Quantifying Instream Habitat in the Upper Shavers Fork Basin at Multiple Spatial Scales

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Abstract: Brook trout *(Salvelinus fontinalis)* populations in the upper Shavers Fork, a high elevation watershed in eastern West Virginia, have been severely impacted by a loss of quality habitat. Successful restoration of these populations will require a comprehensive understanding of current habitat conditions at a watershed scale. We describe a statistically based habitat survey designed to quantify physical habitat conditions within the watershed at a range of spatial scales. Our study also addresses the following specific objectives: 1) to describe discrete hydraulic channel units that commonly occur in our study area, and 2) to identity statistical differences in the microhabitat characteristics among each of the channel unit types. We identified 5 recurring channel unit types within the basin: bluff pool complexes, riffle-run complexes, intermediate gradient riffles, low gradient riffles, and glides. Univariate and multivariate statistical analyses indicated that there were consistent, interpretable differences in the microhabitat characteristics of each channel unit type. Specifically, we found that channel units were most easily differentiated on the basis of variables that describe channel complexity (depth and distance to cover), stream flow (current velocity), and substrate composition. Statistically based habitat surveys, such as the one we present here, provide the basis of stream habitat management plans, and our results represent an important first step in efforts to restore a productive brook trout fishery to the upper Shavers Fork drainage.

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Loss of essential habitat is one of the most pervasive factors influencing stream fish populations in North America (Karr 1991). The Shavers Fork of the Cheat River, a high elevation (>1100 m) river located in the Appalachian Mountains of eastern West Virginia, is an example of a system that has undergone substantial changes in its physical and biological characteristics. Historically, this drainage supported one of the most productive brook trout *(Salvelinus fontinalis)* fisheries in the region. However, intensive logging in the drainage since the turn of the 20th century, along with more recent surface mining activities, have led to dramatic changes in stream channel morphology and associated fish populations.

Because of its historical value as a premier native brook trout fishery, there is considerable local and regional interest in restoring stream habitat conditions in the Shavers Fork to historical standards. Successful restoration efforts, however, require detailed information on instream habitat conditions and fish habitat preferences at a range of spatial scales (Frissell et al. 1986, Rabeni and Sowa 1996, Nislow et al. 1999). Statistically based habitat surveys are needed to quantify the types of habitats that are available in a system and to determine the geomorphic processes and fluvial forces that create them (Rabeni and Jacobson 1993). In addition, quantitative habitat inventories are needed to evaluate the effectiveness of habitat restoration programs and to monitor changes in habitat quality resulting from management decisions (Dolloff et al. 1997).

Unfortunately, it is very difficult to obtain detailed information on habitat quality simultaneously at large and small spatial scales. Nevertheless, habitat restoration efforts increasingly focus at the watershed scale, and statistically based habitat surveys conducted over a large area are necessary to make important management decisions. Here, we describe a habitat sampling procedure designed to quantify instream habitat conditions in the upper Shavers Fork drainage basin at 3 spatial scales: microhabitat (1 m), channel unit (e.g., pools and riffles) (10–50 m), and stream segment (10–20 km). The general design combines elements of the Representative Reach Extrapolation Technique (RRET) and the Basinwide Visual Estimation Technique (BVET) described by Dolloff et al. (1997). Our design provides a statistically rigorous approach to extrapolating detailed microhabitat data obtained from representative study reaches to the entire basin.

In addition to presenting our general habitat survey design, we address the following specific objectives: 1) to identify discrete hydraulic channel units that commonly occur in our study area, 2) to provide quantitative descriptions of each channel unit type, and 3) to identity statistical differences in the microhabitat characteristics of hydraulic channel units. Our results are an important first step in our effort to restore critical fish habitats to the upper Shavers Fork drainage.

Methods

Study Area

Our study area consists of a 32-km stretch of the upper Shavers Fork drainage basin located in the central Appalachian Mountains of eastern West Virginia (Pocahontas and Randolph counties). The watershed surrounding the upper Shavers Fork is part of the Monongahela National Forest and is comprised of a mixed deciduous-coniferous forest. The abandoned logging town of Spruce, West Virginia (1197 m elevation), demarcates the upper extent of the study site. The study site extends downstream to the U.S. Route 250 bridge at 1099 m elevation. This section of the Shavers

Fork is characterized by low to intermediate gradient reaches (0.8–1.7% slope). Average width of the Shavers Fork mainstem varies from 10 m at the upper extent to 30 m at the downstream boundary. Average depths range from 30 cm upstream to 68 cm downstream, and dominant substrates are comprised of cobble and gravel with occasional pockets of intermediate sized to large boulders.

Multi-scale Habitat Sampling Design

The success of future restoration efforts in the drainage depends on a comprehensive knowledge of current habitat conditions and the fluvial and geologic processes that control habitat availability. Our habitat sampling procedure is designed to provide information on instream conditions and the forces that create them at multiple spatial scales (Fig. 1). First, our study area was divided into 3 regions (upstream, midstream, and downstream) that differ significantly in stream width and relative discharge. The upstream region is the area upstream of Second Fork (average width = 10 m), the midstream region is below Second Fork and above First Fork (average width = 18 m), and the downstream region is below First Fork (average width = 26 m) (Fig. 1a). Along the entire course of the study area, we have mapped instream channel units or discrete physical spaces in the stream (e.g., pools, riffles, glides, etc.) (sensu Bisson et al. 1982, Rabeni and Jacobson 1993). This information was used to quantify the relative availability of specific channel types that consistently recur throughout the basin.

Second, habitat and channel morphology measurements were taken along transects spaced every 300 m throughout the entire basin (Fig. 1b). Measurements along these transects include channel unit type, channel width, stream width, average depth

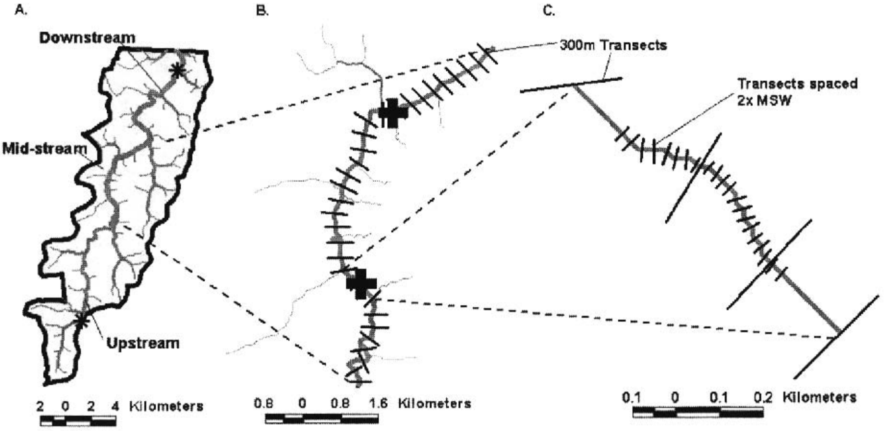

Figure 1. Illustration of our general habitat sampling procedure designed to quantify instream habitat conditions at multiple scales. MSW = Mean Stream Width. Please see text for a detailed description of the sampling design.

and current velocity (measured at 3 equidistant points along each transect), substrate particle size, and streamside vegetation and surficial lithology. Information obtained from these measurements was used to identify instream (e.g., large woody debris and boulders) and streamside (e.g., bedrock outcrops and point bars) geomorphological features that may control the occurrence of specific channel units along the river gradient.

Finally, detailed microhabitat measurements were taken along transects within each of 6 representative study reaches spaced throughout the study area (Fig. 1c). Reach delineation and transect spacing protocols followed the guidelines of Simonson et al. (1994). Along each transect the following channel and streamside features were measured: channel unit type, channel width, stream width, and riparian cover. At 5 equidistant points along each transect we also measured the following microhabitat variables: depth, bottom current velocity, average current velocity, and % substrate composition within a 400 cm^2 quadrat. These procedures provide important quantitative descriptions of microhabitat characteristics within specific channel units that can be extrapolated to describe habitat conditions in areas outside of the representative study reaches. Extrapolation errors are reduced, however, because our microhabitat sampling is stratified with regard to region (e.g., upstream, midstream, and downstream) and channel unit type (e.g., pool, riffle, glide, etc.).

Statistical Description of Hydraulic Channel Units

The primary objective of our study was to identify commonly occurring hydraulic channel units in the Shavers Fork and make statistical comparisons among them. Because the types of channel units available to fishes were most variable in the midstream region, we focused our sampling efforts in 2 representative reaches of this region (Fig. 1b). Both representative reaches were sampled on 23 May 2000. Stream flow at this time was stable at a level just under the mean annual flow.

Channel unit classification within each reach was hierarchical following a modification of Bisson et al. (1982). Ultimately, we based visual channel unit classifications on channel width, hydraulic characteristics (depth, velocity, and turbulence), and the degree of lateral (i.e., within unit) variability. To be recognized as a distinct channel unit, the length of the channel unit had to exceed the average wetted width (Arend 1999).

To quantify the microhabitat characteristics of specific channel unit types, we measured microhabitat variables at 5 equidistant locations along 21 transects placed in each reach. Following the guidelines of Simonson et al. (1994) transects were spaced every 2 mean stream widths, giving a total reach length of 40 mean stream widths (Fig. 1c). In the midstream region of the Shavers Fork, this resulted in a total reach length of approximately 800 m. This spacing ensures adequate coverage of the available habitat sequences in streams that are greater than 5 m wide (Simonson et al. 1994). At each transect we measured channel width and stream width. At each point along a transect we recorded the channel unit type, and measured water depth, bottom current velocity (BCV), average current velocity (ACV, i.e., current velocity at 60% of the depth), and percent substrate composition based on a modified Wentworth scale. Current velocities were measured (±1 cm/second) with a Marsh-McBirney Model 501 electromagnetic flow meter. Substrate composition was estimated visually within a 400 cm^2 quadrat. In addition to these measures, we also estimated the distance (in meters) from each microhabitat point to the nearest cover object. Because adult brook trout are our ultimate target species for habitat restoration, we defined cover as any object (boulder, woody debris, undercut bank) large enough to conceal a 15–20 cm fish.

Statistical Analyses

We used a combination of univariate and multivariate tests to quantify statistical differences in the microhabitat characteristics of channel units that commonly occur in the upper Shavers Fork. The objective of these tests was to determine if distinct channel units could be properly identified using visual estimation techniques. In addition, our statistical tests were used to classify channel units on the basis of quantitative microhabitat measurements.

To meet these objectives we performed 4 separate statistical tests ($\alpha = 0.05$ unless otherwise noted). First, we used 1-way ANOVA and post-hoc Tukey Tests to assess statistical differences in univariate microhabitat variables among the five channel unit types. Physical variables tested included depth, average current velocity, distance to cover, and % substrate composition (boulder, cobble, gravel, sand, silt, debris). Separate tests were run for each microhabitat variable. Data from both reaches, however, were pooled to ensure adequate sample sizes. All analyses were conducted on transformed data (log-transformation for depth, distance to cover, and current velocity data and arcsine transformation for % substrate composition data) to meet normality and homogeneous variance assumptions of parametric tests.

Second, we used Multivariate Analysis of Variance (MANOVA) to assess statistical differences in microhabitat variables among channel unit types. Physical variables listed above for the univariate ANOVA were included in the multivariate tests.

Third, we used Principal Component Analysis to identify microhabitat variables that best differentiated among the different channel unit types. Principal component scores were then calculated for each channel unit type and used in the ANOVA and Tukey Tests to test for pair-wise statistical differences among types (Petty and Grossman 1996, Thompson et al. 2001).

Finally, we used stepwise linear discriminant function analysis for each of the 5 channel unit types and multivariate misclassification analysis to determine if the channel unit types could be objectively differentiated on the basis of multiple microhabitat variables (Jowett 1993). This procedure was also used to determine which microhabitat variables were the most consistent predictors of channel unit type in the Shavers Fork.

Results

Through a hierarchical classification procedure based on channel width, depth, current velocity, turbulence, and the degree of lateral (i.e., within unit) variability, we

Table 1. Description of commonly occurring hydraulic channel units in the Upper Shavers Fork drainage basin.

Hydraulic channel unit	Distinguishing features
Bluff pool complex	Bluff Pool Complexes are defined by their structural complexity and high variability of microhabitat characteristics. This HCU is formed when bedrock or boulder bluffs confine the stream channel producing a HCU that is generally deep with low current velocity, and short distance to cover. Bluff pool complexes provide fish with a variety of foraging microhabitats and are likely important refugia during drought and winter (Rabeni and Jacobson 1993).
Riffle-run complex	Riffle-run complexes are heterogeneous HCUs that contain microhabitats generally associated with riffle and run habitats in a complex mosaic. Depth and current velocity are intermediate and distance to cover is low. Deep pockets are common along with a wide range of cover including large woody debris and boulders. The structural complexity of these channel units and their value as sites for macroinvertebrate production create important fish habitats.
Intermediate gradient riffle	Mostly homogeneous channel unit. Microhabitats within intermediate gradient riffles are characterized by high current velocities, shallow depths, long distance to cover, and substrates dominated by cobble and gravel. These HCUs likely are important sources of macroinvertebrate production, however lack of sufficient cover limits their value to drift-feeding fishes.
Low gradient riffle	Very homogeneous channel unit dominated by cobble, gravel, and sand substrata. These HCUs are shallow with intermediate current velocities and long distance to cover measurements. Shallow depths and lack of cover likely limit fish use of these habitats.
Glide	Homogeneous channel units. Glides have an undefined thalweg and surface turbulence is minimal. Microhabitats are moderately deep and current velocity is low, however distance to cover is high indicating a lack of structural complexity. Glides may serve as juvenile fish habitat.

identified 5 recurring hydraulic channel units: bluff pool complexes, riffle-run complexes, intermediate gradient riffles, low gradient riffles, and glides (Table 1). Both the bluff pool complexes and the riffle-run complexes tended to have a substantial amount of variability at a microhabitat scale. Consequently, these units fit the description of a "habitat complex" described by Bisson et al. (1982) and Hankin and Reeves (1988). The low and intermediate gradient riffles and glides, in contrast, tended to possess much more homogeneous habitat conditions (Table 1).

Univariate and multivariate statistical analyses of microhabitat data generally supported our visual classifications of channel unit types. The MANOVA test indicated that there were strong statistical differences in microhabitat characteristics among the 5 channel unit types ($F = 7.46$, $P < 0.01$). Hence, the 9 microhabitat variables analyzed together provided an effective means for discriminating among the channel types. One-way ANOVAs conducted on each microhabitat variable separately indicated that, although each of the nine of variables played a role in discriminating among channel units, the best discriminators tended to include depth, distance to cover, and % silt (Table 2).

Principal Component Analysis of the microhabitat data set extracted 2 significant (i.e., eigenvalues > 1.0) components (Table 3). Principal Component 1 repre-

Table 2. Mean (± S. E.) microhabitat values for each of the 5 commonly occurring hydraulic channel units in the Upper Shavers Fork. Also presented are summary statistics (*F*-statistic and *P*-value) for ANOVA tests. Letters identify channel units that differ significantly (Tukey's HSD, $P < 0.05$) for each microhabitat variable.

	Bluff Pool complex		Riffle Run complex		Intermediate gradient riffle		Low Gradient riffle		Glide			
Variable	*N*	Mean(S.E.)	*N*	Mean(S.E.)	*N*	Mean(S.E.)	*N*	Mean(S.E.)	*N*	Mean(S.E.)	*F*	*P*-value
Depth (cm)	48	44 (4.5)A	50	26 (1.4)B	28	15 (1.2)C	24	18 (1.8)C	55	21 (1.4)C	14.1	<0.01
Avg. Vel. (cm/s)	48	15 (1.5)A	50	25 (2.6)B	28	39 (4.4)B	24	25 (3.1)B	55	22 (1.5)B	6.0	<0.01
Dist_Cov. (m)	48	6 (0.7)A	50	5 (0.5)A	28	14 (1.7)B	24	17 (1.9)B	55	17 (1.9)B	25.7	<0.01
% Boulder	48	26 (3.7)A	50	30 (4.7)A	28	6 (2.0)B	24	10 (3.5)B	55	11 (2.9)B	7.9	<0.01
% Cobble	48	31 (3.5)B	50	34 (3.5)B	28	64 (2.3)A	24	41 (5.0)B	55	43 (3.0)B	9.4	<0.01
% Gravel	48	13 (1.6)B	50	12 (1.2)B	28	19 (1.4)A	24	16 (3.2)B	55	14 (1.3)B	2.8	0.03
% Sand	48	12 (1.5)A	50	13 (1.9)A	28	6 (0.7)A	24	23 (3.7)B	55	20 (1.9)B	8.4	<0.01
% Silt	48	13 (1.0)A	50	7 (0.5)B	28	4 (0.8)B	24	7 (1.0)B	55	9 (0.7)B	17.5	<0.01
% Debris4	48	7 (1.0)A	50	4 (0.7)B	28	2 (0.6)B	24	3 (0.7)B	55	5 (0.8)B	5.8	<0.01

sented a cover/depth/substrate axis where high positive scores describe microhabitats that are deep, closer to cover, and possess high percentages of boulder and silt. In contrast, negative component scores describe microhabitats that are shallow, further from cover, and possess high quantities of cobble and gravel (Table 3). Principal Component 2 represented an erosional/depositional continuum with negative values characterizing microhabitats with high current velocities and low amounts of sand, silt, and debris (Table 3).

Analysis of Variance tests conducted on mean factor scores indicated that there were significant differences in the microhabitat characteristics among channel unit types (PC1: F = 32.7, $P < 0.01$; PC2: F = 5.8, $P < 0.01$) and that these differences were generally consistent with findings from ANOVAs conducted on univariate datasets. Post hoc Tukey's tests of the Component 1 and 2 data illustrate the following specific differences in habitat characteristics among the five channel units (Fig. 2). (1) Bluff pool complexes are significantly deeper and possess shorter distances to cover than any of the other channel units. Low current velocities and high quantities of depositional substrata relative to intermediate gradient riffles and riffle-run complexes further characterize these channel units. (2) Riffle-run complexes are characterized by intermediate depths and distances to cover and high current velocities. Riffle-run complexes cannot be distinguished from intermediate gradient riffles on the basis of Principal Component 2, but strong differences exist among these channel units with regard to depth and distance to cover (i.e., along Principal Component 1) (Fig. 2). (3) Glides and low gradient riffles are statistically indistinguishable along both Principal Components (Fig. 2). Both channel units possess longer distances to cover and shallower microhabitats than the bluff pool and riffle-run complexes. In addition, glides and low gradient riffles are characterized by low current velocities and high amounts of depositional substrata (Fig. 2). (4) Intermediate gradient riffles are shallow, have long distances to cover, high current velocities, and low amounts of depositional substrata. Although intermediate gradient riffles differ significantly for the other channel units along Principal Component 1, they cannot be distinguished from riffle-run complexes on Principal Component 2 (Fig. 2).

Finally, stepwise discriminant function analysis entered 6 variables into a final model used to maximize statistical separation among channel unit types: distance to cover ($R^2 = 0.340$), % silt ($R^2 = 0.252$), % sand ($R^2 = 0.142$), depth $R^2 = (0.114)$, % boulder ($R^2 = 0.061$), and average current velocity ($R^2 = 0.058$). This result indicates that a combination of structural (distance to cover and depth), flow (average current velocity), and substrate (% sand, silt, and boulders) variables are required to effectively discriminate among channel units in the Shavers Fork. Misclassification analysis of these data demonstrated that individual microhabitats could be accurately classified into hydraulic channel units for most habitat types (Table 4). This was particularly true for bluff pool complexes, intermediate gradient riffles, and glides. Despite generally accurate classifications overall, misclassification was prevalent for low gradient riffles, which were often misclassified as intermediate gradient riffles and glides (Table 4).

Table 3. Factor loadings for Principal Components 1 and 2. Only factor loadings $> |0.4|$ are presented.

	Principal Component 1	Principal Component 2
Eigenvalue	2.5	2.0
% Contribution	27.3	22.1
Depth	0.510	—
Avg. Velocity	—	–0.687
Dist. to cover	–0.475	—
Boulder	0.657	–0.627
Cobble	–0.785	—
Gravel	–0.454	—
Sand	—	0.563
Silt	0.647	0.539
Debris	—	0.545

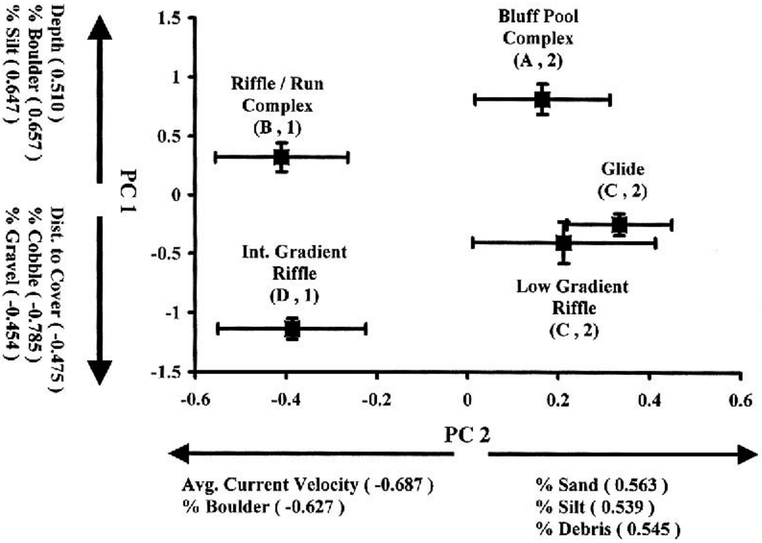

Figure 2. Mean (± S. E. Bars) factor scores (Principal Component 1 and 2) for each of the 5 commonly occurring channel units. Letters beside channel unit headings identify units that differ significantly ($P < 0.05$) along Principal Component 1 (y-axis). Numbers identify units that differ along Principal Component 2 (x-axis).

Table 4. Summary of classification/misclassification results. Presented are the number and percentage (in parentheses) of microhabitats from each hydraulic channel unit type that were classified using the dominant discriminant function into each channel unit type. For example, 33 (or 69%) of microhabitats measured in bluff pool complexes were correctly classified. Five (or 10%) microhabitats, however, were misclassified as part of a riffle-run complex.

	Classified As:				
Observed as:	Bluff pool complex	Riffle-run complex	Intermediate gradient riffle	Low gradient riffle	Glide
Bluff pool complex	33 (69)	5 (10.5)	4 (8)	1 (2)	5 (10.5)
Riffle-run complex	9 (18)	25 (50)	10 (20)	4 (8)	2 (4)
Intermediate gradient riffle	0 (0)	2 (7)	20 (72)	2 (7)	4 (14)
Low gradient riffle	1 (4)	1 (4)	9 (38)	5 (21)	8 (34)
Glide	3 (6)	4 (7)	4 (7)	10 (18)	34 (62)

Discussion

A common definition of hydraulic channel units (HCUs) given by Arend (1999) is that they are relatively homogenous areas, at least one mean stream width in length, that differ in microhabitat characteristics (e.g., depth, current velocity, substrate composition) from adjacent areas. An alternative definition is that HCUs are mosaics of relatively similar microhabitats and possess a temporal stability that is greater than any one of the constituent microhabitats (Frissell et al. 1986, Hildrew and Giller 1994). Regardless of one's working definition, visually identifying and classifying HCUs is a relatively easy process as long as microhabitats within the channel unit are, in fact, "relatively homogeneous" as described by Arend (1999). Small-scale variation in microhabitat characteristics, however, is a common feature of lotic ecosystems (Grossman et al. 1995, Petty and Grossman 1996, Thompson et al. 2001). As a consequence, it is often difficult to identify homogeneous areas that are large enough to be considered channel units under any definition.

Despite the difficulty of classifying channel units in variable environments, habitat management decisions are strongly dependent on an ability to identify and quantify channel unit sequences within streams and rivers (Rabeni and Jacobson 1993). Consequently, there are 2 alternative means for dealing with microhabitat scale variability. The first alternative is to relax the definition of HCUs as it relates to size and classify a channel unit even if it is shorter than one mean stream width. For example, Vadas and Orth (1998) classified habitats in warmwater streams into 3 lateral categories (main channel, side-channel, and backwater) and 7 secondary categories when pools, runs, and riffles within the main channel were discriminated on the basis of depth and/or surface turbulence. Multi-level classification schemes, such as the one adopted by Vadas and Orth (1998), often result in channel units that do not meet the length criterion set in previous definitions and likely describe microhabitat variability rather than habitat variability at the hydraulic channel unit scale.

In contrast, we followed a second alternative, which attempts to meet the channel unit length criterion by incorporating microhabitat variability as a factor when classifying channel units (Hankin and Reeves 1988, Dolloff et al. 1993, Roper and Scarnecchia 1995). Our classification scheme identified 5 distinct channel units that differed markedly with regard to microhabitat scale variability. HCUs characterized by low levels of within unit variability included glides, low gradient riffles, and intermediate gradient riffles. In contrast, bluff pool complexes and riffle-run complexes possessed a high level of microhabitat variability.

We decided to define heterogeneous channel units as complexes rather than attempt to separate complexes into multiple smaller, yet homogeneous units for 3 reasons. First, previous studies have shown that classifying highly variable areas as complexes reduces classification errors associated with delineating small channel units within a laterally complex system (Dolloff et al. 1993, Roper and Scarnecchia 1995). Second, statistical analyses strongly supported our classification scheme. The high degree of within-unit variability of the complexes should have decreased the likelihood of detecting statistical differences among the complexes and other channel units. Nevertheless, channel units consistently exhibited significant and interpretable differences, suggesting that the 5 channel units that we identified visually represent statistically distinct areas within the Shavers Fork. Third, and most importantly, our approach recognizes that complex channel units (e.g., bluff pool and riffle-run complexes) are functionally different from more homogeneous units (e.g., riffles and glides). Different types of habitats are important to fishes as foraging, reproductive, and refuge areas, and the complexes provide a variety of these necessary microhabitat types within close proximity (i.e., 5–10 m).

Increasingly, fisheries managers are attempting to restore historically productive fish populations by managing for quality stream habitats (White 1996). An improved understanding of fish movement (Gowan et al. 1994) and landscape influences on fish populations (Schlosser 1995) has increased the need for habitat management plans designed at a watershed scale. In turn, this has increased the need for information on physical habitat conditions at a large spatial scale. Conventional approaches, such as the Representative Reach Extrapolation Technique (RRET), rely on physical habitat data obtained from a few study reaches to infer habitat conditions throughout a larger drainage basin. While this approach is useful in obtaining detailed information from the representative reaches, extrapolation errors associated with conferring information across spatial scales are expected to be high (Hankin and Reeves 1988). The Basinwide Visual Estimation Technique (BVET) was developed in response to concerns over extrapolation errors and attempts to avoid these errors by obtaining visually estimated information on channel unit sequences at a basinwide scale (Hankin and Reeves 1988, Dolloff et al. 1997).

Although the BVET successfully avoids problems associated with the RRET (Dolloff et al. 1997), the approach, on its own, has an important shortcoming: it fails to provide detailed statistical information on the microhabitat characteristics of visually identified channel units. This is an important shortcoming for 2 reasons. First, statistical information is needed to assess the validity of channel unit classifications and the transferability of those classifications to different areas within a watershed (e.g., from upstream to downstream). Most BVET studies do not assess the accuracy of their HCU classifications (but see Vadas and Orth 1998) or the degree to which HCU characteristics change over a longitudinal gradient. Incorporating a rigorous statistical approach to visual estimation techniques, as we present here, will make it possible for habitat managers to address HCU classification problems (Vadas and Orth 1998).

Second, detailed microhabitat data are needed to quantify spatial variation in fish habitat suitability and to assess the effects of habitat remediation actions on in-stream habitat conditions. Foraging based habitat suitability models recently produced for a variety of fish species (Hughes and Dill 1990, Hill and Grossman 1993, Baker and Coon 1997) provide powerful habitat assessment tools for fisheries managers. They make it possible to quantify habitat suitability parameters in a manner that is independent of habitat use by fishes, and they are transferable among a variety of stream ecosystem types (from sub-Arctic streams to high gradient mountainous streams, to low gradient rivers). In a recent application, Nislow et al. (1999) demonstrated how foraging based models could be used to identify critical habitat needs and monitor stream habitat response to remediation efforts in Atlantic salmon streams of New England. Foraging based models such as the one employed by Nislow et al. (1999), however, are strongly dependent on detailed microhabitat data. Unfortunately, sufficient data to employ these models are not obtained following traditional BVET designs. Furthermore, the ability to apply these models at a watershed scale is greatly diminished under traditional RRET designs.

The overall objective of our research in the Shavers Fork is to design a habitat management plan that effectively restores foraging, reproductive, and refuge habitats for brook trout. Our studies in the watershed indicate that brook trout move throughout the watershed and depend on a variety of habitat types to complete their life cycle (Petty et al., unpubl. data). Consequently, a successful restoration plan must be based on a knowledge of habitat conditions at the watershed scale. Furthermore, a statistically robust habitat sampling approach that can be used to identify areas of critical need and to monitor stream habitat changes over time is of particular importance in this watershed. Herein, we present a stream habitat sampling methodology that incorporates longitudinal changes in stream characteristics, basin-wide estimates of hydraulic channel unit sequences, and detailed microhabitat information. Development of statistically robust habitat sampling procedures will improve our ability to evaluate changes in stream habitat quality and improve the accuracy of foraging based habitat suitability models, both of which are vital in a successful habitat management program.

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