream processes, or the consequences in contiguous reaches (Pretty et al. 2003). This lack of published information on responses prevents subsequent project teams from learning or building upon successes (and failures) of prior restoration efforts.

In their earlier evaluation of fish responses to NCD restoration in three or four reaches, Baldigo et al. (2008; 2008) showed that community richness, biomass, and equitability generally increased when fish assemblages, initially dominated by sculpin populations or dace and sculpin populations before restoration, were replaced by assemblages dominated by one or more trout species following restoration. Large increases in density and biomass of one or more trout species were the main reason for shifts in structure and function of fish communities at many restored reaches (Baldigo and Warren 2008). Additional evaluations by Baldigo et al. (in press) and Ernst et al. (in press) determined that the restorations generally produced positive responses at the six restored reaches; however, indicators of stream stability and habitat quality did not consistently improve at two of six reaches, and trout habitat suitability indices (HSIs) and density and biomass of trout populations also decreased at the same two reaches after restoration. These analyses used BACI sampling and analysis designs to isolate effects caused primarily by the restoration (Stewart-Oaten, Murdoch, and Parker 1986; Underwood 1994).

This article summarizes important findings presented in prior publications, evaluates relations between fish and habitat responses, proposes potential thresholds for selected variables and indices, and discusses future monitoring and research needs in Catskill Mountain streams. These efforts are a small component of a NYCDEP stream-management program, which is designed to sustain or improve the quality of streams that supply drinking water to inhabitants of New York City.

Methods Used

The NYCDEP selected stream reaches for restoration demonstration projects that had high rates of bed and bank erosion, rapid rates of channel migration, overly wide or shallow channels, homogeneous riffle habitat, or high levels of suspended solids. Riffles are stream reaches with fast moving, shallow water broken by streambed rocks and boulders. The Greene County Soil and Water Conservation District designed and implemented the five restoration projects described here in an effort to increase channel stability and reduce adverse effects on water quality, public and private property, flood and riparian areas, and stream habitat and fisheries.

Many headwater Catskill Mountain streams have steep slopes, poorly drained soils, glacial geology, and a long history of damaging floods. Most have been repeatedly modified by humans in an effort to reduce stream-bank erosion and sediment deposition onto adjacent floodplains. Over time, natural floods and man-made transportation infrastructure, gravel harvests, and attempts to harden

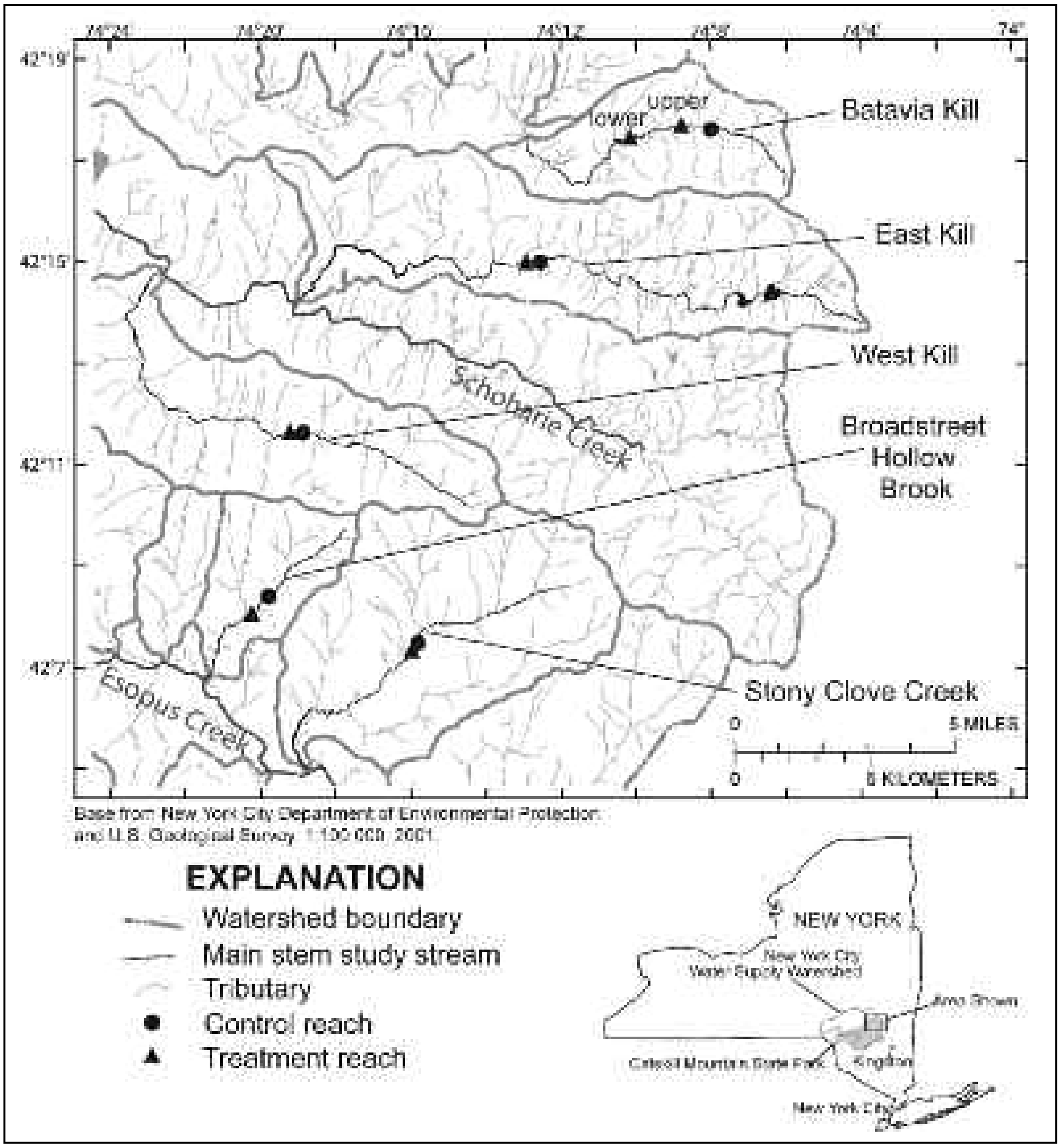

Figure 1. The six treatment reaches and five control reaches studied in the eastern Catskill Mountain State Park and the New York City, West-of-Hudson, Water Supply Watershed, 1999–2007. [Modified from Baldigo et al. (in press).]

stream banks have disconnected streams from their floodplains and altered normal rates of sediment transport. A major goal of the treatments was to restore normal stream sediment transport functions and floodplain dynamics. The projects used Rosgen's (1994, 1996) stream classification system, bankfull-channel characteristics of nearby stable reference reaches, and natural channel principles in all designs. Four streams (East Kill, West Kill, Broadstreet Hollow Brook, and Stony Clove Creek) had single pairs of control and treatment reaches, but Batavia Kill contained one control and two treatment reaches ***(Figure 1)***. Thus, there were six pairs of treatment–control reaches. The methods used to monitor fish assemblages and habitat and to assess responses to NCD restorations are described in detail by Mulvihill (2003), Baldigo et al. (2008; 2008), and Ernst (in press), and are only summarized below.

Fish-community and habitat surveys were completed annually at paired reaches, one or two years before, and two to five years following restoration. Fish were collected from seine-blocked, 87- to 120-meter-long stream sections during three successive passes using a battery-powered electrofisher and two or more fish netters. All fish from each pass were identified to species, and their lengths and weights were recorded before being returned to the stream. Fish data and sample area were used to calculate mean density, biomass, and 95 percent confidence intervals for each species population (Zippin 1958), and to estimate community density, biomass, richness, diversity, and equitability (Whittaker 1975). Habitat surveys were completed in 74- to 243-meter-long reaches (that encompassed fish-survey reaches) to characterize in-stream channel and bank features at 11 equal-distant transects in each reach. Physical data were used to calculate mean water depth and width, velocity,

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Above: The stable Batavia Kill control reach. Left: Staff from Cornell University, US Geological Survey and Ulster County Community College measure habitat features using point and transect methods at a study reach in a Catskill Mountain stream. Right: Staff from the US Geological Survey and Cornell University are seen here collecting fish from a study reach in a Catskill Mountain stream.

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substrate particle size, embeddedness, shade coverage, and bank stability. Selected habitat variables were used to calculate habitat suitability index (HSI) scores for brook trout *Salvelinus fontinalis* (Raleigh 1982), brown trout *Salmo trutta* (Raleigh, Zuckerman, and Nelson 1986), and rainbow trout *Oncorhynchus mykiss* (Raleigh et al. 1984) at each reach.

Fish and habitat responses to restoration at treatment reaches were evaluated using BACI methods (Underwood 1994; Stewart-Oaten, Murdoch, and Parker 1986) and an analysis of variance (ANOVA) to test hypotheses that NCD restorations (a) increase the quality of stream habitat; (b) improve the health of local fish communities (e.g., increase total richness, diversity, equitability, and biomass, but decrease density); (c) increase density and biomass of trout populations; and (d) decrease density and biomass of dace and sculpin populations. The BACI design scales or standardizes data or indices (e.g., density, biomass, richness, equitability, mean channel width, and mean velocity) at each treatment reach to the same index measured at corresponding control reaches by calculating index differentials. A differential is simply the index value at a given treatment reach minus its value at the corresponding control reach for a given survey period (year). The net before–after response is the increase or decrease in the mean index differential following restoration compared to the mean index differential before restoration. Fish communities at control reaches tend to simulate healthy target assemblages for unstable treatment reaches and change naturally with annual fluctuations in local climatic and environmental conditions. Two-factor ANOVAs were used to test for (a) differences in each index differential before and after restoration, (b) stream-to-stream differences in differentials, and (c) factor interaction. Differences were considered significant where $P < 0.05$ and moderately significant for $0.05 < P < 0.10$. (The term P is the probability of observing a test statistic as low as listed, assuming the null hypothesis is true.)

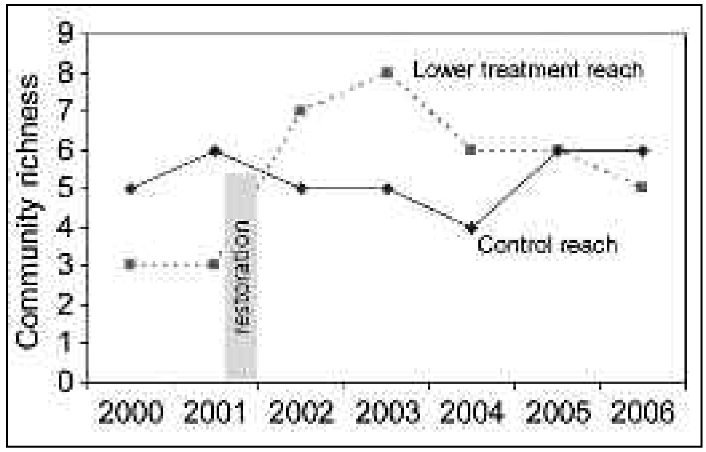

Figure 2. Total fish-community richness (number of species) at lower Batavia Kill treatment and control reaches before and after restoration, 2000–2006. [Modified from Baldigo et al. (in press).]

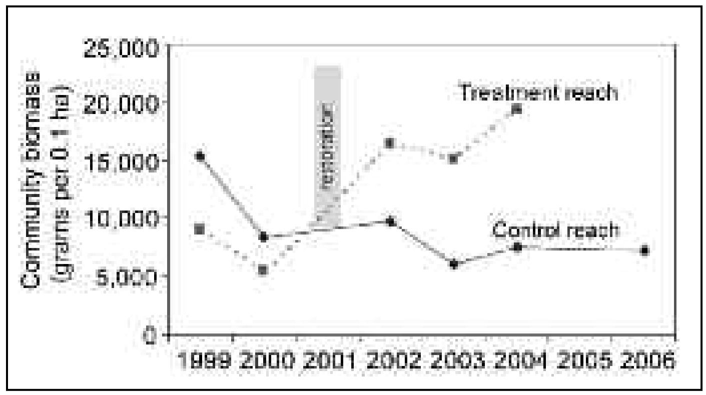

Figure 3. Total fish-community biomass at Broadstreet Hollow Brook treatment and control reaches before and after restoration, 1999–2006. [Modified from Baldigo et al. (in press).]

Response of Fish Assemblages

The responses of fish assemblages (populations and communities) and stream habitat to NCD restorations generally were positive across streams and reflected hypothesized responses; however, net changes were sometimes neutral or negative at one or more restored reach depending on the index and stream (Baldigo et al. in press; Ernst et al. in press; Baldigo, Warren, Gallagher-Ernst et al. 2008). These prior articles report that net changes in community richness, diversity, and equitability were significant and averaged 30 to 40 percent following restoration. Although richness did not change, or decreased slightly in two reaches, net increases in richness averaged about two fish species across all reaches and as high as five species at the lower Batavia Kill for the first two years after restoration ***(Figure 2)***. Net decreases in community density were generally not significant, but averaged 443 fish/0.1 hectare (ha) or 16 percent. Net increases in total biomass also were not significant, but averaged 1,041 gram (g)/0.1 ha, or 9 percent after restoration at all reaches. Net increases in biomass were significant and averaged 3,249–4,827 g/0.1 ha, or 35 to 52 percent; however, only when one or two reaches were excluded. Community biomass at treatment and control reaches in Broadstreet Hollow Brook, 1999–2006 ***(Figure 3)*** depicts typical restoration responses. Net increases in species diversity averaged 0.71, or 40 percent, and increases in species (and biomass) equitability ranged from 0.05, or 12 percent, to 0.16, or 32 percent, at all restored reaches. Changes in fish indices often became larger, and some insignificant results became significant when data from one or two reaches (usually Stony Clove Creek and West Kill) were excluded from respective analyses. Fish communities created in restored reaches generally resembled the more natural, evenly balanced fish communities found in corresponding control reaches (Baldigo et al. in press; Baldigo, Warren, Ernst et al. 2008).

Above: The unstable Lower Batavia Kill treatment reach in 2000, before restoration

Right: The stabilized Lower Batavia Kill treatment reach in 2004, following restoration

Photos by Barry Baldigo, USGS

The density and biomass of fish communities at most treatment reaches were often dominated by one or more prey species (e.g., blacknose dace, longnose dace, and slimy sculpin) and no or few predator species (trout) before restoration, and by brown trout, brook trout, and (or) rainbow trout after restoration. Net changes were significant, and trout density increased on average by 104 to 147 trout/0.1 ha, or 98 to 232 percent; trout biomass increased on average by 3,402 to 4,037 g/0.1 ha, or 180 to 265 percent, when data from Stony Clove Creek or from Stony Clove Creek and West Kill were excluded. All three trout species were absent from the Lower Batavia Kill treatment reach before restoration, but their numbers and biomass increased considerably following restoration ***(Figure 4)***. Net decreases in density and biomass of dace and sculpin populations were significant only if data from Broadstreet Hollow Brook were excluded from analyses. Brown trout populations generally benefited more than any other fish species at restored reaches. Net increases in brown trout density averaged 75 trout/0.1 ha, or 155 percent, and biomass averaged 2,369 g/0.1 ha, or 153 percent, when data from Stony Clove Creek or both Stony Clove Creek and West Kill were excluded from analyses. These findings show that NCD restorations do not produce consistent results, but can improve the health and sustainability of fish communities in compromised (eroding or unstable) Catskill Mountain streams over the short term.

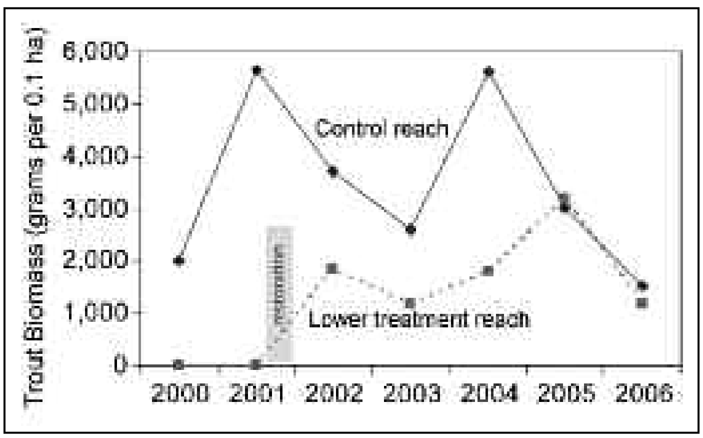

Figure 4. Pooled biomass for the three trout species at lower Batavia Kill treatment and control reaches before and after restoration, 2000–2006. [Modified from Baldigo et al. (in press).]

Changes in Stream Habitat

The recent article by Ernst et al. (in press) showed that channel dimensions at treatment reaches following restoration became more characteristic of those found at stable streams in the region. Indices of bank stability and habitat suitability for resident trout species at treatment reaches generally increased in the two to five years following restoration. Bank stability indices improved significantly (on average by 15 to 56 percent) at restored reaches, although several component habitat features did not improve at the West Kill and Stony Clove Creek. Visual stability estimates at lower Batavia Kill treatment and control reaches ***(Figure 5)*** typify changes following restoration. Mean channel depth, thalweg (deepest) depth, and pool-riffle ratio generally increased, whereas mean channel width, bank angle, and percent streambank coverage by trees generally decreased at most treatment reaches after restoration. An exception is Stony Clove Creek, where mean width increased substantially following restoration ***(Figure 6)***. All measures of shade decreased in the two to five years following restoration because most treatments required a major readjustment of stream channels and banks, which

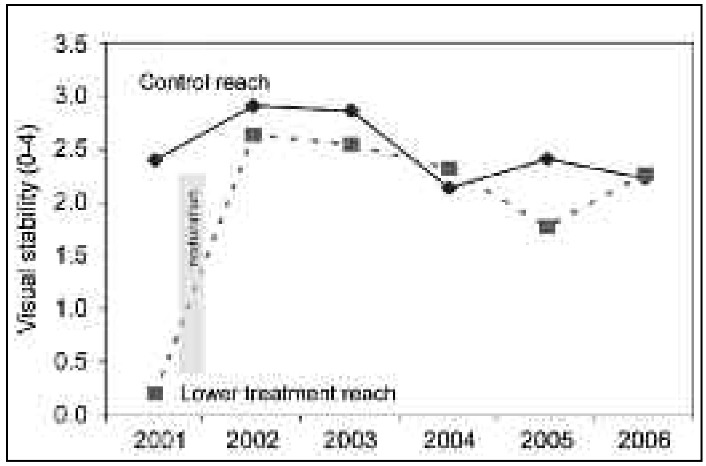

Figure 5. Visual stability estimates at lower Batavia Kill treatment and control reaches before and after restoration, 2001–2006. The relative stability scale ranges from low (0) to high (4). [Modified from Ernst et al. (in press).]

removed riparian vegetation. Shade is expected to increase over the long term as replanted riparian vegetation matures.

Changes in trout HSIs, or habitat suitability indices, generally mirror changes in important habitat variables. The HSIs for the three trout species decreased on average by 11 percent at West Kill and Stony Clove Creek, but increased significantly on average by 13 percent at the other four restored reaches (Ernst et al. in press). Brown trout HSIs were > 0.78 at both West Kill and Stony Clove Creek treatment reaches before restoration, and were comparable to HSIs at control reaches; therefore, NCD restorations may not have been able to effectively improve habitat quality. Brown trout HSIs were < 0.70 at the other four treatment reaches before restoration, and were much lower than HSIs at their respective control reaches; thus, NCD restorations could benefit habitat quality and trout populations in treatment streams. Habitat condition prior to restoration, therefore, predetermines the potential for NCD restoration to positively affect habitat quality and abundance and biomass of local trout populations. These findings demonstrate that NCD restorations generally improve habitat conditions in degraded Catskill Mountain streams; however, differences in habitat quality before restoration limit the magnitude of improvement and may actually cause a decrease in the quality of stream habitat and resident trout populations.

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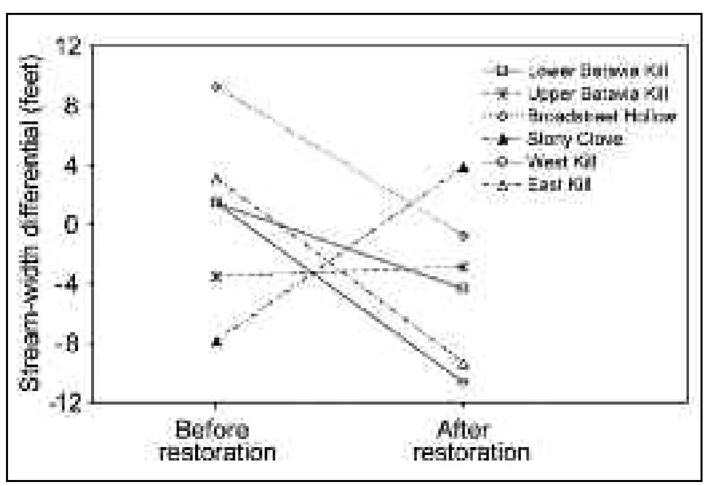

Figure 6. Mean stream-channel width differentials (in feet) before and after restoration in six treatment reaches in the Catskill Mountains. [Modified from Ernst et al. (in press).]

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Fish and Habitat Thresholds

Differences in fish and habitat indices at control and treatment reaches (before restoration) point to several general thresholds that may help identify impaired stream ecosystems in the Catskill Mountain region. Fish communities at unrestored treatment reaches usually had fewer species (< 6 species; several had only 2 or 3), lower total biomass (< 10,000 g/0.1 ha), lower Shannon-Wiener diversity (< 2.0), and lower biomass equitability (< 0.50) and higher total density (> 2,500 fish/0.1 ha) than communities at control reaches. Pooled trout density and biomass estimates in unstable reaches were often lower (< 250 trout/0.1 ha and < 3500 g/0.1 ha) and total dace and sculpin density and biomass was often higher (> 2000 fish/0.1ha and > 8000 g/0.1 ha) than those estimates at stable control reaches. Although the density of several species populations were highly variable and not indicative of different conditions among treatment and control reaches, brown trout biomass was often lower (< 2,500 g/0.1 ha) and sculpin biomass was often higher (> 4,500 g/0.1 ha) than estimates at control reaches. More interestingly, the density and biomass of native brook trout populations at unrestored reaches were consistently lower (< 10 trout/0.1 ha and < 500 g/0.1 ha), and the density and biomass of blacknose dace were consistently higher (> 1000 dace/0.1 ha and > 500 g/0.1 ha) than estimates at control reaches.

Thresholds were not identified for physical channel dimensions, probably because the range of stream sizes in the study prevented this. However, unrestored treatment reaches had lower estimates for visual stability (< 2.4) and a higher percentage of bare banks (> 62 percent) than control reaches. Only trout HSI scores closely tracked changes in many fishery (trout population) indices. The habitat at reaches with initial brown trout HSI scores less than 0.70 appeared to be relatively poor and capable of improving sufficiently (with restoration) to significantly increase the densities and biomass of trout populations. Trout populations at reaches with initial brown trout HSI scores > 0.78 (Stony Clove and West Kill) were moderately healthy, and restorations had either neutral or negative effects on HSI scores and on the density and biomass of all three trout populations.

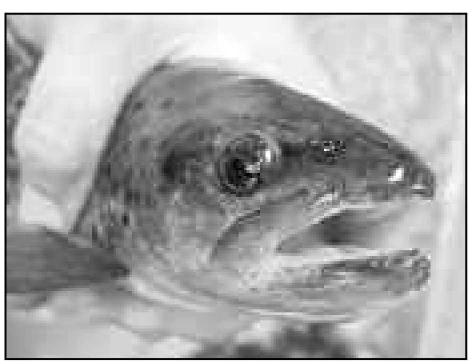
Although nearly 100 biologic and abiotic variables were measured and assessed to quantify restoration impacts, our results suggest that subsequent studies may be able to focus on the most responsive variables or those of greatest concern. Various measures of bank stability and channel dimensions, along with community indices of biodiversity (richness, Shannon-Wiener diversity, and equitability) commonly differed between treatment and control reaches and were all responsive to NCD restorations. Trout HSIs, pooled trout biomass, and density and biomass of brook trout and blacknose dace populations were also responsive to restoration. These variables were effective indicators of impairment and some of the best attributes to monitor and assess the effects of restoration on aquatic ecosystems in Catskill Mountain streams.

Study Implications

Our investigations show that stream habitat and fish assemblages can (but not always) benefit from NCD restorations. These findings have some important implications for continued monitoring of ecosystem responses to restoration of streams of the Catskill Mountains and elsewhere:

- Our studies demonstrate that NCD restorations can help reconstitute more diverse, balanced, and complete fish communities and enhance the biological integrity of disturbed Catskill Mountain streams over the short term.
- Similar shifts in dominant species and general increases in fish community richness at restored reaches indicate that NCD restorations can effectively increase the quality, quantity, and diversity of stream habitat when the treatments increase bank stability.
- Habitat suitability indices for the three trout species usually increase at reaches where bank stability increases following restoration. Increases in density and biomass of trout populations were most evident or significant at reaches where bank stability increased, and less apparent at reaches where bank stability decreased. Therefore, stream habitat and stability are linked to each other and strongly affect trout populations.
- Improvements in habitat quality and fisheries were limited in some situations where habitat was not initially impaired by poor stability. Consequently, the response of fish assemblages, habitat quality, and channel stability were highly variable and did not always respond in unison. This means that the direction and magnitude of responses to restoration cannot always be generalized across streams.
- Losses of riparian tree cover (and shade), general increases in stream stability, initial changes in stream habitat, varying responses of fish assemblages, and limited temporal data from most reaches indicate that ecosystem responses in these streams will continue to evolve. Because understanding long-term impacts is crucial to fish-management agencies, channel designers, anglers, and other entities that use or regulate stream resources, long-term assessments of stability, habitat, and fish resources should be a high priority in these streams, and in similarly restored streams of the region.

Walt Keller (Cornell University) holds a mature brown trout collected at the restored East Kill treatment reach. Effectively, no trout were collected from this reach prior to restoration.



Brown trout are the fish species which benefits most from restoration in Catskill Mountain streams.

Longnose dace is one of the fish species that is often abundant in unstable Catskill Mountain streams.

Photos by Barry Baldigo, USGS

- Differences in initial habitat and fishery data and indices at stable control reaches and unstable treatment reaches (before restoration) suggest that thresholds may exist for some key indices. Such thresholds could be valuable tools used to identify ecosystem impairment and the need to rehabilitate selected streams in the region.
- Lastly, and perhaps most important, reporting the results from monitoring efforts (described herein) is unusual because so few programs measure or publish data to quantify the effectiveness of stream restoration projects. Post-restoration monitoring of responses and publishing critical findings can only increase the overall understanding of restoration impacts and aid designers of other restoration projects who need to address similar stream stability, habitat, and fish-management issues.

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Acknowledgments

The authors extend their appreciation to the New York City Department of Environmental Protection, Cornell University, Greene County Soil and Water Conservation District, US Geological Survey, and Ulster County Community College for field support for this study. Special thanks go to Walter Keller (Cornell University; retired New York State Department of Environmental Conservation) for his commitment to this study, incessant advice, and relentless efforts to protect natural resources of the Catskill Mountain Region. This research was funded by the New York City Department of Environmental Protection, Greene County Soil and Water Conservation District, and the US Geological Survey.

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