Microhabitat Use by Brook Trout Inhabiting Small Tributaries and a Large River Main Stem: Implications for Stream Habitat Restoration in the Central Appalachians

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Abstract: Brook trout (*Salvelinus fontinalis)* habitat restoration is needed across a range of stream sizes; however, studies quantifying brook trout habitat preferences in streams of differing sizes are rare. We used radio-telemetry to quantify adult brook trout microhabitat use in a central Appalachian watershed, the upper Shavers Fork of the Cheat River in eastern West Virginia. Our objectives were to: 1) quantify non-random microhabitat use by adult brook trout in the Shavers Fork main stem (drainage area = 32 km^2) and an adjacent tributary, Rocky Run (drainage area = 7 km^2); and 2) construct stream-specific habitat suitability curves (HSCs) for four important microhabitat variables (depth, average current velocity, maximum current velocity within one meter, and distance to cover). Brook trout used a subset of available microhabitats in both the main stem and Rocky Run: trout tended to occupy microhabitats that were deeper, higher velocity, and closer to cover than expected by chance alone. Although specific microhabitat values differed between the main stem and tributary populations, the overall patterns in brook trout microhabitat use were consistent regardless of stream size. Habitat suitability curves were constructed based on brook trout microhabitat use and will be used to design and monitor the effectiveness of future habitat restoration efforts in the Shavers Fork watershed. Our results suggest that habitat enhancement projects that increase the availability of deep, high velocity microhabitats adjacent to cover would benefit brook trout in both small tributaries and larger river main stems.

Key words: Appalachian streams, brook trout, microhabitat use, stream restoration

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Habitat loss is a major factor contributing to declining fish populations worldwide (Karr 1991). The upper Shavers Fork is a central Appalachian stream impacted by extensive habitat alterations (Petty et al. 2001). Since the turn of the 20th century, many factors have impacted the system and degraded the aquatic habitat, including acid precipitation, sedimentation, ice scour, stream channelization, and habitat fragmentation from impassible culverts (Petty and Thorne 2005, Petty et al. 2005, Poplar-Jeffers et al. 2008). Despite these problems, there remains considerable local and regional interest in restoring the upper Shavers Fork to its historical status as a premier brook trout fishery.

Successful stream restoration requires detailed information on instream habitat conditions and fish habitat preferences at a range of spatial scales from microhabitats to whole watersheds (Petty et al. 2001, Fausch et al. 2002, Roni 2005). Statistically-based habitat surveys are a key component needed to quantify available habitat and to monitor changes induced from deleterious events and restoration efforts. Such efforts are required at the microhabitat scale, the hydraulic channel unit scale (e.g., pools and riffles), and the drainage network scale (e.g., variation in brook trout distributions among small tributaries or variation along a stream size continuum). In our study, we describe efforts to quantify brook trout habitat preferences at the microhabitat scale.

Habitat suitability curves (HSC) are important tools for evaluating stream fish habitat. HSCs are quantitative models that represent the ecological value of various microhabitat parameters, such as depth and current velocity, for stream fish (Baker and Coon 1997). They also are important components of the "instream flow incremental methodology" (IFIM), which was developed to model the effects of changing flow regimes on fish habitat (Bovee 1982, Baltz 1990). In this study we constructed HSCs for brook trout using frequency of use data standardized based on the overall availability of the microhabitat. This approach is preferred over a basic frequency of use approach because it factors in the effect of habitat availability on habitat use. However, this approach does not address the fact that microhabitat characteristics tend to co-vary and that trout microhabitat selection is a blending of multiple variables chosen to maximize energy intake while minimizing expenditure and threat from predation (Hughes and Dill 1990, Hill and Grossman 1993, Dolloff et al. 1994, Li et al. 1994). Despite this limitation, HSCs based on field data offer important insights into species' preferences either for monitoring or restoration projects (Baltz 1990).

In this study, we addressed the following objectives: 1) quantify non-random microhabitat use by brook trout in the Shavers Fork (a large river main stem) and Rocky Run (an adjacent tributary), and 2) construct habitat suitability curves for four important microhabitat variables. Information obtained from this study will be used to identify restoration priorities and monitor stream channel restoration effectiveness in recovering brook trout habitat.

Study Area

The upper Shavers Fork of the Cheat River is a large, low gradient (<1 %), high elevation central Appalachian watershed (>1500 m). We conducted fieldwork within the main stem of the upper Shavers Fork and a second order tributary, Rocky Run. The study area was located entirely within the Monongahela National Forest in central West Virginia. Land cover is dominated by a mixed deciduous-coniferous forest. Natural variation in bedrock geology and stream size produces a high degree of variability in water chemistry and habitat characteristics in this watershed (Petty et al. 2001, Petty et al. 2005). The physical and biological characteristics of the upper Shavers Fork main stem and Rocky Run study areas differ dramatically (Table 1). The main stem is relatively wide and shallow, has a low gradient and an open canopy, is warmer, and is more productive than Rocky Run and other tributaries (Bopp 2002). Rocky Run is higher gradient and narrow, has a dense canopy and a high occurrence of large boulders and large woody debris (LWD) (Table 1). Although many small streams in the watershed are acidic as a result of acid precipitation, both the main stem and Rocky Run are generally circum-neutral (i.e., possess a baseflow pH between 6.6 and 7.0).

Methods

Microhabitat Availability

We sampled microhabitat availability using protocols from Simonson et al. (1994) and Petty et al. (2001). Instream flows averaged between 1.3–1.4 m^3/sec for the majority of the time tagged trout were at large, and microhabitat availability sampling was conducted at similar flows in summer 2001. Rocky Run was considered a small tributary based on wetted stream width measurements (mean stream width (MSW) = 4.9 m) (*sensu* Simonson et al. 1994). Microhabitat measurements were taken at five evenly distributed points along transects spaced every three MSWs (transect spacing = 15m). A total of 28 transects were distributed across a 405-m long study reach on Rocky Run that began approximately 100 m upstream of the tributary mouth. This resulted in 140 microhabitat quadrats sampled in Rocky Run. The Shavers Fork main stem was considered a large stream based on wetted stream width (MSW = 14 m). Microhabitat was sampled at five evenly spaced locations along 80 transects spaced every two MSWs (transect spacing = 28m). The main stem study reach was 2,212 m long with a total of 400 microhabitat quadrats sampled. The mid-point of the main stem study reach was located at the Rocky Run confluence. A greater sample area was needed in the main stem in order to encompass the range of movements exhibited by tagged trout.

Table 1. Summary statistics for the mainstem of the Shavers Fork and the adjacent study tributary, Rocky Run, within the boundaries of the study area. Numbers within parentheses represent minimum and maximum value ranges. Summer temperatures are based on average daily temperatures measured from 1 June–31 August.

Parameters	Rocky Run	Shavers Fork
Basin area (km^2)	7	32
Wetted width (m)	5.0 (3–11)	14.3 (10–32)
Canopy cover (%)	70 (33–90)	24 (10–40)
Summer temp. (C)	16 (12–19)	19 (15–23)
pH	6.4 (5.6–7.2)	6.7 (6.2–7.4)
Alkalinity (mg/L CaCO3)	11.2 (4–22.8)	51.1 (22–136)
Benthic macroinvertebrate density (n/m^2)	2770 (1800–3750)	4866 (2900–6100)
Benthic macroinvertebrate biomass (mg/m^2)	220 (80–550)	493 (300–700)
Brook trout density (*n*/m)	0.60 (0.30–1.02)	0.06 (0.03–0.10)
Brook trout age structure		
YOY (%)	30	14
Small adults(<150mm, %)	54	46
Large adults (>150mm, %)	16	40
Fish species richness	6	18

At each location along a sample transect we measured the following variables: average current velocity (AVCV) (+ 1 cm/s), water depth (+ 0.5 cm), and distance to nearest cover item (DTC) (+ 0.1 m). ACVC was defined as the current velocity at 0.6 of the total depth and was measured with a Marsh-McBirney flow meter. Cover items were defined as any object capable of concealing a 170-mm long fish and were categorized as boulder, LWD, or undercut bank. Water temperature was measured with HOBO remote temperature loggers anchored in the stream bottom. One temperature logger was placed at the downstream end of the Rock Run study area and another at the downstream end of the main stem study area.

Trout Microhabitat Use

Brook trout microhabitat use was quantified over a period of 70 days during each of three separate seasons: summer 2000 and 2001 (5 June–15 August), and fall 2000 (5 September–15 November). Trout used for the study were initially captured with electrofishing techniques. Tagged fish were captured within study reaches and returned after surgery as close to their original location as possible. During each season, eight brook trout were tagged and monitored for microhabitat use in Rocky Run and 20 in the main stem. A greater number were tagged in the main stem because of our expectation that movement rates, and therefore fish disappearance rates, would be higher in the main stem than the tributary.

Trout were surgically implanted with internal radio transmitters following protocols derived from multiple sources (Courtois 1981, Ross and Kleiner 1982, Winter 1983, Swanberg 1997) and were handled according to the guidelines of the West Virginia University Animal Care and Use Committee (protocol # 9801-12). Clove oil was used as an anesthetic and antiseptic for the surgery (Anderson et al. 1997). Some fish were held to ensure proper post-surgery recuperation, but none were held longer than a total of 24 hours after surgery. Transmitters (Lotek Industries, MBFT series) weighed 1.8 to 2.0 grams and transmitted at frequencies every 0.010 MHz between 149.540 and 150.720 MHz. In order to comply with the "modified Winter rule" of 2.5% body weight for maximum transmitter weight, all tagged fish were larger than 72 grams (approximately 170 mm standard length) (Winter 1983, Matthews 1996).

To ensure full recovery and resumption of normal behaviors, tracking was initiated one week after tagging. All fish at large for each season were located with a Lotek SRX 600 Datalogger receiver at least twice per week between 0600 hours to 2100 hours. An exhaustive effort was made throughout each track to locate all tagged trout. If a fish was not located during three consecutive tracks it was considered lost either from predation, harvest, or emigration. To minimize the effect of the time of day on habitat use, a random starting point within the study area was chosen to begin each daily track ensuring all tagged trout were encountered at varying times throughout the day. The accuracy of trout relocations via telemetry was estimated to be approximately 0.75m (Hansbarger 2005). However, most (95% of observations) trout were relocated visually.

Upon locating each tagged fish we measured: focal point temperature, average current velocity (AVCV), focal point current velocity (FPCV), water depth (D), maximum current velocity within 60cm (MCV), distance to cover (DTC), and cover type. Focal point refers a position held by a drift feeding fish that is returned to after excursions to catch passing prey (Hughes and Dill 1990).

Statistical Analyses

Our first objective was to quantify microhabitat use by trout and determine if they used a non-random subset of available microhabitats in Shavers Fork and Rocky Run. As an initial step, we constructed frequency distribution histograms of habitat availability and use by brook trout separately for each microhabitat variable in each stream. We then used X^2 analysis to test the null hypothesis of no significant differences between microhabitat use and availability (α = 0.05). To minimize bias from multiple observations of the same individuals, we randomly selected five observations from each individual for these analyses. All trout were observed at least five times in each season.

Our second objective was to construct HSCs for four important microhabitat variables. For each variable of interest (ACV, MCV, depth, and DTC), frequency of use data was divided by availability data for each category of values (e.g., 5 cm/sec, 10cm/sec, etc.). The largest ratio obtained was divided into all other values for that variable, standardizing all categories to a value of 1. This gave microhabitat categories used the most a score of 1 (optimal habitat), with all others a fraction of this based on the observed use/availability ratio. We did not record MCV during the availability measurements. Consequently, to create the associated HSCs, we standardized all use observation categories by dividing all by the largest frequency of use category value.

Results

Microhabitat availability differed significantly between Rocky Run and the Shavers Fork main stem (Table 2). In general, the main stem possessed slightly higher average current velocities (X^2 = 38.2, df = 5, P < 0.001) and greater depths (X^2 = 44.8, df = 4, P < 0.001) than Rocky Run. In addition, microhabitat quadrats were

Table 2. Mean (±SE) mircrohabitat availability and use by brook in Rocky Run and the Shavers Fork mainstem. Maximum current velocity refers to the maximum current velocity available within 0.6 m of a focal position. This measure was not taken during availability sampling (ND = no data). Cover was defined as any object (upstream or downstream) capable of concealing a large adult brook trout (> 170 cm).

	Depth (cm)	Avg. current velocity (cm/sec)	Maximum current velocity (cm/sec)	Distance to cover (m)
Rocky Run				
Availability	11 (0.9)	15 (1.3)	ND	1.0 (0.7)
Brook trout				
Spring 2000	15 (0.8)	19 (1.6)	38 (1.5)	1.8 (0.3)
Fall 2000	17 (0.4)	23 (0.6)	29 (0.4)	0.8 (.06)
Spring 2001	18 (0.9)	26 (1.0)	36 (1.2)	0.3 (0.1)
Shavers Fork				
Availability	17 (0.6)	22 (0.7)	ND	2.0 (0.1)
Brook trout				
Spring 2000	23 (1.1)	25 (1.2)	39 (1.5)	4.5 (0.4)
Fall 2000	20 (0.6)	25 (1.1)	31 (1.5)	0.6 (0.3)
Spring 2001	22 (0.7)	26 (0.8)	36 (0.8)	0.5 (0.1)

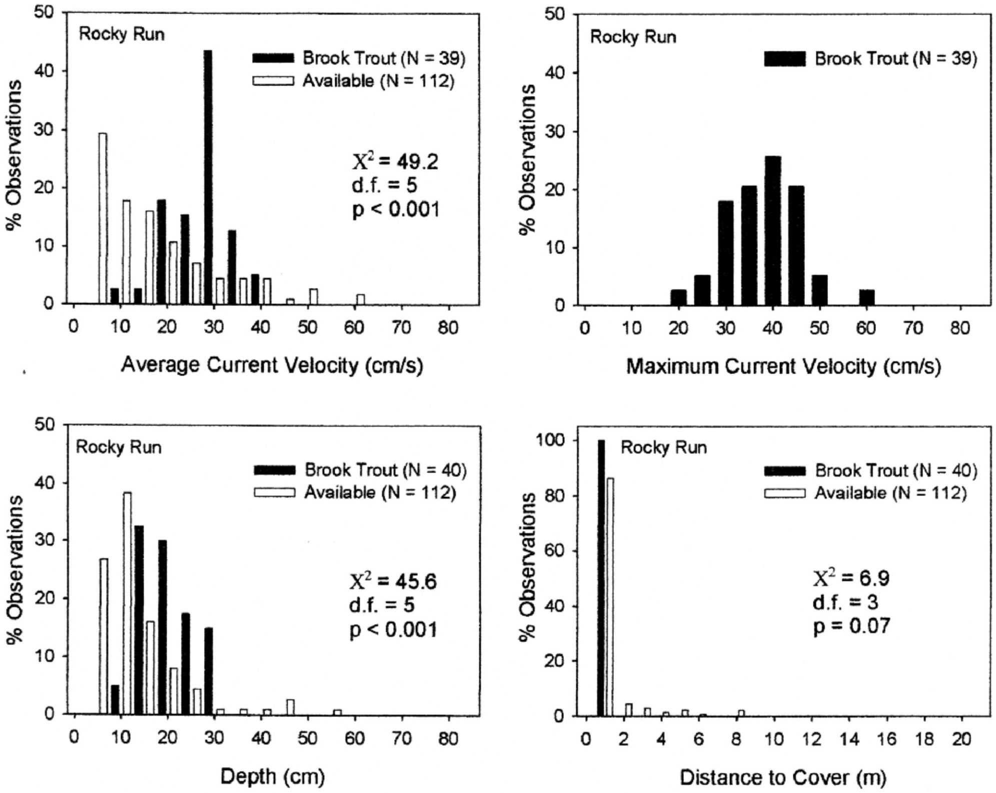

Figure 1. Microhabitat use by brook trout and availability of average current velocity, maximum current velocity within 60 cm, depth, and distance to cover in Rocky Run, summer 2001. Also presented are results of X^2 analyses comparing microhabitat use to availability. No statistical test of maximum current velocity was run due to a lack of availability data.

significantly closer to cover items in Rocky Run than in the main stem ($X^2 = 12.1$, df = 3, $P < 0.001$) (Table 2).

Patterns in microhabitat use by brook trout were similar among seasons. Hence, for brevity we present results for summer 2001 only. Despite differences in microhabitat availability between the main stem and tributary, microhabitat use by brook trout was consistent between the two study areas (Table 2, Figures 1, 2). Brook trout demonstrated a consistent preference for deeper, higher velocity microhabitats than expected by chance alone in both Rocky Run and main stem reaches (Figures 1, 2). Also, brook trout avoided microhabitats located far from protective cover, and this was especially true for brook trout inhabiting Rocky Run where fish were never observed greater than 1 m from a cover item (Figure 1).

Although the overall patterns in microhabitat use were consistent between Rocky Run and the main stem, specific attributes of brook trout microhabitat preferences differed measurably between the two study areas. These differences are best illustrated by the site-specific HSCs developed for brook trout (Figure 3). In Rocky Run, preferred brook trout microhabitats tended to have the following characteristics: average current velocities ranging from 25–35 cm/sec; maximum current velocities ranging from 30–45 cm/sec; water depths ranging from 25–30 cm, and cover objects within 1 m. In all cases, HSCs for Rocky Run were unimodal (Figure 3). In the main stem, brook trout HSCs were more complex. The maximum current velocity HSC in the main stem was very similar to Rocky Run. HSCs for average current velocity and water depth, however, were bimodal in the main stem (Figure 3). HSCs exhibited one peak at current velocities and depths similar to those observed in Rocky Run and a second peak at a higher velocity (45–50 cm/sec) and greater depth (55 cm) (Figure 3). Also, there was a tendency for brook trout in the main stem to occupy microhabitats further from cover (up to 5 m) (Figure 3).

Discussion

Our findings are generally consistent with previous studies of trout microhabitat use (Flebbe and Dolloff 1995, Young 1995, Baker and Coon 1997). Most studies have found that trout preferentially select deeper, higher velocity microhabitats located in close proximity to cover objects. Mechanistic studies of trout habitat use (Hughes and Dill 1990, Hill and Grossman 1993) have shown that trout select microhabitats that maximize net energy intake. Deep, high velocity microhabitats provide maximum access to drifting food items. Cover objects nearby provide low velocity resting positions, opportunities for ambush feeding on small fishes, and protection from avian and aquatic predators (Hughes and Dill 1990, Flebbe and Dolloff 1995, Young 1995).

A central finding from our study was that microhabitat use by brook trout was similar for fish residing in the small tributary and the larger river main stem. Initially, we expected microhabitat use to differ between the streams because of significant differences in

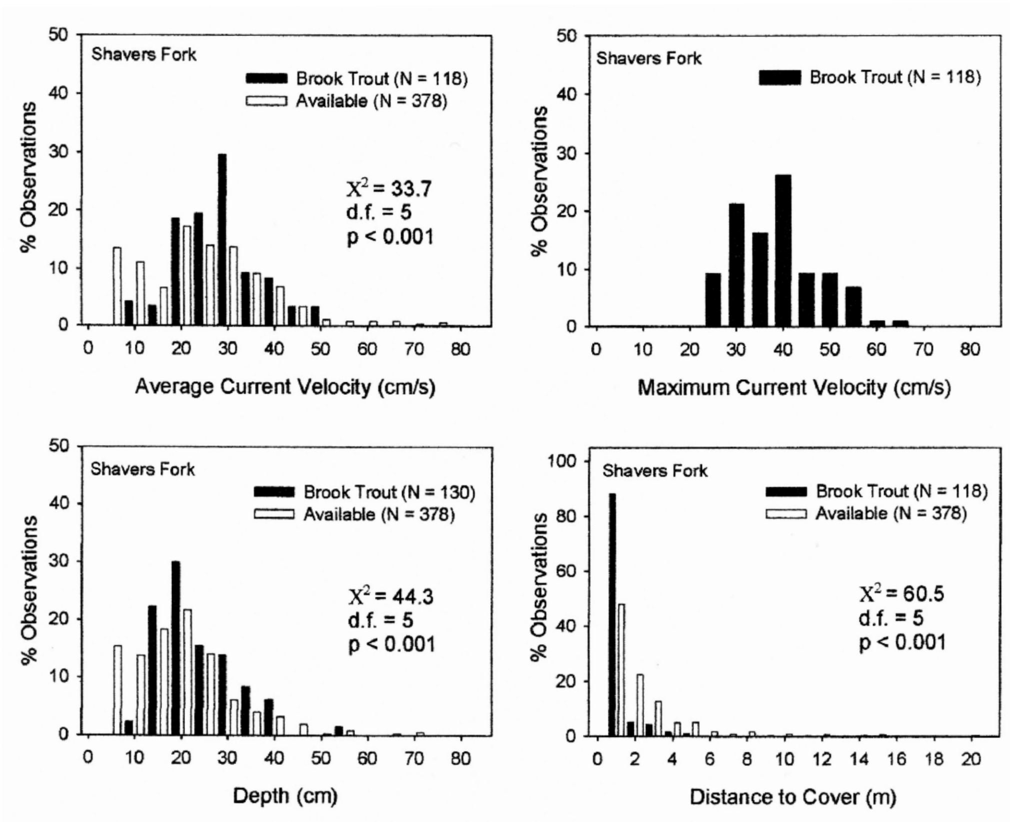

Figure 2. Microhabitat use by brook trout and availability of average current velocity, maximum current velocity within 60 cm, depth, and distance to cover in the Shavers Fork main stem, summer 2001. Also presented are results of X^2 analyses comparing microhabitat use to availability. No statistical test of maximum current velocity was run due to a lack of availability data.

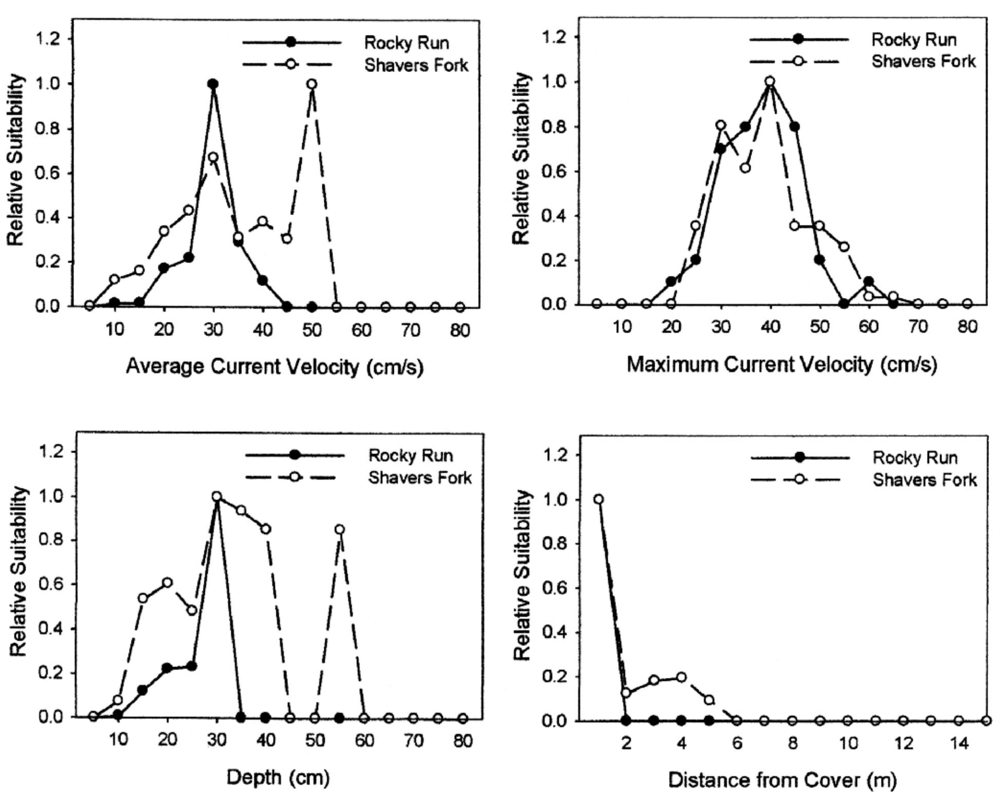

Figure 3. Habitat suitability curves for brook trout for average current velocity, maximum current velocity within 60 cm, depth, and distance to cover in Rocky Run and the Shavers Fork main stem summer 2001.

the habitat characteristics of each stream. Similar microhabitat use despite differences in habitat availability suggests that the benefits of preferred microhabitats remain constant along a continuum from small headwater tributaries to larger segments downstream. These results, along with previous research (Petty et al. 2005), support the hypothesis that large adult brook trout move throughout the upper Shavers Fork watershed and select the highest quality microhabitats available in the watershed. This occurs regardless of whether the microhabitats are located within a small tributary or within the larger river main stem.

The bimodal HSCs that we observed for brook trout inhabiting the Shavers Fork main stem were unexpected. To our knowledge, all published HSCs for brook trout have tended to be unimodal and very similar to the patterns that we observed in Rocky Run (see Baker and Coon 1997 for examples). The bimodal HSCs in the main stem were produced by a high degree of preferential use of rare microhabitats that combined depths exceeding 50 cm and current velocities exceeding 40 cm/sec. In Rocky Run, these microhabitat characteristics do not occur simultaneously. Extremely deep microhabitats in Rocky Run tend to be associated with large, low velocity pools. In the Shavers Fork main stem, however, high velocity bluff pool – run complexes often occur on the outside edge of stream meander bends (JT Petty unpublished data). Within these channel units you will often find microhabitats characterized by a unique combination of exceptional depth and high current velocity (Petty et al. 2001). The results of our current study suggest that these are especially valuable habitats for large adult brook trout inhabiting the Shavers Fork main stem. Our results also suggest that habitat enhancement projects that seek to increase the availability of this microhabitat type may greatly benefit brook trout populations in this system.

Baker and Coon (1997) argued that microhabitat use by brook trout in Hunt Creek was unconstrained by predator avoidance due to a lack of both avian predators and piscivorous fishes. However, we frequently observed belted kingfishers (*Ceryle alcyon*) and great blue herons (*Ardea herodias*) actively feeding along the upper Shavers Fork main stem. Also, large brown trout are present in many of the larger pools and runs and present another predator which could influence habitat selection by brook trout. These predators are rare or absent in Rocky Run, and consequently, we would have expected brook trout to be found further from cover in the tributary than in the mainstem. We found, however, the opposite was true: there was a greater tendency for brook trout to use microhabitats further from cover in the main stem than in the tributary. We can think of two possible explanations for this finding. First, the main stem was more likely to experience brief periods of increased turbidity following rainfall events than Rocky Run. Consequently, it is possible that brook trout residing in the main stem use periods of elevated turbidity to access feeding areas further from cover. Second, because the main stem is significantly more productive than the tributary (i.e., has more food available), brook trout may be willing to accept a greater amount of risk from predation in the main stem. This explanation is consistent with previous studies showing that fishes attempt to maximize the ratio between energy intake and predation risk (Gilliam and Fraser 1987). Nevertheless, despite greater distances to cover for main stem trout, brook trout were never observed to occupy a microhabitat that was further than 5 m from a cover item.

We know that water temperature is a critical factor influencing habitat selection by stream dwelling salmonids (Bermen and Quinn 1991, Kaeding 1996, Torgersen et al. 1999), and this is true of brook trout residing in the upper Shavers Fork as well (Hansbarger 2005). Whenever instream temperature levels exceed 20 C, large adult brook trout use a subset of preferred microhabitats in the upper Shavers Fork (Hansbarger 2005). During critical thermal periods brook trout select preferred microhabitats close to cover and adjacent to tributary outflows, later groundwater seeps, and instream hyproheic upwelling zones (Hansbarger 2005). This type of thermo-regulated behavior is well documented in stream dwelling trout (Swanberg 1997, Bunnell et al. 1998). Interestingly, behavioral adjustments to high water temperatures do not affect the physical characteristics (e.g., depth and current velocity) associated with microhabitats used by brook trout in the main stem. Brook trout simply use preferred microhabitats in areas of coldwater inputs (Hansbarger 2005). This behavior, however, results in a highly constrained distribution of brook trout during periods of high water temperatures: brook trout are constrained to areas that combine preferred microhabitats with tolerable water temperature (< 20 C)

An important shortcoming of this study is that our results apply only to large adult brook trout. This study was part of a larger study examining the distribution and movement behaviors of brook trout in the upper Shavers Fork watershed (Hansbarger 2005, Petty et al. 2005). Radio-telemetry was a central component of this study, and consequently, we were not able to effectively tag and track smaller individuals. Future studies will need to consider the microhabitat use behaviors of juvenile and small adult brook trout, and how this may affect stream restoration decisions.

In conclusion, the results of this study provide an objective, quantitative baseline upon which stream channel restoration projects can be designed to enhance brook trout habitat in the upper Shavers Fork watershed. We have determined that microhabitat preferences of large adult brook trout are consistent between small tributaries and the large river main stem. We have also determined that any habitat enhancement projects should attempt to increase the availability of deep, high velocity microhabitats that are in close proximity to instream cover items. Given findings from other, related research (Hansbarger 2005, Petty and Thorne 2005, Petty et al. 2005) a successful brook trout restoration program in this system must recognize: 1) the complementary interrelationships between small tributaries as spawning habitat and the larger main stem as productive foraging habitat, 2) the overriding influence of water temperature as a determinant of habitat quality in the main stem, and 3) the need to remove dispersal barriers so that brook trout can move freely between tributaries and the main stem. In doing these things, then habitat enhancement projects will have the greatest potential for improving brook trout productivity within the upper Shavers Fork.

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