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Fish Communities and Habitat of Geomorphically Stable Reference Reaches in Streams of the Catskill Mountain Region, New York

Scientific Investigation Report 2009-5047

U.S. Department of the Interior
U.S. Geological Survey

Cover. Warner Creek, near Willow, New York.

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U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
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Conversion Factors, Datum and Acronyms

Multiply	By	To obtain
	Length	
centimeter (cm)	0.3937	inch (in.)
millimeter (mm)	0.03937	inch (in.)
meter (m)	3.281	foot (ft)
	Area	
square meter (m^2)	10.76	square foot (ft^2)
hectare (ha)	0.003861	square mile (mi^2)
square kilometer (km^2)	0.3861	square mile (mi^2)
	Flow rate	
cubic meter per second (m^3/s)	35.31	cubic foot per second (ft^3/s)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F= (1.8×°C) +32$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C= (°F-32)/1.8$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83) .

Altitude, as used in this report, refers to distance above the vertical datum.

List of Acronyms

C	Simpson index or dominance
C.I.	Confidence intervals
CV	Coefficient of variation
d	Species diversity
DO	Dissolved oxygen
GCSWCD	Greene County Soil and Water Conservation District
H’	Shannon-Wiener index or equitability
HSI	Habitat suitability index
NAWQA	National Water Quality Assessment Program (USGS)
NCD	Natural channel design
NYCDEP	New York City Department of Environmental Protection
NYCWOH	New York City West of Hudson
Onset	Onset Computer Corporation
p	Linear regression significance
PVC	Polyvinyl chloride
r	Linear regression correlation coefficient
R^2	Coefficient of determination
S	Mean community richness (number of species)
SD	Standard deviation
USGS	U.S. Geological Survey
YSI	Yellow Springs Instruments Company (now YSI Inc)

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Fish Communities and Habitat of Geomorphically Stable Reference Reaches in Streams of the Catskill Mountain Region, New York

By Christiane I. Mulvihill, Barry P. Baldigo, and Anne G. Ernst

Abstract

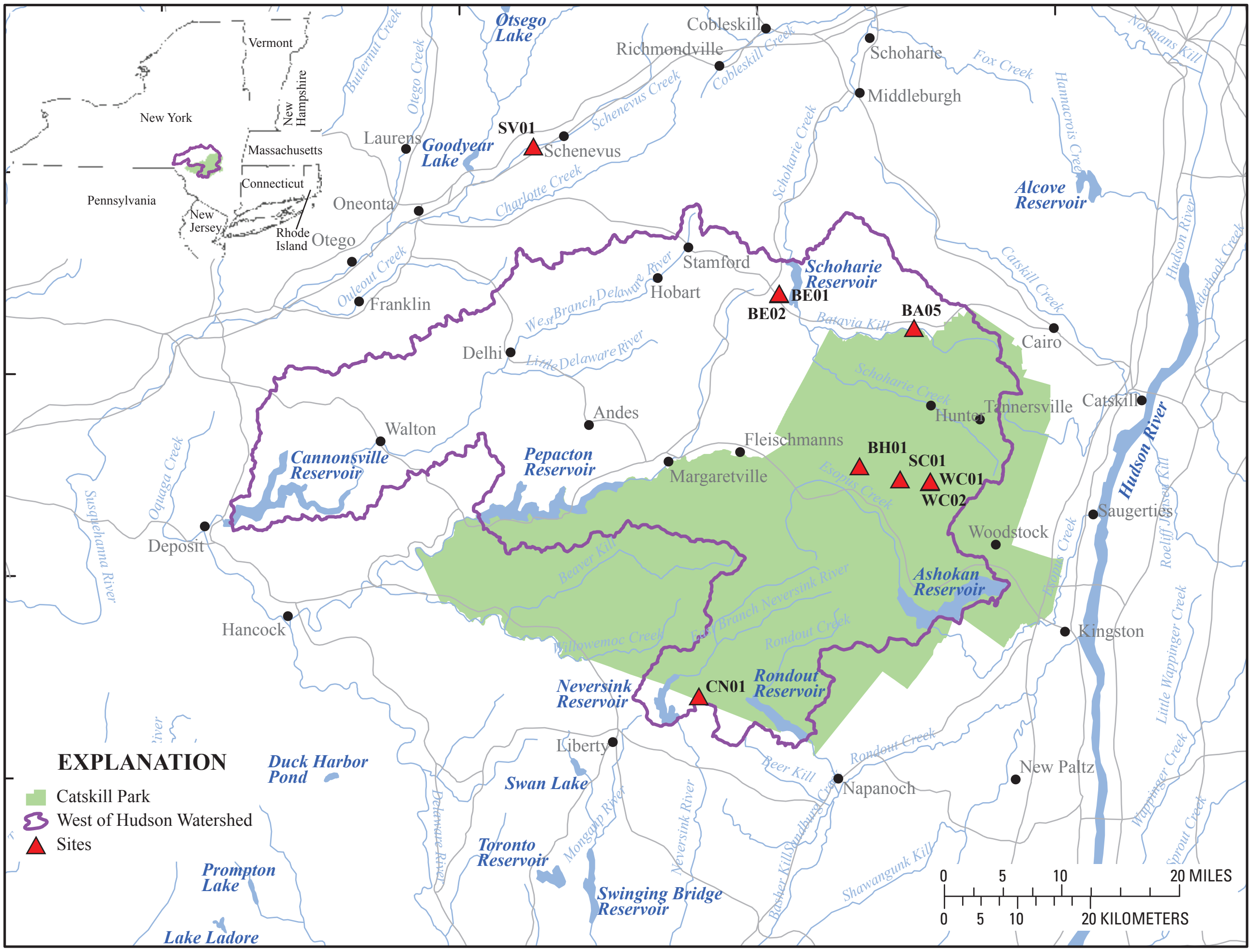
In 2002, the U.S. Geological Survey, in cooperation with the New York City Department of Environmental Protection, began a 5-year study to develop a database that documents the physical and biological characteristics of nine stable reference reaches from seven streams in the New York City West of Hudson Water Supply Watershed in the Catskill Mountain region of New York State. Primary objectives of this study were to (1) develop a reference-reach database of morphology, aquatic biology, and fluvial processes, and (2) summarize the relations between fish communities, aquatic habitat, and stable stream morphology in streams in the Catskill Mountain region. Secondary objectives included documenting year-to-year variability in fish populations and stream habitat in geomorphically stable streams and demonstrating how reliably Habitat Suitability Index models can be used to characterize habitat conditions and predict the presence and abundance of populations of trout species.

Fish and habitat databases were developed, and several important relations were identified. Fish-community indices differed considerably among sites where trout were present and where they were either absent or present in very low numbers; these differences were reflected in higher Habitat Suitability Index scores at trout-dominated sites. Several fish-community and habitat variables were found to be strongly associated with indices of stability and, therefore, determined to be useful tools for evaluating stream condition. Lastly, preliminary results suggest Rosgen stream type data can help refine fish and habitat relations and assist in our ability to predict habitat potential and fish-community composition.

Introduction

The New York City Department of Environmental Protection (NYCDEP) Stream Management Program, in cooperation with the Greene County Soil and Water Conservation District (GCSWCD) and other county Soil and Water Conservation Districts, are implementing a series of stream-restoration projects in the New York City West of Hudson (NYCWOH) Water Supply Watershed in the Catskill Mountain region of New York State (fig. 1). These projects are designed to address several stream-management goals, including reducing flood hazard risks and damages, improving stream-channel stability and sustainability, reducing loadings of suspended sediments, and restoring fish habitat and the biodiversity and integrity of resident fish communities. These channel restorations are designed to produce self-sustaining reaches that satisfy multiple management goals because the restorations are based on the form (geomorphology) and function (hydraulics and sediment transport) of naturally stable streams (Baldigo and others, 2008a; Rosgen, 1994, 2006). Most of these “natural channel design” (NCD) projects start with the Rosgen stream-classification system (Rosgen, 1994, 1996) that categorizes streams according to bankfull-discharge hydraulic geometry and then build on **geomorphic**[1] assessment and design methods using data on bankfull, flood-plain, and valley characteristics collected at nearby stable reference streams of the desired type in a similar valley setting (Rosgen, 1994, 1996, 2006). The primary assumption for this approach is that stable streams are best suited to satisfy the greatest number of management and restoration goals. Furthermore, this approach assumes that stable, naturally functioning stream reaches can be created through careful documentation and construction of stable stream morphology. What remains poorly documented to date (2008) is a quantitative expression of stable stream conditions (for example, morphology, biology, physical habitat and fluvial processes) that managers can use to better document restoration success. This report provides critical baseline data on fish-community composition, habitat characteristics, and trout:habitat correlations that can be used to evaluate the biological impact of stream restorations in the Catskill Mountain region.

[1] **Boldface** terms are explained in glossary.



Base from U.S. Geological Survey, Digital Line Graph, 1:2,000,000
Univeral Transverse Mercator projection, Zone 18, NAD83

Figure 1. Location of the Catskill Mountain region in southeastern New York State, and nine reference reaches sampled in 2002, 2004, and 2006.

Background

NCD restoration strives to reestablish naturally stable stream channels that can transport sediment with balanced rates of deposition and erosion such that bed aggradation and degradation and lateral channel migration are minimized. NCD restoration focuses on mitigating causes of channel instability, installing instream structures that control grade or the energy and direction of streamflow, planting riparian vegetation to stabilize banks and provide habitat, and reshaping unstable stream reaches into functional streams and floodplains (Rosgen, 1994, 2006; Doll and others, 2003). Biological enhancements follow natural channel design; by stabilizing channel geometry, the structure and function of stream channels become more natural, which promotes restoration of natural aquatic ecosystems (Doll and others, 2003).

The basic assumption behind this study is that the biological conditions of reference reaches, although not necessarily optimal, represent the range of natural conditions present in undisturbed streams in the region. Therefore, any stream restoration that mimics these conditions should successfully restore the channel to a natural and stable condition of biological equilibrium. Documenting biological conditions of stable stream reaches is a critical step in documenting baseline conditions of achievable healthy aquatic communities.

Because a comprehensive database summarizing the stream-habitat characteristics and fish-community composition of reference reaches in the Catskill Mountain region did not exist prior to 2002, the U.S. Geological Survey (USGS), in cooperation with the NYCDEP and GCSWCD, conducted a 5-year study (2002–06) to create such a database by collecting data from nine reference reaches in seven streams in the

NYCWOH Water Supply Watershed (Davis and Miller, 2002). Drainage areas of the study sites ranged from 2.38 to 241 km^2 and elevations ranged from 366 to 609 m (table 1). The selected study reaches represent **Rosgen stream types B, C, and F**, which are the stream types most commonly encountered regionally in design and comparison monitoring. All reaches were assessed for predicted stability prior to inclusion in this study (New York City Department of Environmental Protection, 2005).

The primary objective of this investigation was to characterize relations among fish communities, stream habitat, and stable stream morphology in streams in the Catskill Mountain region. Secondary objectives included (1) documenting year-to-year variability in fish populations and stream habitat, (2) demonstrating that **Habitat Suitability Index** (HSI) models can be used to characterize habitat conditions and to predict the presence and abundance of trout species populations, and (3) suggesting areas of further study that would increase understanding of the relations between fish populations, stream-habitat conditions, and stable stream morphology.

Hydrologic Conditions

Hydrologic conditions that affected stream habitat and fish communities during the study period ranged from drought to flood; therefore, the biological conditions reported herein are presumed to be representative of the range of natural conditions present in Catskill Mountain region streams during dry, normal, and wet **water years**. In 2002, streamflow in the Catskills was 30–50 percent of normal, and most of the region was under drought watches and warnings (Butch and others, 2003). Above-normal rainfall in October 2002 ended the drought, and consistent precipitation kept reservoir levels 110 to 120 percent of normal throughout the 2003 water year and near capacity from March through September (Butch and others, 2004). In 2004, the region experienced above-normal precipitation, and runoff was 150–170 percent of normal (Butch and others, 2005). Widespread flooding affected much of the region during April 2–3, 2005 (Suro and Firda, 2007), and again during June 26–29, 2006 (U.S. Geological Survey, 2007).

Methods

Fish communities and stream-habitat characteristics at each of nine stable reference reaches in seven streams were surveyed three times over a 5-year period (2002, 2004, and 2006) (table 1 and fig. 1). Additional details on fish sampling, stream-habitat characterization, and quality-assurance procedures can be found in Baldigo and others (2008a), Mulvihill and others (2003), and New York City Department of Environmental Protection (2005), respectively.

Fish Communities

Fish in the survey reaches were collected from seine-blocked, 87- to 120-m-long stream sections during three or four successive passes using a battery-powered backpack electrofisher and three to six fish netters (Baldigo and others, 2008a). Fish from each pass were identified by species and counted; the lengths and weights were recorded. Fish greater than 150 mm long were weighed and measured

Table 1. Descriptive information for nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[km^2, square kilometers; m, meters. Site locations are shown in figure 1]

Site code	USGS station number	Site name	Drainage area (km^2)	Latitude	Longitude	Elevation (m)
WC02	0136235475	Warner Creek below Edgewood	8.08	42 06 59.9	74 13 07.5	610
WC01	0136235474	Warner Creek near Edgewood	7.87	42 07 03.9	74 13 03.7	610
BE02	0135003033	Bear Kill below Grand Gorge	52.3	42 21 01.6	74 27 59.1	440
BE01	0135003032	Bear Kill near Grand Gorge	52.0	42 21 05.3	74 27 59.2	440
BH01	0136223076	Broadstreet Hollow Brook above Allaben	10.4	42 08 14.0	74 20 06.5	410
CN01	01365210	Chestnut Creek near Curry	2.38	41 51 13.6	74 36 12.9	420
SV01	01497819	Schenevus Creek above Maryland	241	42 32 04.6	74 52 32.8	370
SC01	0136234191	Stony Clove Creek at Lanesville	37.3	42 07 13.1	74 16 05.4	430
BA05	01349873	Batavia Kill East of Windham	74.6	42 18 27.2	74 14 33.9	460

individually. Fish smaller than about 150 mm were measured individually—approximately 40 to 50 individuals of each species; thereafter, total weights and counts by species were recorded in batches of 10 to 50 individuals. Fish were returned to the stream after all processing was completed.

The number of fish captured during each pass was used to estimate annual mean population sizes and 95-percent confidence intervals (C.I.) for each fish species and for the entire fish community by using the Moran-Zippin method of proportional reduction (Zippin, 1958) and Microfish (v. 1) software (Van Deventer and Platts, 1985). Estimates of community **richness** (number of species-S), diversity (d), equitability (Shannon-Wiener index-H′), and dominance (Simpson index-C) were calculated using standard methods described in Whittaker (1975). Two indices of equitability were calculated using either (1) number of individuals of each fish species or (2) total weight of each species at each reach. Total community density (number of fish per 0.1 ha) and biomass (grams of fish per 0.1 ha) at each reach were calculated from the estimated number or biomass of all fish divided by the surface area of each survey reach. Overlap of 95-percent C.I.s was used to assess absolute differences ($p < 0.05$) in indices of community density and biomass between reaches or within reaches among sampling dates. This assessment method is analogous to a two-tailed Student's t-test.

Fish Habitat

The habitat sampling protocol used in this study was designed to ensure consistency, minimize observer bias, and maximize repeatability in the collection of qualitative and quantitative data (Mulvihill and others, 2003). A detailed explanation of the methods used to establish reach boundaries, assign pool class ratings, and conduct transect surveys is provided in Mulvihill and others (2003). Following is a description of the method used to measure or estimate each sampled habitat variable:

- *Discharge*—Measured by standard USGS methods (Rantz, 1982). Used to assess year-to-year variations in streamflow that could affect habitat variables.
- *Dissolved oxygen (DO)*—Field measurements of DO were made with a YSI 85 at a range of water temperatures. These measurements were used to develop models of temperature-to-DO relations at each site.
- *Water pH*—Water samples were collected and analyzed at the USGS Watersheds Laboratory in Troy, N.Y. in accordance with standard methods (Lincoln, 2002).
- *Water temperature*—Water temperatures were recorded year-round in hourly increments at each reach by Onset StowAway Tidbit or Hobo Water Temp Pro in-situ temperature loggers.
- *Quantity and quality of pools*—The percentage of the reach occupied by pools, a pool class rating, and a pool-to-riffle ratio were determined for each reach.
- *Streambed temperature, water depth, and velocity*—Water temperature was measured with a field meter on the streambed. A wading rod was used to measure water depth and thalweg depth. A pygmy meter was used to measure water velocity (Rantz, 1982).
- *Characterization of streambed substrate*—Particle-size distribution, degree of embeddedness, and dominant substrate material were assessed inside a $0.61m^2$ PVC frame positioned on the streambed. Particle-size distribution was evaluated by selecting two particles at random from inside the frame and measuring their intermediate axes. The embeddedness of one randomly chosen cobble or larger particle was estimated at each sampling point. Visual estimates of dominant particle size (the particle-size class that covers the greatest surface area within the PVC frame) were made at each sample point.
- *Habitat cover*—The presence of deep pools, large boulders, debris piles, undercut banks, aquatic macrophyte beds, and overhanging vegetation large enough to shelter at least one (25.4 cm) trout was recorded.
- ***Channel aspect***—Channel aspect was measured with a compass at the center of each transect (looking downstream) to the nearest degree azimuth from magnetic north.
- ***Canopy angles***—Left and right canopy angles were measured from the center of each transect and used to calculate open-canopy angle. Measurements were made by sighting the tallest vegetation on each bank with a clinometer and recording the angle with respect to horizontal.
- *Percent shade*—Percent shade was estimated by looking along the transect tape and visually estimating the percentage of the transect that would be shaded between 1000 and 1400 hours.
- *Characterization of Bank and Riparian Conditions*—Bank and riparian-vegetation characteristics that might affect channel stability, water temperature, or the inputs of allochthonous (externally derived) material were measured at both ends of every transect. Bank height was measured from the bottom of the active channel to the top of the bank with a standard survey stadia rod. Bank angle was measured as the deviation from horizontal for a line between the bottom of the active channel and the top of the bank. Dominant and subdominant bank material were visually estimated.
    - *Bank vegetation cover*—Percentage of each bank covered by bare ground, grass, shrubs, and trees was visually estimated.

- ◦ *Bank visual stability*—Bank visual stability was assigned a qualitative score of 1 (0–24 percent stable), 2 (25–49 percent stable), 3 (50–74 percent stable), or 4 (75–100 percent stable), depending on bank height, substrate, angle, and vegetation type and density.
- ◦ *Bank percent rooted vegetation and stable rocky ground cover*—Percentage of rooted vegetation and stable rocky ground cover was assigned a qualitative score of 1 (0–24 percent), 2 (25–49 percent), 3 (50–74 percent), or 4 (75–100 percent).
- ◦ *National Water-Quality Assessment (NAWQA) bank stability*—An index calculated from measurements of bank angle, height, dominant substrate, and vegetative cover (Fitzpatrick and others, 1998).

- ***Riparian canopy closure***—This variable was measured with a concave spherical densiometer using techniques outlined in Platts and others (1987).

Analysis of habitat data used Habitat Suitability Index (HSI) models to summarize the combined effect of all riparian and instream habitat characteristics. Each model consists of a series of habitat variables that have been shown to affect growth, survival, or biomass of brook trout (Raleigh, 1982), brown trout (Raleigh and others, 1986), or rainbow trout (Raleigh and others, 1984). Field measurements of each habitat variable were converted to an index of suitability from 0.0 to 1.0; 0.0 indicates unsuitable conditions for trout habitat and 1.0 indicates optimum conditions (Raleigh, 1982). The final HSI score was calculated by averaging the scores of all the variables. Linear regression analysis was used to determine the correlation (r) and significance (p-value) of relations between independent habitat characteristics and fish-community indices, trout density, and trout biomass.

Fish Communities and Habitat of Geomorphically Stable Reference Reaches in Streams of the Catskill Mountain Region

The mission of the NYCDEP Stream Management Program includes sustaining or improving local fisheries and stream habitat (Davis and Miller, 2002). How successful stream restoration and protection strategies have been in achieving these objectives can only be monitored if data on fish communities and habitat in geomorphically stable reference reaches in nearby streams are available for comparison. This is the intended use of the baseline fish community and habitat conditions and correlations for geomorphically stable streams in the Catskill Mountain Region presented herein.

Fish Communities

A fish community is a group of fishes belonging to a number of different species that live in the same area and interact with each other (Fitzpatrick and others, 1998). The structure of a fish community is determined in part by the species present, their abundance, and their distribution within the watershed (Fitzpatrick and others, 1998). Fish-community assessments provide valuable information on the chemical and physical conditions of streams because fish can be sensitive indicators of water-quality conditions (Fausch and others, 1990), and changes in riparian conditions and stream morphology can have a significant impact on fish-community structure (Hughes and others, 1982).

This study used **fish-community indice**s of density, biomass, richness, equitability (evenness), diversity, and **dominance** to quantify the biological integrity of reference reaches. Biological integrity has been defined as “the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region” (Karr, 1981; Karr and Dudley, 1981). By this definition, reaches subject to little or no anthropogenic stress would be expected to have high biological integrity and relatively low year-to-year variability. Biological integrity in reference reaches, although not necessarily optimal, should reflect the natural fluctuations of fish-community indices in the region.

Fish-Community Indices

Mean community indices differed considerably among sites where trout were present and where they were either absent or present in very low numbers (table 2; community indices for individual sample dates and sites are provided in appendix 1). Most fish communities where brown, brook, and rainbow trout accounted for the majority of the biomass (WC02, WC01, BH01, CN01; table 6) had lower richness (< 5 species), density (< 1,200 fish/0.1 ha), equitability (< 0.43), and diversity (< 1.60) but higher dominance (> 0.48) than communities with few or no trout (BE02, BE01, SV01, BA05; table 6), whereas most sites with few or no trout generally had higher estimates of richness (> 9 species), density (> 1,500 fish/0.1 ha), equitability (>0.48), and diversity (> 2.00), but lower estimates of dominance (< 0.48) than sites with communities dominated by trout populations. SC01 supported a large trout population but also had several other species, which were reflected in intermediate average values for most indices (table 2).

Mean equitability, diversity, and richness were positively correlated and dominance was negatively correlated with mean survey (sampling) area ($p < 0.10$); mean survey area accounted for 68 to 81 percent of the variability in the four indices. Total community density and biomass were not significantly correlated with survey area because each was

Table 2. Mean community richness (number of species-S), density (number of fish per 0.1 hectare), biomass (grams of fish per 0.1 hectare), diversity (d), equitability (Shannon-Wiener index-H'), dominance (Simpson index-C), and sampling area (m^2) for fish-community surveys at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1]

Community index	Study sites								
	WC02	WC01	BE02	BE01	BH01	CN01	SV01	SC01	BA05
Sampling area	399	439	636	635	628	85	1,145	812	722
Species richness	3.00	3.00	9.00	9.70	4.00	2.30	14.70	6.00	9.33
Total density	456	426	3,785	1,768	815	1,126	2,007	1,908	3,314
Total biomass	8,203	6,852	13,215	8,873	7,408	22,290	4,901	16,353	12,909
Shannon-Wiener diversity	1.39	1.38	2.76	3.21	1.54	1.20	4.58	2.00	2.86
Equitability	0.26	0.25	0.48	0.60	0.42	0.16	0.70	0.47	0.68
Dominance	.67	.70	.49	.38	.49	.77	.27	.43	.31

already standardized by the survey area. These findings show that fish communities vary in a predictable manner among streams of different sizes and suggest that differences in survey areas at the same stream should be minimized between years to reduce potential index variations caused by different sampling areas. The most effective means to reduce variability in survey area is to always sample the same stream under similar flow conditions.

Coefficients of variation (CV) for each index show how much year-to-year variability might be expected in each index and which index may be most useful for assessing ecosystem trends or perturbations (table 3). Mean CVs of community indices ranged from 12 to 28 percent, except for total density, where the mean CV was 47 percent (table 3). The mean CV for total biomass was 23 percent. These results were not surprising, because total community biomass is generally more conservative than density when responding to biotic, habitat, and water-quality stresses and, thus, is considered a better gauge of community stability (Baldigo and Lawrence, 2001). Mean CVs for both richness and diversity were even lower than that for biomass (12 percent). In general, richness did not vary at trout-dominated communities; three of the four trout-dominated communities (WC02, WC01, and BH01; table 6) and SC01 had a CV of 0 for richness (table 3). The fourth trout-dominated stream (CN01; table 6) had a CV of 25 percent for richness, mainly because a single golden shiner was found during the 2004 survey (appendix 2).

CVs for richness in streams with few or no trout (BE02, BE01, SV01, BA05; table 6) were much more variable, ranging from 11 to 30 percent (table 3). The amount of variation in all the other community indices was unrelated to the presence or absence of trout. These results indicate that (1) sampling areas within the same sites should remain consistent from year to year, (2) species richness and diversity are the most stable measures of community health, (3) fish density is a poor indicator of disturbance, and (4) most species were similarly sensitive to the environmental factors (for example, temperature, precipitation, and streamflow) that are probably responsible for the year-to-year variability in overall community indices.

Density of Species Populations

Estimated densities of individual species populations (number of fish per 0.1 ha) varied greatly from stream to stream (fig. 2, table 4; densities for individual sample dates and sites are provided in appendix 2). WC02, WC01, and CN01 were mainly inhabited by trout species, which are intolerant of high sediment loads and warm water. BH01 had populations of brook, brown, and rainbow trout as well as a large number of slimy sculpins. SC01 supported populations of brook, brown, and rainbow trout as well as more tolerant species (longnose dace and slimy sculpin). The fish communities at SV01 and BA05 had low densities of trout but higher numbers of more tolerant species (minnows, suckers, dace, and slimy sculpin). No trout and only tolerant species were collected at BE02 and BE01 (table 4).

The CVs for mean density of each species population sampled during the 5-year study varied from 11 to 173 percent (table 5). In general, sites with fewer species had lower overall density variability, whereas those sites with more species had greater overall density variability. No single species had a CV that was consistently low among sites, but the CVs for one or more trout species generally ranged near 50-70 percent at sites where they dominated corresponding fish communities (for example, WC01, WC02, BH01, and CN01; table 5).

Table 3. Coefficients of variation (CVs) in percent for community indices at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1]

Community index	Study sites									Mean (percent)
	WC02	WC01	BE02	BE01	BH01	CN01	SV01	SC01	BA05	
Sampling area	27	25	51	22	14	26	53	17	16	28
Species richness	0.0	0.0	11	30	0.0	25	22	0.0	16	12
Total density	71	58	68	21	9	32	54	47	60	47
Total biomass	42	28	34	25	2	21	39	2	10	23
Shannon-Wiener diversity	8	10	7	28	2	13	15	6	19	12
Equitability	7	28	20	4	23	68	1	28	20	22
Dominance	6	14	25	10	29	23	4	38	38	21

Biomass of Species Populations

Mean biomass (grams of fish per 0.1 ha) estimates are similar to the density results; trout dominated the community biomass at sites where their density was high and also at SC01, where trout population density was low (fig. 3, table 6, biomass values for individual sample dates and sites are provided in appendix 3). Total trout biomass averaged 5,949 g/0.1 ha across the nine sites and as high as 22,287 g/0.1 ha for the three surveys done at CN01. On average, total community biomass across the nine sites averaged 11,223 g/0.1 ha; trout constituted 49 percent of total biomass at all nine sites and 62 percent of total biomass at the seven reference sites where trout were present (table 6).

The CVs for mean trout biomass were typically near or less than 50 percent unless species numbers were relatively low (for example, brook trout at SV01 and SC01) or when one unusually large individual was captured during one survey (for example, brown trout at WC02 in 2006) (table 7 and appendix 3). In general, CVs for the mean biomass of trout species were lower than those of most other fish species collected at the nine study sites, suggesting that this index is not overly sensitive to normal year-to-year fluctuations in temperature, precipitation, and streamflow. Therefore, trout biomass may be a useful tool for monitoring changes in stream condition because large and sudden changes could be indicative of a change in stream condition, especially if the biomass of more then one species is affected.

Fish Habitat

Fish-habitat assessments are critical in determining the limiting natural and human factors that affect water chemistry and aquatic biological communities (Fitzpatrick and others, 1998). An important assumption underlying this study is that the habitat conditions preferred by healthy trout populations—silt-free rocky substrate in riffle-run areas; an approximate 1:1 pool-riffle ratio with areas of slow, deep water; well-vegetated streambanks; abundant in-stream cover; and relatively stable streamflow, temperature regimes, and streambanks (Raleigh, 1982)—are the same conditions that successful stream restorations need to replicate in order to address flood-hazard, water-quality, and property-protection issues. Habitat quality of reference reaches, although not necessarily optimal for a particular species or community, was expected to reflect the natural conditions of geomorphically stable streams in the region.

Habitat data, their variability, and HSI scores for brook, brown, and rainbow trout were analyzed to better define the relations between habitat quality and trout populations. The main goals of this analysis were to determine (1) how stream-habitat variables fluctuated within each site and among sites during the three sampling periods, (2) if trout HSI scores reflect similar site-to-site and year-to-year variability, and (3) if trout HSI scores can accurately predict trout biomass and density in streams of the Catskill Mountain region.

Habitat Variability

Habitat variables with a CV of 25 percent or less were considered to have low variability, whereas those variables with a CV greater than 25 percent were considered to have high variability (Archer and others, 2004). Bank features (bank material, bank angle, bank height, visual stability, percent bank bare, and percent rooted and stable vegetation), streambed composition (particle size and substrate categories), channel aspect, riparian canopy closure at stream edge, percent shade, canopy angle covered by riparian vegetation, and streambed temperatures generally had low variability within each site and across sites (table 8, individual data

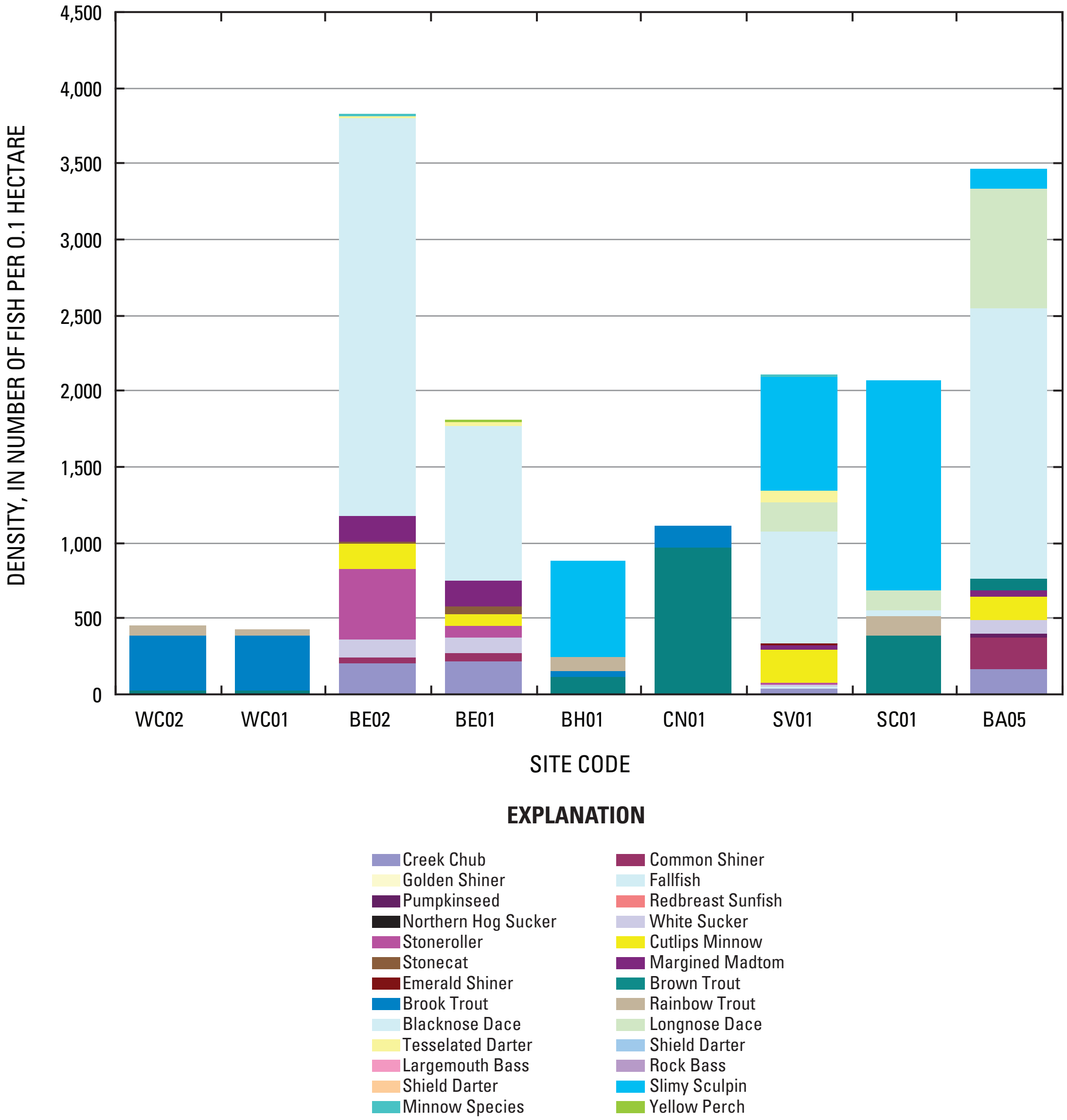


Figure 2. Mean density (number of fish per 0.1 hectare) for each species population at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006. (Location of sites shown on figure 1.)

Table 4. Mean density (number of fish per 0.1 hectare) for each species at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1. --, species not present]

Species	Study sites								
	WC02	WC01	BE02	BE01	BH01	CN01	SV01	SC01	BA05
Creek chub	--	--	206.7	220.3	--	--	33.7	--	173.8
Common shiner	--	--	40.7	57.4	--	--	9.4	--	195.1
Golden shiner	--	--	--	--	--	3.2	--	--	--
Fallfish	--	--	--	--	--	--	4.7	--	2.0
Pumpkinseed	--	--	.3	--	--	--	--	--	25.2
Redbreast sunfish	--	--	--	--	--	--	--	--	2.7
Northern hog sucker	--	--	--	--	--	--	0.6	--	--
White sucker	--	--	112.5	96.5	--	--	13.5	0.7	91.9
Stone roller	--	--	461.7	78.8	--	--	18.1	--	--
Cutlips minnow	--	--	179.4	82.0	--	--	212.5	--	155.6
Stonecat	--	--	4.5	42.3	--	--	.6	--	2.8
Margined madtom	--	--	174.7	179.0	--	--	36.4	--	41.0
Emerald shiner	--	--	--	--	--	--	6.4	--	--
Brown trout	25.0	20.6	--	--	115.6	964.7	2.9	382.5	77.6
Brook trout	362.8	364.3	--	--	37.9	147.0	.9	6.4	--
Rainbow trout	69.6	41.8	--	--	93.9	--	--	127.3	--
Blacknose dace	--	--	2,627.0	1,021.5	--	--	734.5	34.3	1,778.1
Longnose dace	--	--	--	--	--	--	196.0	129.2	784.1
Tesselated darter	--	--	7.2	15.0	--	--	69.7	--	--
Largemouth bass	--	--	--	0.6	--	--	--	--	--
Rock bass	--	--	--	--	--	--	--	--	0.8
Shield darter	--	--	--	--	--	--	9.1	--	--
Slimy sculpin	--	--	--	3.8	633.1	--	749.3	1,392.1	141.3
Minnow spp.	--	--	9.0	2.6	--	--	3.7	--	--
Yellow perch	--	--	0.3	4.9	--	--	--	--	--

Table 5. Coefficient of variation (CV) in percent for density at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites									Average CV (percent)
	WC02	WC01	BE02	BE01	BH01	CN01	SV01	SC01	BA05	
Creek chub	--	--	57	26	--	--	78	--	11	43
Common shiner	--	--	147	99	--	--	122	--	66	108
Golden shiner	--	--	--	--	--	173	--	--	--	173
Fallfish	--	--	--	--	--	--	133	--	173	153
Pumpkinseed	--	--	173	--	--	--	--	--	173	173
Redbreast	--	--	--	--	--	--	--	--	173	173
Hognose sucker	--	--	--	--	--	--	173	--	--	173
White sucker	--	--	162	96	--	--	58	173	115	121
Stone roller	--	--	60	22	--	--	146	--	--	76
Cutlips minnow	--	--	55	20	--	--	66	--	22	41
Stonecat	--	--	173	173	--	--	173	--	173	173
Margined madtom	--	--	19	51	--	--	62	--	133	66
Emerald shiner	--	--	--	--	--	--	93	--	--	93
Brown trout	26	47	--	--	59	37	87	72	37	52
Brook trout	67	64	--	--	54	77	101	92	--	76
Rainbow trout	121	47	--	--	41	--	--	65	--	68
Blacknose dace	--	--	78	26	--	--	40	120	84	70
Longnose dace	--	--	--	--	--	--	75	113	57	82
Tessalated darter	--	--	113	159	--	--	76	--	--	116
Largemouth bass	--	--	--	173	--	--	--	--	--	173
Rock bass	--	--	--	--	--	--	--	--	173	173
Shield darter	--	--	--	--	--	--	118	--	--	118
Slimy sculpin	--	--	--	173	11	--	52	79	52	73
Minnow spp.	--	--	173	173	--	--	140	--	--	162
Yellow perch	--	--	173	99	--	--	--	--	--	136
Mean	72	53	115	99	41	96	106	102	103	119

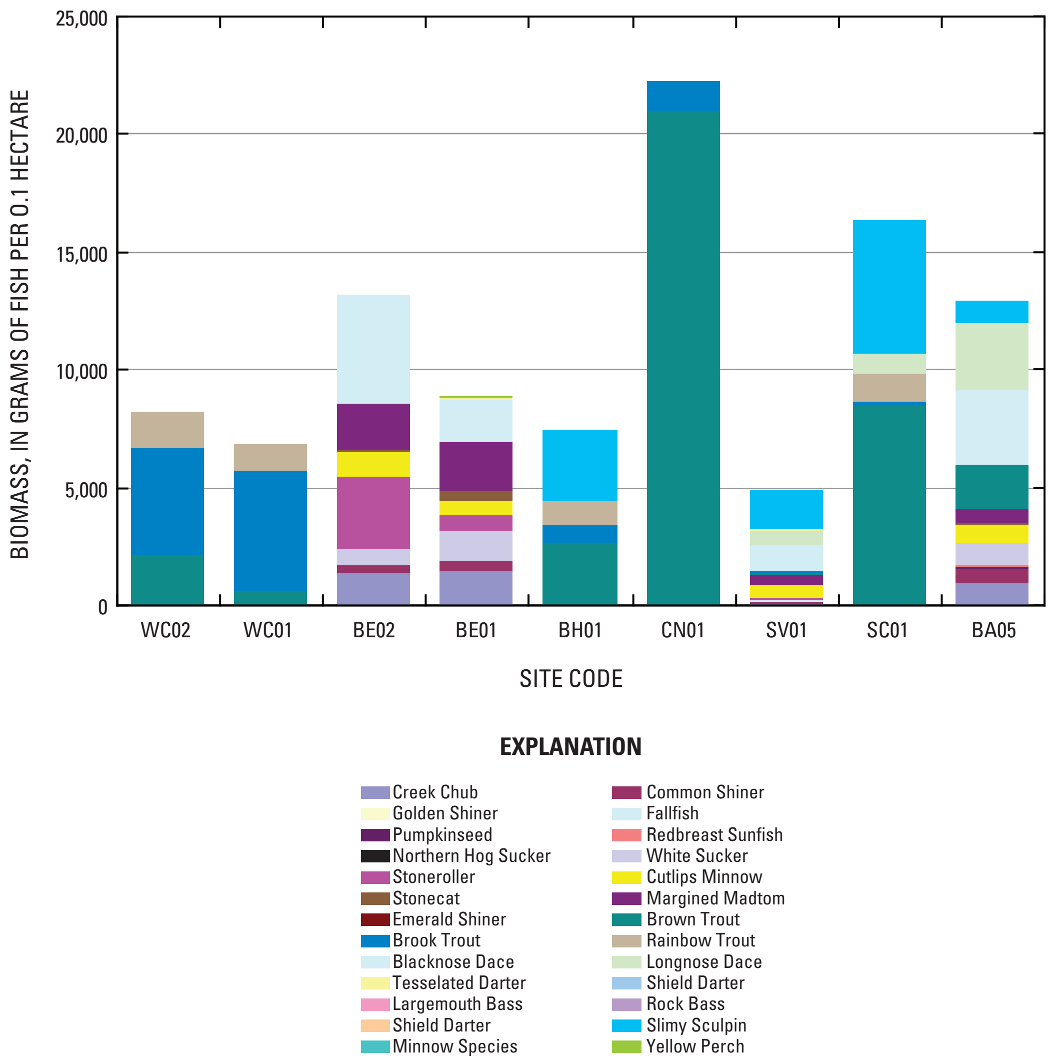


Figure 3. Mean biomass (grams of fish per 0.1 hectare) for each species at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006. (Location of sites shown in figure 1.)

Table 6. Mean biomass (grams of fish per 0.1 hectare) for each species population at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites								
	WC02	WC01	BE02	BE01	BH01	CN01	SV01	SC01	BA05
Creek chub	--	--	1,387.5	1,494.9	--	--	119.2	--	969.2
Common shiner	--	--	294.5	404.9	--	--	19.8	--	579.0
Golden shiner	--	--	--	--	--	3.2	--	--	--
Fallfish	--	--	--	--	--	--	96.2	--	1.4
Pumpkinseed	--	--	5.0	--	--	--	0.3	--	81.8
Redbreast	--	--	--	--	--	--	--	--	47.0
Hognose sucker	--	--	--	--	--	--	.3	--	--
White sucker	--	--	732.9	1,287.1	--	--	22.9	30.5	992.6
Stone roller	--	--	3,070.4	696.7	--	--	51.8	--	--
Cutlips minnow	--	--	1,041.7	576.2	--	--	549.9	--	784.3
Stonecat	--	--	97.0	405.7	--	--	12.8	--	45.3
Margined madtom	--	--	1,940.4	2,047.2	--	--	426.1	--	646.6
Emerald shiner	--	--	--	--	--	--	10.7	--	--
Brown trout	2,156.2	639.3	--	--	2,636.8	20,992.4	57.1	8,410.0	1,858.5
Brook trout	4,554.8	5,061.1	--	--	766.0	1,294.3	66.8	169.0	--
Rainbow trout	1,492.2	1,151.7	--	--	1,026.7	--	--	1,203.2	--
Blacknose dace	--	--	4,611.9	1,851.4	--	--	1,128.4	37.1	3,124.0
Longnose dace	--	--	--	--	--	--	568.5	876.3	2,859.6
Tessalated darter	--	--	16.4	27.5	--	--	101.7	--	--
Largemouth bass	--	--	--	14.1	--	--		--	--
Rock bass	--	--	--	--	--	--	--	--	25.2
Shield darter	--	--	--	--	--	--	21.3	--	--
Slimy sculpin	--	--	--	17.3	2,978.9	--	1,630.8	5,626.7	894.6
Minnow spp.	--	--	17.0	2.9	--	--	16.5	--	--
Yellow perch	--	--	0.7	46.7	--	--	--	--	--

Table 7. Coefficient of variation (CV) in percent for biomass at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites									Average CV (percent)
	WC02	WC01	BE02	BE01	BH01	CN01	SV01	SC01	BA05	
Creek chub	--	--	78	36	--	--	73	--	27	54
Common shiner	--	--	152	96	--	--	142	--	63	113
Golden shiner	--	--	--	--	--	173	--	--	--	173
Fallfish	--	--	--	--	--	--	157	--	173	165
Pumpkinseed	--	--	173	--	--	--	173	--	173	173
Redbreast	--	--	--	--	--	--	--	--	173	173
Hognose sucker	--	--	--	--	--	--	173	--	--	173
White sucker	--	--	123	78	--	--	82	173	116	114
Stone roller	--	--	69	19	--	--	114	--	--	67
Cutlips minnow	--	--	19	25	--	--	54	--	45	36
Stonecat	--	--	173	173	--	--	173	--	173	173
Margined madtom	--	--	66	82	--	--	66	--	131	86
Emerald shiner	--	--	--	--	--	--	93	--	--	93
Brown trout	115	35	--	--	13	27	92	53	62	57
Brook trout	49	34	--	--	24	66	170	122	--	77
Rainbow trout	93	40	--	--	25	--	--	43	--	50
Blacknose dace	--	--	55	29	--	--	24	72	58	47
Longnose dace	--	--	--	--	--	--	71	57	21	50
Tessalated darter	--	--	88	150	--	--	81	--	--	106
Shield darter	--	--	--	--	--	--	97	--	--	97
Largemouth bass	--	--	--	173	--	--	--	--	--	173
Rock bass	--	--	--	--	--	--	--	--	173	173
Slimy sculpin	--	--	--	173	8	--	37	80	48	69
Minnow spp.	--	--	173	173	--	--	87	--	--	145
Yellow perch	--	--	173	146	--	--	--	--	--	160
Mean	86	36	112	104	17	89	110	86	103	117

Table 8. Mean, standard deviation (SD), and coefficient of variation (CV, in percent) of each habitat characteristic at each of nine reference reaches and the average CV for each characteristic at all nine reaches in the Catskill Mountain region surveyed in 2002, 2004, and 2006.

[Site codes are presented in table 1. °C, degrees Celsius; m, meter; mm, millimeters; NAWQA, National Water-Quality Assessment Program; DO, dissolved oxygen; mg/L, milligrams per liter; m³/s, cubic meters per second]

Habitat characteristic	Study sites								
	WC02	WC02	WC02	WC01	WC01	WC01	BE02	BE02	BE02
	Mean	SD	CV (percent)	Mean	SD	CV (percent)	Mean	SD	CV (percent)
Temperature (°C)	17.4	1.8	10	17.8	1.0	6	22.8	1.6	7
Depth (m)	0.14	0.03	19	0.09	0.02	26	0.10	0.06	59
Velocity (m/s)	.14	.05	40	.17	.04	25	.21	.10	47
Particle size (mm, 198 particles)	321	69	21	317	32	10	250	38	15
Substrate category (Wentworth scale)	8.38	.14	2	8.58	.46	5	8.51	.47	5
Embeddedness (percent)	16	11	67	21	16	75	17	16	96
Fish cover	8	4	48	9	7	71	2	2	92
Total width (m)	5.79	1.22	21	5.18	.61	12	6.10	.61	10
Thalweg depth (m)	.33	.06	18	.28	.05	18	.21	.10	49
Channel aspect (degree)	225	2	1	146	2	2	188	1	1
Percent canopy closed (angle coverage by riparian vegetation)	96	3	3	98	2	2	42	6	15
Percent shade (visual estimate, 1000–1400)	83	12	14	88	6	7	6	0	7
Riparian canopy closure at stream edge (percent)	97	3	3	99	1	1	28	9	32
Bank height (m)	4.33	.76	18	3.75	.46	12	1.19	.40	33
Bank angle (degree)	32	2	6	31	6	20	16	5	35
Bank material (Wentworth scale)	4.11	.87	21	3.50	.12	3	2.48	.41	16
Percent bank bare	61.06	2.71	4	57.35	5.29	9	5.00	4.38	88
Percent bank grass	.15	.26	173	1.06	1.02	97	79.55	1.85	14
Percent bank shrub	0	0	--	0	0	--	13.64	6.18	45
Percent bank tree	39.79	2.65	7	41.67	6.37	15	1.67	1.99	119
NAWQA bank stability	15.00	1.00	7	14.67	1.53	10	8.67	.58	7
Visual stability (0–4)	3	0	7	3	0	14	4	0	2
Rooted and stable vegetation (0–4)	3	0	3	3	0	5	4	0	2
Pool:riffle ratio	1	0	40	1	1	52	1	0	67
Average minimum DO (mg/L)	9.20	.32	3	8.95	.21	2	8.55	.21	2
Maximum or minimum pH	6.60	0	0	6.40	0	0	7.00	0	0
Length of reach (m)	112.5	23.2	21	117.3	2.4	17	12.7	1.7	9
Streamflow day of survey (m³/s)	.06	.07	104	.07	.06	91	.11	.13	114

Table 8. Mean, standard deviation (SD), and coefficient of variation (CV, in percent) of each habitat characteristic at each of nine reference reaches and the average CV for each characteristic at all nine reaches in the Catskill Mountain region surveyed in 2002, 2004, and 2006.

[Site codes are presented in table 1. °C, degrees Celsius; m, meter; mm, millimeters; NAWQA, National Water-Quality Assessment Program; DO, dissolved oxygen; mg/L, milligrams per liter; m³/s, cubic meters per second]

Habitat characteristic	Study sites								
	BE01	BE01	BE01	BH01	BH01	BH01	CN01	CN01	CN01
	Mean	SD	CV (percent)	Mean	SD	CV (percent)	Mean	SD	CV (percent)
Temperature (°C)	22.3	2.8	12	16.4	1.5	9	16.4	2.0	13
Depth (m)	0.10	0.05	55	0.12	0.02	16	0.21	0.06	30
Velocity (m/s)	.17	.06	36	.26	.09	35	.27	.09	34
Particle size (mm, 198 particles)	304	30	10	244	27	11	30	18	60
Substrate category (Wentworth scale)	8.56	.10	1	8.77	.20	2	4.16	1.24	30
Embeddedness (percent)	18	19	107	20	14	72	15	4	29
Fish cover	1	1	87	5	4	75	22	10	45
Total width (m)	9.14	1.52	17	4.88	1.22	25	1.52	.00	0
Thalweg depth (m)	.25	.10	39	.27	.05	17	.29	.08	27
Channel aspect (degree)	163	6	4	227	13	6	54	5	9
Percent canopy closed (angle coverage by riparian vegetation)	78	3	4	94	2	3	28	2	9
Percent shade (visual estimate, 1000–1400)	53	19	37	84	6	8	18	11	59
Riparian canopy closure at stream edge (percent)	72	6	9	94	1	1	12	5	43
Bank height (m)	2.26	.30	14	2.50	.79	32	.88	.06	7
Bank angle (degree)	31	9	29	22	4	17	24	12	52
Bank material (Wentworth scale)	3.26	.78	24	4.82	2.06	43	2.52	.14	6
Percent bank bare	37.20	7.98	21	53.38	9.48	18	4.32	.23	5
Percent bank grass	24.55	13.44	55	14.05	1.14	8	78.48	11.60	15
Percent bank shrub	1.29	2.23	173	2.12	2.05	97	17.12	11.79	69
Percent bank tree	36.97	9.20	25	3.45	9.35	31	.08	.13	173
NAWQA bank stability	12.00	1.73	14	1.67	1.53	14	8.67	1.15	13
Visual stability (0–4)	3	0	14	3	0	7	4	0	3
Rooted and stable vegetation (0–4)	3	0	2	3	0	6	4	0	1
Pool:riffle ratio	1	1	81	1	0	60	1	0	45
Average minimum DO (mg/L)	8.55	.21	2	9.05	.37	4	9.08	.40	4
Maximum or minimum pH	7.00	0	0	6.50	0	0	6.40	0	0
Length of reach (m)	169.8	39.0	23	123.4	1.1	8	53.0	16.8	32
Streamflow day of survey (m³/s)	.15	.12	78	.11	.08	76	.06	.04	72

Table 8. Mean, standard deviation (SD), and coefficient of variation (CV, in percent) of each habitat characteristic at each of nine reference reaches and the average CV for each characteristic at all nine reaches in the Catskill Mountain region surveyed in 2002, 2004, and 2006.

[Site codes are presented in table 1. °C, degrees Celsius; mm, millimeters; NAWQA, National Water-Quality Assessment Program; DO, dissolved oxygen; mg/L, milligrams per liter; m^3/s, cubic meters per second]

Habitat characteristic	Study sites									Average
	SV01	SV01	SV01	SC01	SC01	SC01	BA05	BA05	BA05	
	Mean	SD	CV (percent)	Mean	SD	CV (percent)	Mean	SD	CV (percent)	CV (percent)
Temperature (°C)	19.7	1.2	6	18.9	0.7	4	18.8	1.1	6	10
Depth (m)	0.28	0.08	28	0.15	.02	10	0.18	0.04	20	31
Velocity (m/s)	.33	.17	53	.30	.10	33	.19	.10	56	42
Particle size (mm, 198 particles)	91	1	1	182	30	17	172	9	6	17
Substrate category (Wentworth scale)	6.52	.21	3	7.68	.38	5	7.51	.25	3	6
Embeddedness (percent)	23	16	69	20	10	50	25	17	70	67
Fish cover	1	2	173	5	2	43	4	3	69	82
Total width (m)	16.5	1.52	9	9.45	2.44	26	7.32	2.13	29	16
Thalweg depth (m)	.44	.09	21	.34	.06	18	.33	.06	20	25
Channel aspect (degree)	239	52	22	229	3	1	248	9	4	5
Percent canopy closed (angle coverage by riparian vegetation)	59	3	5	78	6	8	71	3	4	6
Percent shade (visual estimate, 1000–1400)	20	3	14	63	15	25	38	7	17	23
Riparian canopy closure at stream edge (percent)	87	7	8	74	13	18	63	5	7	14
Bank height (m)	2.44	.40	16	1.58	.21	13	3.90	1.01	26	19
Bank angle (degree)	37	9	24	31	7	24	22	5	23	25
Bank material (Wentworth scale)	2.27	.27	12	3.26	.79	24	4.18	.80	19	18
Percent bank bare	32.2	6.99	22	48.94	8.41	17	3.00	7.18	24	23
Percent bank grass	29.47	1.14	34	14.02	1.32	74	61.21	4.82	8	50
Percent bank shrub	22.88	11.28	49	4.62	2.53	55	5.23	2.97	57	77
Percent bank tree	15.3	4.69	31	31.06	8.74	28	3.41	2.08	61	56
NAWQA bank stability	12.00	1.00	8	11.00	1.00	9	13.00	2.00	15	11
Visual stability (0–4)	3	0	5	3	0	9	3	0	4	7
Rooted and stable vegetation (0–4)	3	0	7	3	0	6	3	0	4	6
Pool:riffle ratio	1	1	70	0	0	40	2	2	77	60
Average minimum DO (mg/L)	9.10	.28	3	9.05	.49	5	8.70	.17	2	3
Maximum or minimum pH	7.10	0	0	6.50	0	0	6.90	0	0	0
Length of reach (m)	241.4	56.7	23	163.4	17.4	11	145.1	17.4	12	18
Streamflow day of survey (m^3/s)	1.48	1.06	72	.35	.18	53	.24	.20	83	84

for each variable measured during the surveys are provided in appendix 4). An exception to this was the particle size at CN01, where the 2006 sampling was done immediately after floods washed away most of the fine sediments (CV of 60 percent, table 8). Variables directly affected by streamflow (depth, velocity, fish cover, pool-to-riffle ratio) and those that were subjectively evaluated (embeddedness and bank vegetative composition) had high variability within each site and among sites. Other studies have documented similar patterns in variability of habitat features: low variability in most reach and bank features and greater variability in descriptive channel features (Archer and others, 2004; Kaufmann and others, 1999). High variation due to differences in streamflow were not surprising, because CVs for streamflow (at the time of surveys) averaged 84 percent across all sample dates for all sites and ranged from 53 to 114 percent across the nine sites (table 8). CVs were deceptively large, however, when a habitat feature was very small and varied slightly from year to year; for example, with bank vegetative composition, percent grass at WC02 ranged from 0.00 to 0.45 and had a CV of 173 percent, percent shrub at BE01 ranged from 0.00 to 3.86 and had a CV of 173 percent, and percent tree at CN01 ranged from 0.00 to 0.23 and had a CV of 173 percent (appendix 4 and table 9). Variability in habitat measurements within the same study reach may be attributed to (1) different field crews assessing subjective and quantitative features, (2) differing streamflow conditions among sample dates, and (3) the normal year-to-year changes in habitat condition because of disturbances such as floods during the 2-year intervals between each habitat survey.

Examination of the average overall CV for each habitat characteristic at all nine reaches shows that temperature, particle size, substrate category, channel aspect, canopy closure, riparian canopy closure, bank height, bank material, percent bank bare, NAWQA bank stability, visual stability, rooted and stable vegetation, average minimum DO, and maximum or minimum pH had average CVs of less than 25 percent (table 8). The low variability of these features during the 5-year study period suggests they are not sensitive to normal year-to-year fluctuations in temperature, precipitation, and streamflow. Therefore, these relatively constant features may prove to be useful tools for monitoring changes in stream condition, because a large and simultaneous change in several of them could be indicative of a change in stream condition caused by anthropogenic actions (for example, channel restoration and flow diversion) or natural perturbations (for example, extreme floods and climate change).

Several guidelines should be followed when habitat characteristics are used to assess stream condition: (1) all observers should be trained to follow the same protocol when collecting quantitative and subjective data, (2) multiple surveys of the same reach are needed to reliably characterize the natural variability of habitat conditions, and (3) all data should be collected under comparable flow conditions because many habitat variables are directly affected by streamflow, which can vary greatly from day to day, season to season, and year to year (Archer and others, 2004). If these guidelines are followed, stream-habitat assessments provide a method of stream-condition evaluation that requires moderate personnel, time, training, and equipment commitments, yet can provide consistent and reliable results, as evidenced by the low CVs of many habitat characteristics (table 8).

Habitat Suitability Index Models

HSI models are intended to consolidate scientific information on species-habitat relations and are based on the assumption of a positive relation between the index and habitat-carrying capacity (Schamberger and others, 1982). Field measurements of each habitat variable were converted to an index of suitability from 0.0 (unsuitable) to 1.0 (optimum), and the final HSI score was calculated by averaging the scores of each variable. HSI scores at the nine reference reaches ranged from 0.66 to 0.92 for brook trout, 0.59 to 0.78 for brown trout, and 0.59 to 0.89 for rainbow trout (table 9). The **standard deviations** (SD) and CVs for mean HSI scores within each site were usually less than 5 percent and always less than 8 percent (table 9). This is not surprising because the HSI scores assigned to each variable were based on the premise that extreme rather than average values of a variable most commonly limit the carrying capacity of the local reach (Raleigh, 1982). These findings indicate that (1) no habitat features varied sufficiently or became too extreme at any site during the three surveys to substantially alter habitat quality for the three trout species, and (2) HSIs are useful tools for monitoring changes in stream condition because they exhibited low year-to-year variability in undisturbed streams despite known differences in hydrologic conditions during the study period.

The means and standard deviations for brook, brown, and rainbow trout HSI scores (fig. 4) show small differences in the quality or suitability of trout habitat among sites and species. The HSI scores for brook trout were consistently higher than those for rainbow trout, and scores for rainbow trout were consistently higher than the scores for brown trout. This result was anticipated because most of the headwater study sites were small and temperatures were cold; thus, conditions should tend to favor brook-trout populations (Raleigh, 1982). The differences in HSI scores likely reflect small differences in streambank stability, riparian condition, fish cover, sediment loads, and inputs of woody debris because high-quality habitat is characterized by a diversity of roughness elements, such as cobble, boulders, and woody debris, and an intact riparian community that provides shade and a source of organic material to the stream (Baur and Ralph, 2001). Because HSI scores for each species generally varied little from year to year within each study site as well as across study sites (though HSIs for some sites were consistently lower than others), the conclusion is that these assessments provide reliable baseline information on the suitability of stream reaches for the three trout species.

Table 9. Mean, standard deviation (SD), and coefficient of variation (CV) for brook, brown, and rainbow trout Habitat Suitability Index (HSI) scores at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1]

Site	Year	Brook HSI	Brown HSI	Rainbow HSI
WC02	2002	0.80	0.66	0.76
	2004	.88	.77	.84
	2006	.88	.76	.84
	mean	.85	.73	.81
	SD	.05	.06	.05
	CV (percent)	5.71	7.82	6.01
WC01	2002	.78	.70	.74
	2004	.82	.75	.81
	2006	.81	.70	.77
	mean	.80	.72	.77
	SD	.02	.03	.03
	CV (percent)	3.00	4.17	4.17
BE02	2002	.70	.62	.64
	2004	.69	.61	.62
	2006	.72	.62	.67
	mean	.70	.62	.64
	SD	.01	.01	.03
	CV (percent)	2.05	1.07	4.29
BE01	2002	.66	.59	.59
	2004	.74	.62	.66
	2006	.74	.62	.67
	mean	.71	.61	.64
	SD	.05	.02	.05
	CV (percent)	6.90	3.19	7.12
BH01	2002	.84	.69	.77
	2004	.79	.70	.74
	2006	.87	.73	.82
	mean	.83	.71	.79
	SD	.03	.02	.03
	CV (percent)	3.42	2.45	3.90

Table 9. Mean, standard deviation (SD), and coefficient of variation (CV) for brook, brown, and rainbow trout Habitat Suitability Index (HSI) scores at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1]

Site	Year	Brook HSI	Brown HSI	Rainbow HSI
CN01	2002	0 .85	0.74	0 .82
	2004	.83	.72	.82
	2006	.92	.78	.89
	mean	.87	.75	.85
	SD	.05	.03	.04
	CV (percent)	5.69	4.24	4.83
SV01	2002	.78	.67	.75
	2004	.76	.65	.70
	2006	.76	.65	.72
	mean	.77	.66	.73
	SD	.01	.01	.02
	CV (percent)	1.61	1.68	3.40
SC01	2002	.80	.70	.77
	2004	.83	.74	.79
	2006	.83	.70	.76
	mean	.79	.69	.75
	SD	.04	.04	.04
	CV (percent)	5.11	5.45	4.79
BA05	2002	.76	.69	.71
	2004	.77	.69	.73
	2006	.81	.71	.75
	mean	.78	.69	.73
	SD	.02	.01	.02
	CV (percent)	2.94	1.85	2.59

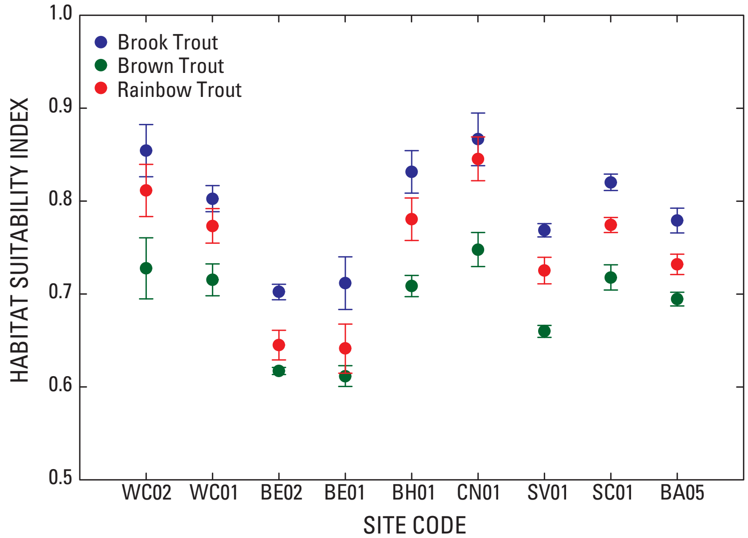


Figure 4. Mean (dot) and standard deviation (bars) of brook, brown, and rainbow trout Habitat Suitability Index scores at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

Relations Between Habitat Suitability Index Scores and Trout Density and Biomass

Even though HSI scores are meant to be relative indicators of habitat suitability and are not intended to reliably predict standing crops of trout (the total number of trout present in a specific area at a given time; Raleigh, 1982), relations between density and biomass of the three trout species and their corresponding HSI scores were evaluated to determine how accurately HSI scores can predict trout indices. The mean HSI scores at each site were compared to mean density and biomass for each trout species from the three surveys (fig. 5); the species-specific HSIs could account for 90 to 91 percent of the variability in brown-trout density and biomass, 70 to 74 percent of the variability in brook-trout density and biomass, and 68 to 69 percent of the variability in rainbow-trout density and biomass (excluding rainbow data from CN01 where they were not found). When data from CN01, where the rainbow HSI was high (mean = 0.85, table 9), were included in the relation, the HSI was not significantly related to the density ($R^2 = 0.26$) or biomass ($R^2 = 0.27$) of rainbow-trout populations (p-values were 0.18 and 0.17, respectively). This poor relation may result simply because the rainbow trout were not distributed within this small watershed (2.38 km^2) or because interspecific competition, predation, disease, water nutrient levels, or some other factor not measured by the HSI was affecting the populations at the sampled reach (Raleigh, 1982). These results indicate that HSI scores are usually reliable indicators of species presence, and higher HSI scores commonly indicate greater species abundance and biomass.

Relations Between Stream Stability and Fish Indices

Previous investigations have found that geomorphically unstable streams do not support diverse fish communities with high biological integrity (Baldigo and others, 2008a; Shields and others, 1997, 1998, 2000). This study defines stability as the ability of a stream, over time, to transport the flows and sediment of its watershed in such a manner that the dimension, pattern, and profile of the channel are maintained without either aggrading or degrading the stream (Rosgen, 1996). Streams that are geomorphically unstable may have rapidly eroding or shifting beds and banks; fewer pools than more stable reaches, lower pool area and pool-to-riffle ratios, dramatically higher or lower **width/depth** ratios, and more uniform water velocity; and higher rates of bank erosion, lateral channel migration, and sediment transport (Leopold, 1994, Leopold and others, 1964, Rosgen, 1996). Stream habitat within such channels can be relatively sterile and homogenous with low species diversity and distorted ecosystem structure or function (Pretty and others, 2003; Rosgen, 1994; Scott and Hall, 1997).

This study used the NAWQA bank-stability index to estimate bank stability at each reference reach. This index converts measurements of bank angle, bank height, dominant bank substrate, and bank vegetative cover to an index score ranging from 4 (most stable) to 22 (least stable) (Fitzpatrick and others, 1998). Linear regression analysis was used to quantify the effects of channel stability and related habitat characteristics on fish communities and trout populations. Total-community biomass exhibited an anticipated positive

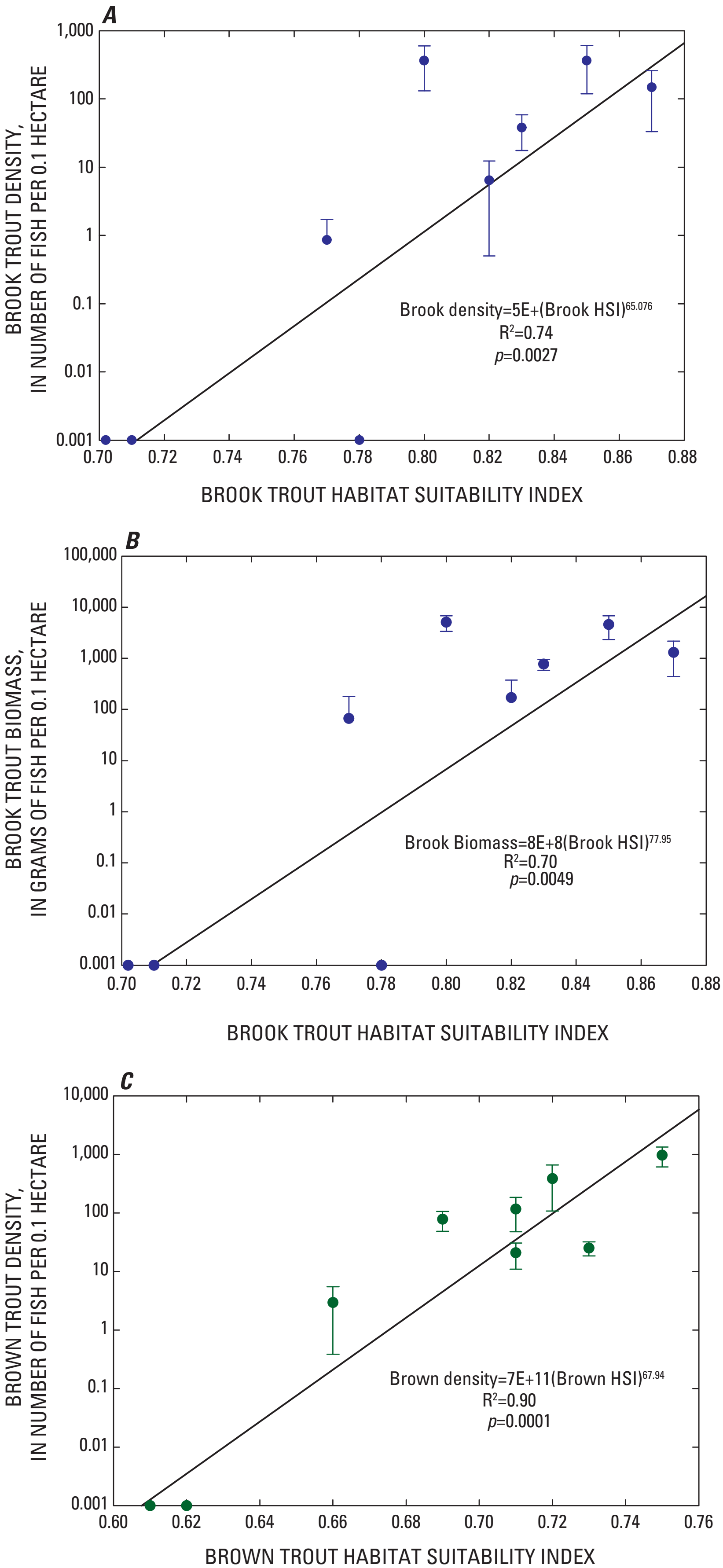


Figure 5. Relation between mean Habitat Suitability Index and the mean and standard deviation of *(A)* brook trout density, *(B)* brook trout biomass, *(C)* brown trout density, *(D)* brown trout biomass, *(E)* rainbow trout density, and *(F)* rainbow trout biomass at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

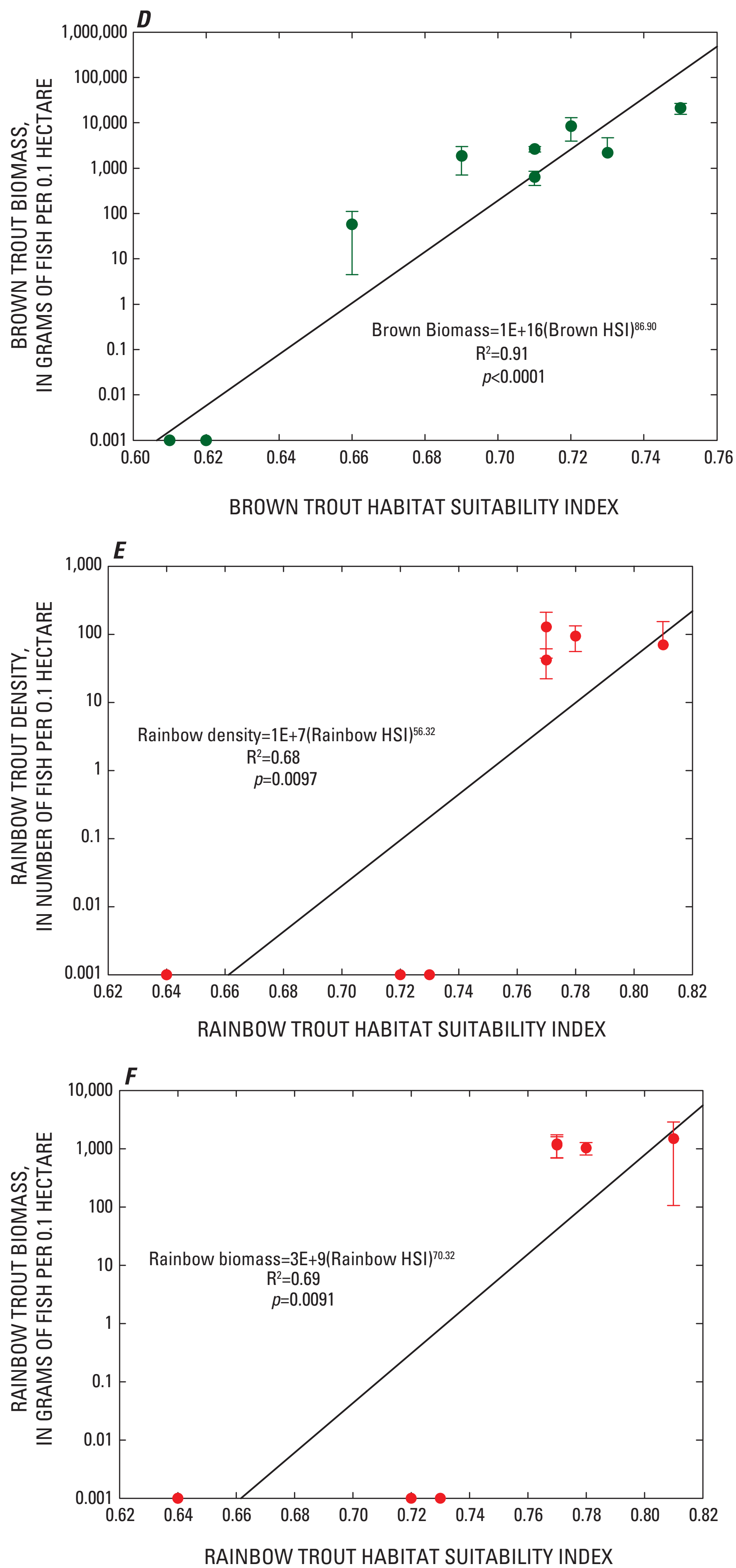


Figure 5. Relation between mean Habitat Suitability Index and the mean and standard deviation of *(A)* brook trout density, *(B)* brook trout biomass, *(C)* brown trout density, *(D)* brown trout biomass, *(E)* rainbow trout density, and *(F)* rainbow trout biomass at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

response to increased bank stability; however, density decreased as banks became less stable, and community richness and equitability were not significantly affected (table 10). The decrease in density could be caused by the significant relation between brown trout and unstable undercut banks (table 10). Adult brown trout tend to seek cover more than any other trout species (Raleigh and others, 1986), and brown trout were responsible for between 9 to 94 percent of the total biomass at six of the nine reaches sampled (fig. 3 and table 6). The lack of a significant relation between richness and equitability and NAWQA stability could be because only nine sites were examined or because these two indices were not sensitive to the relatively narrow range in mean NAWQA stability index scores at the nine study sites (low of 8.67 at BE02 and CN01; high of 15.00 at WC02; table 8).

The contribution of riparian vegetation to the structure and function of aquatic habitats has been well documented. Riparian vegetation provides streambank stability, regulation of stream temperatures, input of nutrients to the system by allochthonous material, direct input of invertebrates as fish food, and fish cover and reduces sediment yield and surface runoff (Wesche and others, 1987; Li and Shen, 1973). The results of this investigation show that there are usually significant relations between streamside vegetation and fish indices. For example, total community density decreases as percent bank tree increases (table 10); this may be because trees protect streambanks by reducing the erosive energy of water and by trapping soils to maintain the streambank (Monsen and Shaw, 1983). Thus, when banks are well vegetated and more stable, fish communities might shift away from an overabundance of a few species tolerant of high sediment loads and towards more balanced assemblages with a greater number of species that are larger, less numerous, and intolerant of high sediment loads. Platts (1983) stated that the banks bordering small streams provide the habitat edges or niches needed to maintain healthy trout populations. Evidence of this is seen in the positive correlation between percent bank tree and riparian canopy closure and populations of brook and rainbow trout (table 10), suggesting both species are responding to the decrease in water temperature, the increase in fish cover, and the reduction in sediment loads provided by well-established riparian vegetation and root structures.

Areas of Further Study

Documenting relations between Rosgen stream types, stream instability, and fish community indices was not one of the original objectives of this investigation. However, preliminary data analysis indicated that an increased understanding of these interactions could (1) enhance the biological impact of NCD, and (2) quantify the extent to which geomorphic instability affects the biological integrity of fish communities. A summary of the preliminary findings and the potential benefits of a more in-depth analysis follow.

Relations Between Rosgen Stream Type and Fish Indices

Previous investigations have shown that stream geomorphology, including the shape, profile, plan view, and structural elements, strongly influences the hydraulic characteristics of streams (Rosgen, 1994), which in turn determine the distribution, abundance, and habitat for fish in streams (Fukushima, 2001). The importance of understanding the effect of hydrological relations on fish-habitat potential has been well documented (Rosgen, 1996), but no previous investigations have evaluated these relations in the Catskill Mountain region. Therefore, a preliminary analysis of the relations between Rosgen stream type and fish indices was included in this study.

The Rosgen stream-classification system divides streams into seven major stream-type categories that differ in **entrenchment**, gradient, width/depth ratio, and **sinuosity** (Rosgen, 1994). Of the eight streams examined (no geomorphology data are available for SC01), one stream was classified as **F-type**, three were classified as **C-type**, and four were classified as **B-type** (table 11). A t-test was used to determine any significant differences in fish indices among the stream types. It was not possible to test if fish-community index values at the single F-type stream differed significantly from those in B- and C-type streams, but results indicate that the F-type stream had the lowest richness, community density, community biomass, diversity, equitability, and brown-trout density and the highest brook-trout density, rainbow-trout density, brook-trout biomass, and rainbow-trout biomass. Among B- and C-type streams, no significant differences were found in richness, community density, diversity, equitability, dominance, brook-trout density, or brook-trout biomass. However, significant differences were found in total biomass ($p = 0.05$, fig. 6a), brown-trout density ($p = 0.04$, fig. 6b), rainbow-trout density ($p = 0.02$, fig. 6c), brown-trout biomass ($p = 0.04$, fig. 6d), and rainbow-trout biomass ($p = 0.007$, fig. 6e). Also, although B- and C-type streams supported almost the same density of brook trout (fig. 6f), B-type streams appear to have a higher brook trout biomass (fig. 6g).

When different trout species are present in the same high-gradient river systems, they tend to occupy the suitable trout habitat in a longitudinally stratified manner from headwater areas downstream (Raleigh and others, 1986). Brook trout typically occupy the colder, swifter, less fertile headwater regions; rainbow trout the mid-regions of the river system with intermediate habitat conditions; and brown trout the deeper, lower velocity, warmer, more fertile downstream regions (Raleigh and others, 1986). The results of this investigation suggest that rainbow trout preferred B-type reaches characterized by moderate entrenchment, moderate gradients, and stable banks (Rosgen, 1996, table 11); brown trout dominate the low-gradient, meandering, alluvial C-type reaches with broad, well-defined flood plains further downstream (Rosgen, 1996, table 11). The fact that C-type channels are more productive is reflected in the significantly

Table 10. Correlation coefficients of the relations between habitat characteristics related to stream stability and fish indices at nine reference reaches in the Catskill Mountain region surveyed in 2002, 2004, and 2006.

[**Boldface** indicates a p-value less than 0.05 and * indicates a p-value less than 0.10]

Habitat characteristics	Richness	Density	Biomass	Diversity	Equitability	Dominance	Brown density	Brook density	Rainbow density	Brown biomass	Brook biomass	Rainbow biomass
NAWQA stability index	-0.11	-0.36*	**-0.49**	-0.07	-0.01	0.02	**-0.47**	**0.41**	0.06	**-0.39**	**0.49**	**0.39**
Bank height	-.10	-.21	**-.52**	-.09	.02	.00	**-.50**	.33*	-.01	**-.45**	**.45**	.29
Bank angle	.02	**-.45**	-.23	.11	.10	-.11	-.17	.08	.03	.02	.12	.22
Bank material	-.29	-.17	-.22	-.31	-.04	.01	-.20	.22	**.43**	-.21	.25	.37*
Percent bank bare	-.27	**-.52**	**-.55**	-.24	-.08	.02	**-.41**	**.38**	**.52**	**-.39**	**.50**	**.63**
Percent bank grass	.21	**.57**	**.59**	.18	.10	-.05	.37*	-.37*	**-.47**	**.37**	**-.49**	**-.64**
Percent bank shrub	**.45**	.27	.17	**.42**	.13	-.09	**.38**	-.31	-.33*	.23	-.37*	**-.45**
Percent bank tree	-.30	**-.55**	**-.49**	-.25	-.16	.11	**-.39**	**.39**	**.39**	-.33*	.48*	**.63**
Visual stability	-.07	**.43**	**.52**	-.11	-.22	.26	.37*	.00	-.29	.33*	-.14	-.38*
Rooted and stable cover	-.22	.28	**.54**	-.23	-.27	.31	**.38**	-.09	**-.42**	**.42**	-.18	**-.38**
Riparian canopy closure	-.01	**-.43**	**-.75**	.02	.13	-.16	**-.61**	.27	.35*	**-.59**	**.39**	**.50**
Percent canopy closed	-.26	**-.38**	**-.59**	-.25	-.03	-.01	**-.54**	.37*	**.47**	**-.54**	**.49**	**.62**
Percent shade	**-.55**	**-.54**	-.37*	**-.53**	-.31	.24	-.29	**.42**	**.45**	-.20	**.54**	**.65**
Undercut banks	-.37*	-.16	**.70**	-.35*	**-.51**	**.53**	**.67**	-.03	-.19	**.87**	-.06	-.17
Deep pools	-.21	-.14	-.03	-.22	-.24	.23	-.10	**.41**	.38*	-.17	**.52**	**.44**
Over-hanging vegetation	-.19	.20	**.53**	-.20	-.33*	.33*	**.76**	.06	-.29	**.58**	-.05	-.32*
Water temperature	**.53**	**.56**	-.09	**.51**	**.44**	-.31	-.33	**-.56**	**-.44**	**-.47**	**-.54**	**-.55**

Table 11. Rosgen stream classification and geomorphology data for eight reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006. (Data collected by the New York City Department of Environmental Protection (NYCDEP)).

[Site codes are presented in table 1; m, meters; m^2, square meters; na, not available; >, greater than]

Site	Rosgen stream type	Mean bankfull width (m)	Mean bankfull depth (m)	Width/ depth ratio	Mean bankfull cross-sectional area (m^2)	Entrenchment ratio	Mean bankfull slope (percent)
WC02	F3	15.64	0.54	29.00	8.42	1.62	na
WC01	B3	14.16	.59	24.00	8.40	1.67	na
BE02	C3	16.84	.58	29.20	9.81	1.86	1.2500
BE01	Bc3	16.51	.63	23.50	10.38	1.44	1.2200
BH01	B3	11.44	.60	19.20	6.91	1.82	3.7500
CN01	C5	4.71	.24	20.80	1.09	>2.2	0.5100
SV01	C4	25.15	1.24	20.50	31.08	6.10	.0018
BA05	Bc3	22.71	1.00	23.40	17.49	1.17	.6500

higher community biomass they supported ($p = 0.05$, fig. 6a). This apparent relation between Rosgen stream type and fish-community composition warrants further investigation because (1) future efforts to use trout as indicators of stream health need to consider existing geomorphologic conditions, (2) the results indicate that stream-habitat assessments can be enhanced by including geomorphology data, and (3) the results verify the assumption that changes in geomorphology (for example, stream restoration) cause changes in habitat, which in turn cause changes in fish-community structure.

Relations Between Geomorphically Unstable Streams and Fish Indices

An underlying assumption of this investigation is that the fish:habitat relations presented herein are found only in geomorphically stable streams, though these relations have not been evaluated in unstable streams in the region. However, such comparisons would be possible using fish-community, stream-habitat, and geomorphology data collected at geomorphically unstable control reaches in the region as part of a related investigation (Baldigo and others, 2008a; Baldigo and Warren, 2008; Baldigo and others, 2008b) or by locating and surveying unstable reaches in the seven streams included in this investigation. Benefits of such an analysis would include (1) verifying that the NAWQA bank-stability index is an accurate measurement of overall stream stability, (2) confirming that trout are not found in reaches with very low HSI scores, (3) verifying that reaches with low biological integrity also have low geomorphic stability, (4) exploring further the relations between Rosgen stream type and fish indices, and (5) documenting the habitat characteristics and fish-community composition of aquatic communities that have been affected by high rates of bed and bank erosion, lateral channel migration, and sediment loading.

Summary

This report provides a critical set of baseline data on the fish-community composition, habitat characteristics, and fish:habitat correlations in geomorphically stable streams in the Catskill Mountain region of New York State. This documentation of the physical and biological conditions of stable stream reaches is an essential step in defining baseline conditions of achievable geomorphic stability and healthy aquatic communities. The NYCDEP Stream Management Program can use these data to quantify biological integrity and habitat quality in stable, undisturbed reaches; these conditions can then be used as benchmarks to monitor the biological impact of stream restorations, floods, and flow diversions.

Indices of fish-community density, biomass, richness, and equitability (evenness) were used to quantify the biological integrity of reference reaches. Mean community indices differed considerably among sites where trout were present and where they were absent or present in very low numbers. Results across all nine sites indicated that (1) sampling areas within the same sites should remain consistent from year to year, (2) species richness and diversity are the most stable measures of community health, (3) fish abundance is generally a poor indicator of disturbance, and (4) most species were similarly sensitive to the environmental factors

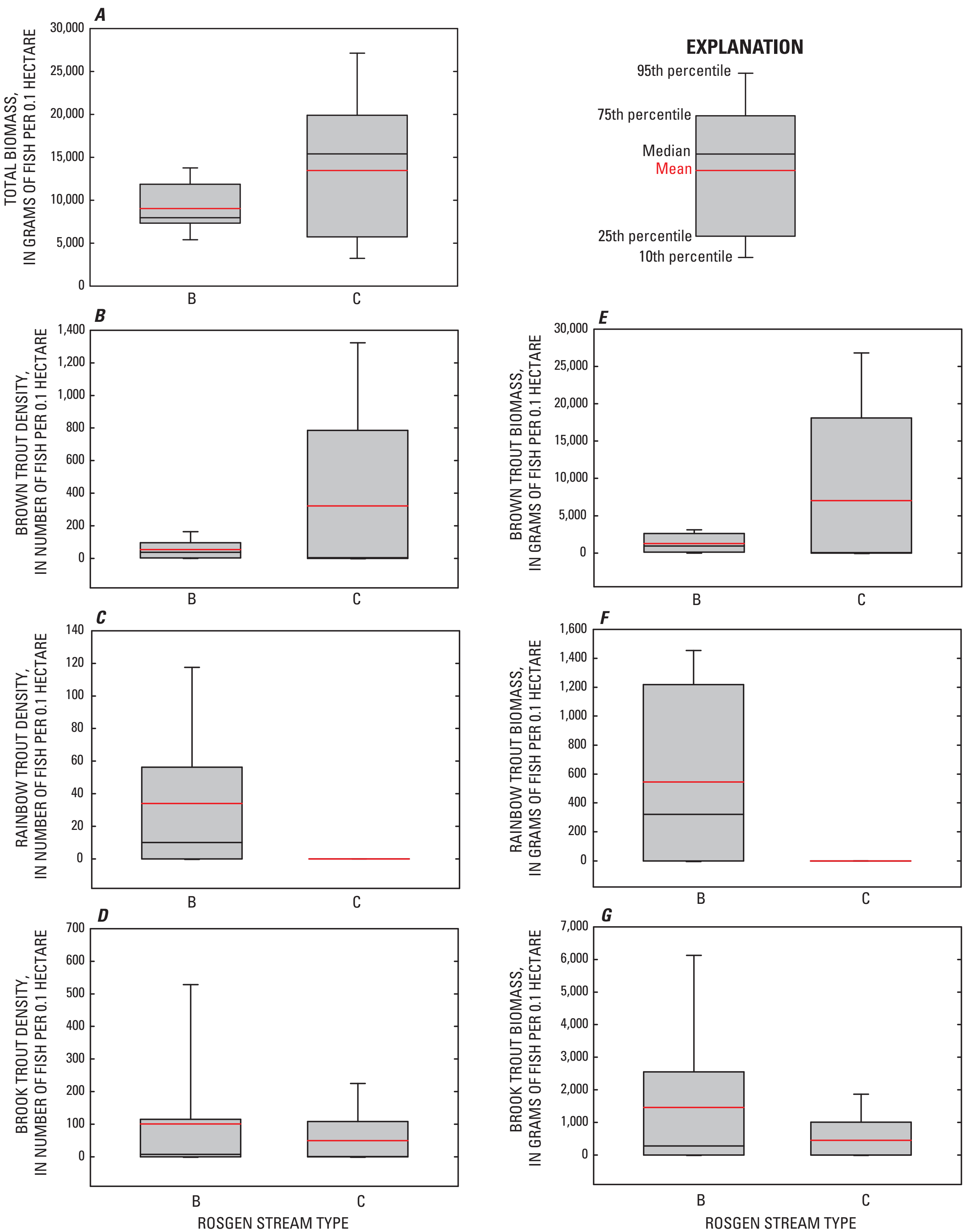


Figure 6. Mean, median, 95th percentile, 75th percentile, 25th percentile, and 10th percentile for *(A)* total biomass, *(B)* brown trout density, *(C)* rainbow trout density, *(D)* brown trout biomass, *(E)* rainbow trout biomass, *(F)* brook trout density, and *(G)* brook trout biomass, separated by Rosgen stream type.

(for example, temperature, precipitation, and streamflow) that probably are responsible for the year-to-year variability in community indices.

HSI scores for brook, brown, and rainbow trout were used to summarize the habitat quality of the nine reference reaches. Results show that species-specific HSIs can account for 90 to 91 percent of the variability in brown-trout density and biomass, 70 to 74 percent of the variability in brook-trout density and biomass, and 68 to 69 percent of the variability in rainbow- trout density and biomass. The relatively low CVs of these scores (<8 percent) indicate that HSIs provide reliable and consistent baseline information on reach condition. However, examination of the variability in the measurement of individual habitat characteristics showed that habitat sampling results can be affected by observer bias and streamflow conditions at the time of the survey. Therefore, although data collected during habitat assessments can be used to help interpret physical (for example, channel characteristics) and chemical (for example, transport of sediment and sediment-associated contaminants) stream properties, the inherent variability of individual habitat characteristics makes it necessary to perform multiple surveys before any conclusions about habitat quality can be made.

Another important finding was that stable streams with well-vegetated banks are characterized by higher quality habitat and biological integrity than streams that are geomorphically unstable. This finding supports the underlying assumption of this investigation, namely that the habitat conditions preferred by healthy trout populations are the same conditions that successful stream restorations need to replicate in order to address flood-hazard, water-quality, and property-protection issues. Therefore, stream restorations that improve habitat quality (as evidenced by higher HSI scores) and biological integrity (as evidenced by higher trout density and biomass) should also have increased bank stability and reduced sediment loads, which are the primary goals of Natural Channel Design restoration.

Preliminary analysis of the relations between populations of trout species and Rosgen stream type showed a potential link between stream morphology and fish-habitat potential. This relation was most evident in the preference of rainbow trout for B-type streams and brown trout for C-type streams. It is important to verify this finding by examining more streams in the region because (1) future efforts to use trout as indicators of stream health may need to consider existing geomorphology conditions, (2) it suggests that stream habitat assessments can be enhanced by including geomorphology data, and (3) it offers strong evidence to support the assumption that changes in geomorphology (for example, stream restoration) cause changes in habitat, which in turn cause changes in fish-community structure.

The data presented herein summarize the biological characteristics of reference reaches in the Catskill Mountain region. Drainage areas of the study sites ranged from 2.38 to 241 km^2, elevations ranged from 366 to 609 m, and hydrologic conditions during the study period ranged from drought to flood. However, even though the reference reaches were subject to extreme climatic conditions during the study period, the average overall CV for most fish-community indices and many habitat characteristics was less than 25 percent. This is an important finding because it shows that stable, undisturbed streams of all sizes in valley and upland regions are able to recover from the effects of precipitation extremes and reestablish biological equilibrium. Therefore, stream restoration efforts that successfully mimic these conditions will have likely created a geomorphically stable channel capable of withstanding floods and transporting sediment without either aggrading or degrading.

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Glossary

Terms that are set in **bold** within the text are discussed here.

C

canopy angle A measure of the openness of a stream to sunlight.

channel aspect Downstream direction of streamflow.

coefficient of variation (CV) (standard error/mean)* 100.

D

dominance Measures what percentage of a community is composed of the most abundant species.

E

entrenchment ratio Vertical containment of a river and the degree to which it is incised in the valley floor (flood prone width/bankfull channel width).

equitability A measure of the evenness in the relative abundance of the different species making up the richness of an area.

F

fish community index Metrics or measurements that represent fish-community attributes.

G

geomorphic Describing the form and function of streams.

H

habitat suitability index (HSI) Provides a numerical index of habitat suitability based on species-habitat relations.

R

richness Refers to the number of species present in a given area.

riparian canopy closure Measure of the density of riparian vegetation at the edge of water.

Rosgen stream type Classifies streams based on quantifiable field measurements to produce consistent, reproducible descriptions of stream condition. The four stream types mentioned in this report are (from Rosgen, 1996):

> **B** Moderately entrenched, moderate gradient, riffle dominated channel, with infrequently spaced pools. Very stable, plan, profile, and banks.
>
> **C** Low gradient, meandering, point-bar, riffle/pool alluvial channels with broad, well defined floodplains.
>
> **F** Entrenched meandering riffle/pool channel on low gradients with high width/depth ratio.

S

Shannon-Wiener diversity A community index that accounts for species abundance and evenness.

sinuosity Stream length/valley length.

standard deviation (SD) Equal to the square root of the arithmetic mean of the squares of the deviations from the arithmetic mean.

W

water year The 12-month period October 1 through September 30, designated by the calendar year in which it ends.

width/depth ratio Bankfull width/bankfull depth.

Wentworth scale Groups particles of different size ranges into different size classes.

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Appendix

Appendix 1. Original community richness (number of species-S), density (number of fish per 0.1 hectare), biomass (grams of fish per 0.1 hectare), species diversity (d), equitability (Shannon-Wiener-H'), dominance (Simpson's-C), and sampling area (m^2) for fish community surveys at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1]

Community index	Study sites								
	WC02	WC02	WC02	WC01	WC01	WC01	BE02	BE02	BE02
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Sampling area	281.8	489.7	426.7	325.4	448.3	544.5	371.2	998.0	538.5
Richness	3	3	3	3	3	3	10	9	8
Density	826.9	300.2	241.4	669.9	435.0	172.6	6,670.3	1,705.4	2,978.6
Biomass	11,395.6	4,568.3	8,645.9	7,953.6	7,977.0	4,625.7	16,262.1	8,001.0	15,382.7
Shannon-Wiener diversity	1.27	1.39	1.50	1.28	1.32	1.54	2.95	2.80	2.54
Equitability	0.27	0.24	0.28	0.17	0 .26	0.31	0.43	0.43	0.60
Dominance	.63	.71	.66	.80	.68	.62	.57	.55	.35
Community index	**Study sites**								
	BE01	BE01	BE01	BH01	BH01	BH01	CN01	CN01	CN01
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Sampling area	519.5	597.0	788.7	524.3	682.0	677.6	88.9	105.1	61.2
Richness	13	8	8	4	4	4	2	3	2
Density	2,184.8	16,38.2	1,480.9	886.9	825.5	733.5	854.9	1,541.4	980.4
Biomass	7,168.2	11,407.7	8,042.2	7,306.7	7,607.8	7,310.8	22,225.0	17,538.5	27,106.2
Shannon-Wiener diversity	4.26	2.69	2.67	1.51	1.53	1.57	1.06	1.38	1.17
Equitability	.60	.58	.63	.44	.51	.32	.26	.19	.04
Dominance	.40	.40	.34	.47	.36	.64	.60	.75	.96
Community index	**Study sites**								
	SV01	SV01	SV01	SC01	SC01	SC01	BA05	BA05	BA05
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Sampling area	1,196.0	1,727.7	509.8	859.1	659.0	917	604.0	730.0	833
Richness	17	16	11	6	6	6	8	9	11
Density	3,146.3	970.1	1,904.7	2,863.5	1,751.1	1,108.0	5,564.6	1,761.6	2,614.6
Biomass	7,001.3	3,225.5	4,475.5	16,182.5	16,214.4	16,661.7	14,381.6	12,334.9	12,010.7
Shannon-Wiener diversity	4.75	5.18	3.83	1.87	2.03	2.10	2.27	2.93	3.37
Equitability	.71	.69	.70	.34	.47	.61	.53	.77	.74
Dominance	.26	.28	.26	.62	.38	.30	.45	.22	.27

Appendix 2. Raw density (number of fish per 0.1 hectare) for each species population at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites								
	WC02	WC02	WC02	WC01	WC01	WC01	BE02	BE02	BE02
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Creek chub	--	--	--	--	--	--	191.3	98.2	330.5
Common shiner	--	--	--	--	--	--	5.4	7.0	109.6
Golden shiner	--	--	--	--	--	--	--	--	--
Fallfish	--	--	--	--	--	--	--	--	--
Pumpkinseed	--	--	--	--	--	--	--	1.0	--
Redbreast	--	--	--	--	--	--	--	--	--
Hognose sucker	--	--	--	--	--	--	--	--	--
White sucker	--	--	--	--	--	--	323.3	5.0	9.3
Stone roller	--	--	--	--	--	--	695.0	153.3	536.7
Cutlips minnow	--	--	--	--	--	--	285.6	91.2	161.6
Stonecat	--	--	--	--	--	--	13.5	--	--
Margined madtom	--	--	--	--	--	--	142.8	210.4	170.8
Emerald shiner	--	--	--	--	--	--	--	--	--
Brown trout	21.3	32.7	21.1	12.3	31.2	18.4	--	--	--
Brook trout	642.4	249.1	196.9	602.3	354.7	135.9	--	--	--
Rainbow trout	166.8	16.3	25.8	58.4	46.8	20.2	--	--	--
Blacknose dace	--	--	--	--	--	--	4,975.8	1,239.5	1,665.7
Longnose dace	--	--	--	--	--	--	--	--	--
Tessalated darter	--	--	--	--	--	--	16.2	--	5.6
Shield darter	--	--	--	--	--	--	--	--	--
Largemouth bass	--	--	--	--	--	--	--	--	--
Rock bass	--	--	--	--	--	--	--	--	--
Slimy sculpin	--	--	--	--	--	--	--	--	--
Minnow spp.	--	--	--	--	--	--	26.9	--	--
Yellow perch	--	--	--	--	--	--	--	1.0	--

Appendix 2. Raw density (number of fish per 0.1 hectare) for each species population at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites								
	BE01	BE01	BE01	BH01	BH01	BH01	CN01	CN01	CN01
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Creek chub	286.8	192.6	181.3	--	--	--	--	--	--
Common shiner	7.7	45.2	119.2	--	--	--	--	--	--
Golden shiner	--	--	--	--	--	--	--	9.5	--
Fallfish	--	--	--	--	--	--	--	--	--
Pumpkinseed	--	--	--	--	--	--	--	--	--
Redbreast	--	--	--	--	--	--	--	--	--
Hognose sucker	--	--	--	--	--	--	--	--	--
White sucker	196.3	80.4	12.7	--	--	--	--	--	--
Stone roller	65.4	72.0	98.9	--	--	--	--	--	--
Cutlips minnow	90.5	92.1	63.4	--	--	--	--	--	--
Stonecat	127.0	--	--	--	--	--	--	--	--
Margined madtom	77.0	207.7	252.3	--	--	--	--	--	--
Emerald shiner	--	--	--	--	--	--	--	--	--
Brown trout	--	--	--	116.3	183.3	47.2	607.4	1,322.5	964.1
Brook trout	--	--	--	53.4	45.5	14.8	225.0	199.8	16.3
Rainbow trout	--	--	--	120.2	111.4	50.2	--	--	--
Blacknose dace	1,309.0	973.2	782.3	--	--	--	--	--	--
Longnose dace	--	--	--	--	--	--	--	--	--
Tessalated darter	42.3	--	2.5	--	--	--	--	--	--
Shield darter	--	--	--	--	--	--	--	--	--
Largemouth bass	1.9	--	--	--	--	--	--	--	--
Rock bass	--	--	--	--	--	--	--	--	--
Slimy sculpin	11.5	--	--	610.3	579.2	709.9	--	--	--
Minnow spp.	7.7	--	--	--	--	--	--	--	--
Yellow perch	9.6	5.0	--	--	--	--	--	--	--

Appendix 2. Raw density (number of fish per 0.1 hectare) for each species population at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites								
	SV01	SV01	SV01	SC01	SC01	SC01	BA05	BA05	BA05
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Creek chub	26.8	11.6	62.8	--	--	--	183.8	186.3	151.3
Common shiner	22.6	1.7	3.9	--	--	--	298.0	50.7	236.5
Golden shiner	--	--	--	--	--	--	--	--	--
Fallfish	11.7	2.3	--	--	--	--	--	--	6.0
Pumpkinseed	--	--	--	--	--	--	--	--	75.6
Redbreast	--	--	--	--	--	--	--	8.2	--
Hognose sucker	--	1.7	--	--	--	--	--	--	--
White sucker	6.7	22.0	11.8	--	--	2.2	67.9	--	207.7
Stone roller	48.5	5.8	--	--	--	--	--	--	--
Cutlips minnow	337.0	61.4	239.3	--	--	--	172.2	178.1	116.4
Stonecat	1.7	--	--	--	--	--	8.3	--	--
Margined madtom	59.4	14.5	35.3	--	--	--	--	102.7	20.4
Emerald shiner	7.5	--	11.8	--	--	--	--	--	--
Brown trout	4.2	4.6	--	275.9	695.0	176.7	91.1	97.3	44.4
Brook trout	0.8	1.7	--	11.6	7.6	--	--	--	--
Rainbow trout	--	--	--	114.1	215.5	52.3	--	--	--
Blacknose dace	1,036.8	450.9	716.0	15.1	6.1	81.8	3,480.1	646.6	1,207.7
Longnose dace	363.7	140.1	84.3	78.0	15.2	294.4	1,278.1	405.5	668.7
Tessalated darter	106.2	8.7	94.2	--	--	--	--	--	--
Shield darter	20.9	6.4	--	--	--	--	--	--	--
Largemouth bass	--	--	--	--	--	--	--	--	--
Rock bass	--	--	--	--	--	--	--	--	2.4
Slimy sculpin	1,159.7	387.8	700.3	2,644.6	928.7	603.1	225.2	112.3	86.4
Minnow spp.	.8	.6	9.8	--	--	--	--	--	--
Yellow perch	--	--	--	--	--	--	--	--	--

Appendix 3. Raw biomass (grams of fish per 0.1 hectare) for each species population at nine reference reaches in the Catskill mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites								
	WC02	WC02	WC02	WC01	WC01	WC01	BE02	BE02	BE02
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Creek chub	--	--	--	--	--	--	1,216.1	401.5	2,545.0
Common shiner	--	--	--	--	--	--	40.4	32.1	811.1
Golden shiner	--	--	--	--	--	--	--	--	--
Fallfish	--	--	--	--	--	--	--	--	--
Pumpkinseed	--	--	--	--	--	--	--	15.0	--
Redbreast	--	--	--	--	--	--	--	--	--
Hognose sucker	--	--	--	--	--	--	--	--	--
White sucker	--	--	--	--	--	--	1,754.6	69.1	375.1
Stone roller	--	--	--	--	--	--	3,705.5	702.9	4,802.6
Cutlips minnow	--	--	--	--	--	--	1,180.0	815.4	1,129.6
Stonecat	--	--	--	--	--	--	290.9	--	--
Margined madtom	--	--	--	--	--	--	481.4	2,890.9	2,448.8
Emerald shiner	--	--	--	--	--	--	--	--	--
Brown trout	1,245.7	259.3	4,963.7	599.3	437.2	881.5	--	--	--
Brook trout	7,065.9	3,757.6	2,840.9	5,833.1	6,246.9	3,103.2	--	--	--
Rainbow trout	3,084.0	551.4	841.3	1,521.2	1,292.9	641.0	--	--	--
Blacknose dace	--	--	--	--	--	--	7,515.6	3,072.0	3,248.1
Longnose dace	--	--	--	--	--	--	--	--	--
Tessalated darter	--	--	--	--	--	--	26.9	--	22.3
Shield darter	--	--	--	--	--	--	--	--	--
Largemouth bass	--	--	--	--	--	--	--	--	--
Rock bass	--	--	--	--	--	--	--	--	--
Slimy sculpin	--	--	--	--	--	--	--	--	--
Minnow spp.	--	--	--	--	--	--	50.9	--	--
Yellow perch	--	--	--	--	--	--	--	2.0	--

Appendix 3. Raw biomass (grams of fish per 0.1 hectare) for each species population at nine reference reaches in the Catskill mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites								
	BE01	BE01	BE01	BH01	BH01	BH01	CN01	CN01	CN01
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Creek chub	1,358.2	2,090.6	1,035.9	--	--	--	--	--	--
Common shiner	27.9	384.4	802.3	--	--	--	--	--	--
Golden shiner	--	--	--	--	--	--	--	9.5	--
Fallfish	--	--	--	--	--	--	--	--	--
Pumpkinseed	--	--	--	--	--	--	--	--	--
Redbreast	--	--	--	--	--	--	--	--	--
Hognose sucker	--	--	--	--	--	--	--	--	--
White sucker	1,408.1	2,221.1	232.0	--	--	--	--	--	--
Stone roller	589.0	655.1	845.9	--	--	--	--	--	--
Cutlips minnow	507.6	738.7	482.4	--	--	--	--	--	--
Stonecat	1,217.1	--	--	--	--	--	--	--	--
Margined madtom	128.4	2,842.2	3,171.0	--	--	--	--	--	--
Emerald shiner	--	--	--	--	--	--	--	--	--
Brown trout	--	--	--	2,733.2	2,932.6	2,244.7	20,517.4	15,664.1	26,795.8
Brook trout	--	--	--	859.2	883.9	554.9	1,707.5	1,864.9	310.5
Rainbow trout	--	--	--	775.3	1,022.3	1,282.6	--	--	--
Blacknose dace	1,628.9	2,460.5	1,464.8	--	--	--	--	--	--
Longnose dace	--	--	--	--	--	--	--	--	--
Tessalated darter	74.9	--	7.6	--	--	--	--	--	--
Shield darter	--	--	--	--	--	--	--	--	--
Largemouth bass	42.3	--	--	--	--	--	--	--	--
Rock bass	--	--	--	--	--	--	--	--	--
Slimy sculpin	52.0	--	--	2,939.2	2,768.9	3,228.6	--	--	--
Minnow spp.	8.7	--	--	--	--	--	--	--	--
Yellow perch	125.1	15.1	--	--	--	--	--	--	--

Appendix 3. Raw biomass (grams of fish per 0.1 hectare) for each species population at nine reference reaches in the Catskill mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; --, species not present]

Species	Study sites								
	SV01	SV01	SV01	SC01	SC01	SC01	BA05	BA05	BA05
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Creek chub	157.2	19.3	181.1	--	--	--	785.4	1,265.9	856.4
Common shiner	52.0	1.4	5.9	--	--	--	923.2	200.0	613.8
Golden shiner	--	--	--	--	--	--	--	--	--
Fallfish	270.1	18.5	--	--	--	--	--	--	4.2
Pumpkinseed	--	--	--	--	--	--	--	--	245.4
Redbreast	--	--	--	--	--	--	--	141.1	--
Hognose sucker	--	0.9	--	--	--	--	--	--	--
White sucker	9.2	15.3	44.1	--	--	91.6	718.0	--	2,259.7
Stone roller	116.1	39.4	--	--	--	--	--	--	--
Cutlips minnow	653.8	217.6	778.3	--	--	--	676.5	1,182.3	494.1
Stonecat	38.5	--	--	--	--	--	135.8	--	--
Margined madtom	741.5	207.2	329.5	--	--	--	--	1,609.0	330.6
Emerald shiner	12.5	--	19.6	--	--	--	--	--	--
Brown trout	67.7	103.6	--	3,340.6	10,075.7	11,813.7	1,410.6	3,168.9	996.0
Brook trout	2.5	198.0	--	109.4	397.6	--	--	--	--
Rainbow trout	--	--	--	657.0	1,261.8	1,690.7	--	--	--
Blacknose dace	1,402.8	851.7	1,130.8	40.2	9.1	62.1	5,158.4	1,731.2	2,482.4
Longnose dace	1,018.7	448.3	238.5	1,338.3	349.0	941.8	3,235.8	2,166.7	3,176.2
Tessalated darter	168.8	10.2	125.9	--	--	--	--	--	--
Shield darter	41.3	22.7	--	--	--	--	--	--	--
Largemouth bass	--	--	--	--	--	--	--	--	--
Rock bass	--	--	--	--	--	--	--	--	75.6
Slimy sculpin	2,247.0	1,054.2	1,591.2	10,697.1	4,121.2	2,061.8	1,338.1	869.7	476.0
Minnow spp.	1.7	17.4	30.4	--	--	--	--	--	--
Yellow perch	--	--	--	--	--	--	--	--	--

Appendix 4. Raw value for each habitat characteristic at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

[Site codes are presented in table 1; na, not available; °C, degrees Celsius; m, meter; m^3/s, cubic meter per second; mm, millimeters; NAWQA, National Water-Quality Assessment Program; DO, dissolved oxygen; mg/L, milligrams per liter]

Habitat characteristics	Study sites								
	WC02	WC02	WC02	WC01	WC01	WC01	BE02	BE02	BE02
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Temperature (°C)	15.4	18.7	18.1	17.0	17.5	18.9	24.6	21.5	22.3
Depth (m)	0.11	0.16	0.16	0.08	0.12	0.08	0.06	0.07	0.16
Velocity (m/s)	0.08	0.18	0.16	0.15	0.22	0.15	0.14	0.17	0.33
Particle size (mm, 198 particles)	385	332	248	351	310	289	281	262	207
Substrate category (Wentworth scale)	8.33	8.54	8.26	9.05	8.13	8.55	8.80	8.75	7.97
Embeddedness (percent)	25	19	4	33	27	3	35	15	2
Fish cover	4	12	9	6	17	5	3	2	0
Total width (m)	4.27	6.40	6.40	4.88	4.88	5.79	5.49	6.10	7.01
Thalweg depth (m)	0.27	0.39	0.34	0.23	0.33	0.28	0.13	0.17	0.33
Channel aspect (degree)	226	223	227	144	149	146	187	188	189
Percent canopy closed (angle coverage by riparian vegetation)	98	97	93	100	99	96	38	40	50
Percent shade (visual estimate, 10–2)	70	94	85	88	94	81	7	6	6
Riparian canopy closure at stream edge (percent)	94	100	98	98	100	99	19	28	36
Bank height (m)	3.60	4.27	5.12	3.26	3.90	4.11	0.76	1.34	1.49
Bank angle (degree)	32	31	34	31	25	37	13	12	22
Bank material (Wentworth scale)	5.09	3.77	3.45	3.36	3.55	3.59	2.45	2.91	2.09
Percent bank bare	58.86	64.09	60.23	55.00	63.41	53.64	0.00	8.18	6.82
Percent bank grass	0.00	0.00	0.45	0.00	2.05	1.14	92.05	72.50	74.09
Percent bank shrub	0.00	0.00	0.00	0.00	0.00	0.00	6.82	18.86	15.23
Percent bank tree	41.14	35.91	39.32	45.00	34.32	45.68	1.14	0.00	3.86
NAWQA bank stability	15	14	16	15	13	16	8	9	9
Visual stability (0–4)	3	3	3	3	3	3	4	4	4
Rooted and stable vegetation (0–4)	3	3	3	3	3	3	4	4	4
Pool:riffle ratio	1	2	1	2	1	1	1	1	0
Average minimum DO (mg/L)	9.20	9.60	9.00	8.95	9.10	8.95	8.55	8.70	8.55
Maximum or minimum pH	6.60	6.60	6.60	6.40	6.40	6.40	7.00	7.00	7.00
Length of reach (m)	86.0	123	129	94.2	133	125	111	132	119
Streamflow day of survey (m^3/s)	0.01	0.14	0.05	0.01	0.14	0.07	0.02	0.06	0.25

Appendix 4. Raw value for each habitat characteristic at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

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Habitat characteristics	Study sites								
	BE01	BE01	BE01	BH01	BH01	BH01	CN01	CN01	CN01
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Temperature (°C)	22.4	19.5	25.0	18.0	15.1	16.0	14.9	17.8	na
Depth (m)	0.04	0.11	0.15	0.09	0.12	0.13	0.16	0.28	0.20
Velocity (m/s)	0.10	0.20	0.21	0.15	0.33	0.30	0.19	0.37	0.25
Particle size (mm, 198 particles)	306	334	273	271	246	216	14	26	49
Substrate category (Wentworth scale)	8.60	8.63	8.44	8.63	9.00	8.69	3.30	3.61	5.59
Embeddedness (percent)	40	10	4	31	24	4	19	10	16
Fish cover	2	2	0	5	1	8	34	16	17
Total width (m)	7.62	10.06	10.06	3.66	5.18	6.10	1.52	1.83	1.52
Thalweg depth (m)	0.14	0.30	0.32	0.22	0.30	0.30	0.23	0.37	0.26
Channel aspect (degree)	159	159	170	235	233	212	52	51	60
Percent canopy closed (angle coverage by riparian vegetation)	77	82	76	91	96	93	31	28	26
Percent shade (visual estimate, 10–2)	35	49	74	78	91	83	21	6	28
Riparian canopy closure at stream edge (percent)	65	78	72	93	94	96	16	6	13
Bank height (m)	1.92	2.38	2.50	1.58	2.93	2.99	0.85	0.82	0.94
Bank angle (degree)	23	31	40	18	24	25	19	14	38
Bank material (Wentworth scale)	3.77	2.36	3.64	7.09	4.27	3.09	2.36	2.64	2.55
Percent bank bare	33.41	46.36	31.82	61.05	55.68	42.95	4.55	4.09	4.32
Percent bank grass	39.77	14.32	19.55	14.64	14.77	12.73	91.36	68.86	75.23
Percent bank shrub	0.00	0.00	3.86	2.27	0.00	4.09	4.09	27.05	20.23
Percent bank tree	26.82	39.32	44.77	21.59	29.55	40.23	0.00	0.00	0.23
NAWQA bank stability	10	13	13	9	12	11	8	8	10
Visual stability (0–4)	3	2	3	3	3	3	4	4	4
Rooted and stable vegetation (0–4)	3	3	3	3	3	3	4	4	4
Pool:riffle ratio	2	0	1	1	0	0	1	0	1
Average minimum DO (mg/L)	8.55	8.70	8.55	8.60	9.40	9.05	9.08	9.40	8.80
Maximum or minimum pH	7.00	7.00	7.00	6.50	6.50	6.50	6.40	6.40	6.40
Length of reach (m)	168	209	132	113	133	123	63.4	61.9	33.5
Streamflow day of survey (m^3/s)	0.02	0.21	0.24	0.02	0.18	0.13	0.02	0.11	0.06

Appendix 4. Raw value for each habitat characteristic at nine reference reaches in the Catskill Mountain region sampled in 2002, 2004, and 2006.

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Habitat characteristics	Study sites								
	SV01	SV01	SV01	SC01	SC01	SC01	BA05	BA05	BA05
Year	2002	2004	2006	2002	2004	2006	2002	2004	2006
Temperature (°C)	19.5	18.7	21.0	19.4	18.4	NA	19.6	18.0	na
Depth (m)	0.19	0.33	0.32	0.14	0.13	0.16	0.15	0.19	0.22
Velocity (m/s)	0.13	0.37	0.47	0.19	0.37	0.33	0.08	0.18	0.29
Particle size (mm, 198 particles)	92	90	90	210	150	187	177	178	161
Substrate category (Wentworth scale)	6.53	6.30	6.73	7.25	7.86	7.94	7.43	7.79	7.31
Embeddedness (percent)	41	16	12	31	19	11	43	22	9
Fish cover	4	0	0	8	4	4	6	4	1
Total width (m)	14.63	17.37	17.37	10.06	6.71	11.58	6.40	5.79	9.75
Thalweg depth (m)	0.34	0.51	0.48	0.27	0.34	0.40	0.25	0.34	0.38
Channel aspect (degree)	300	208	210	229	226	232	252	254	237
Percent canopy closed (angle coverage by riparian vegetation)	59	56	63	86	74	76	74	68	72
Percent shade (visual estimate, 10–2)	20	17	23	63	47	78	44	31	41
Riparian canopy closure at stream edge (percent)	81	95	86	87	60	74	58	65	67
Bank height (m)	2.59	2.71	1.98	1.40	1.49	1.80	4.88	2.87	3.96
Bank angle (degree)	29	35	46	24	29	39	17	22	27
Bank material (Wentworth scale)	2.55	2.00	2.27	4.14	2.59	3.05	4.05	5.05	3.45
Percent bank bare	27.50	40.23	28.86	57.50	40.68	48.64	24.77	38.18	27.05
Percent bank grass	24.55	22.73	41.14	8.64	25.91	7.50	64.55	55.68	63.41
Percent bank shrub	35.91	16.36	16.36	3.64	7.50	2.73	8.64	3.18	3.86
Percent bank tree	12.05	20.68	13.18	26.59	25.45	41.14	1.59	2.95	5.68
NAWQA bank stability	11	13	12	11	10	12	13	11	15
Visual stability (0–4)	3	3	3	3	3	2	4	3	3
Rooted and stable vegetation (0–4)	3	3	3	3	3	3	4	3	3
Pool:riffle ratio	2	1	0	0	0	0	4	2	1
Average minimum DO (mg/L)	9.10	9.30	9.10	8.98	9.40	8.70	8.70	8.60	8.75
Maximum or minimum pH	7.10	7.10	7.10	6.50	6.50	6.50	6.90	6.90	6.90
Length of reach (m)	274	274	176	179	166	145	134	137	165
Streamflow day of survey (m^3/s)	0.28	1.83	2.32	0.15	0.39	0.51	0.05	0.23	0.45

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