

A Comparison of Basinwide and Representative Reach Habitat Survey Techniques in Three Southern Appalachian Watersheds

C. ANDREW DOLLOFF AND HOLLY E. JENNINGS

U.S. Forest Service, Southern Research Station and Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061-0321, USA

MICHAEL D. OWEN¹

Department of Fisheries and Wildlife Sciences
Virginia Polytechnic Institute and State University, Blacksburg, Virginia 24061-0321, USA

Abstract.-We compared estimates of stream habitat at the watershed scale using the basinwide visual estimation technique (BVET) and the representative reach extrapolation technique (RRET) in three small watersheds in the Appalachian Mountains. Within each watershed, all habitat units were sampled by the BVET; in contrast, three or four 100-m reaches were sampled with the RRET. The number of pools was higher and the number of cascades was lower when estimated by the RRET than they were when estimated by the BVET, whereas the average areas of all habitat types estimated by the RRET were smaller. At the watershed scale, eight out of nine estimates of total habitat area by habitat type derived from the RRET were outside the 95% confidence intervals derived from the BVET. Depth estimates were consistently smaller with the RRET than with the BVET. Large woody debris estimates with the RRET were less than with the BVET in two of three watersheds and were greater in one watershed. We observed that the degree to which habitat in a RRET assessment reflects conditions at a larger scale depends on the selection of representative reaches. Habitat estimates based on the BVET were a more accurate reflection of conditions existing in the three small southern Appalachian watersheds than estimates derived from the RRET. The BVET permitted greater amounts of habitat to be surveyed with known accuracy and precision.

Habitat inventories are the building blocks for developing management plans and monitoring environmental change. Data collected in comprehensive, statistically based surveys are needed to evaluate habitat restoration and improvement programs and to monitor changes resulting from management decisions. The selection of an appropriate inventory methodology is a critical step in the design of habitat management plans.

Resource managers working in streams have developed a variety of methods to inventory habitat at spatial scales ranging from individual habitat units to entire watersheds. At one extreme, the most accurate and reliable inventory is a complete count and measurement of all habitats in a watershed. For all but very small or experimental streams, this approach is impractical. One of the most widely used alternatives has been the representative reach extrapolation technique (RRET). With the RRET, biologists measure habitat in a particular reach or reaches of a stream (typically 30-300 m in length) and extrapolate their findings

to a larger scale. Estimates based on the RRET are accurate for the particular representative reach but cannot be extrapolated without an evaluation of natural variation (true "representativeness") at the larger scale (Everest et al. 1986). Hankin (1984) elaborated on this problem, suggesting that habitat estimation in streams usually is a two-stage sampling problem, with each stage making a unique contribution to the variance of the estimates. He showed that first-stage error (error among sampling sites) typically exceeds second-stage error (error associated with sampling an individual site) but noted that more attention is given to reducing second-stage error. Because the RRET is a form of nonprobability sampling, the first-stage error cannot be calculated, and the accuracy of whole stream or basin-scale estimates that are derived from reach-scale data cannot be evaluated.

Recognizing the two-stage nature of habitat estimation in streams, Hankin and Reeves (1988) developed the basinwide visual estimation technique (BVET). To account for natural variation, the sampling universe (typically a stream or streams within a watershed) is stratified by stream segment and by habitat type (e.g. pools, riffles) within stream segments, the objective being to

¹ Present address: U.S. Forest Service, Idaho Panhandle National Forests, St. Maries Ranger District, St. Maries, Idaho 83861, USA.

group similar units for sampling and so minimize within-stratum variance. The larger contiguous strata (stream segments) may be defined by natural features such as tributary junctions, waterfalls, or any readily identifiable boundaries. Users of the BVET visit every segment and habitat unit within a study area to record visual observations and, at preselected intervals, actual measurements of habitat features. Within each stream segment, individual habitat units are identified, and characteristics such as area, depth, and number of wood pieces are estimated and tallied. Estimates of habitat features are summed to provide estimates, with known confidence intervals, at a scale comparable to that of the sample universe.

Our purpose was to compare estimates of stream habitat based on both the RRET and BVET. We inventoried habitat using both techniques in three small southern Appalachian watersheds during late spring and summer of 1989 and 1990.

Methods

Study sites.—Streams in the three watersheds had clear water with relatively high gradients (4.7–9.5%), large substrate, and typical southern Appalachian fish species assemblages (Etnier and Starnes 1993; Jenkins and Burkhead 1994). Riparian vegetation consisted primarily of second-growth eastern hemlock (*Tsuga canadensis*), rhododendron (*Rhododendron* spp.), yellow poplar (*Liriodendron tulipifera*), oaks (*Quercus* spp.), maples (*Acer* spp.), and birch (*Betula* spp.).

We surveyed 8.7 km of stream in the Basin Creek Cove watershed (Basin-Cove), located in the Doughton Park Ranger District, Blue Ridge Parkway, in northwestern North Carolina (Figure 1). We began at a dam on Lower Basin Creek near the parkway boundary. Stream elevations in the Basin-Cove watershed ranged from 427 m above mean sea level (amsl) at the park boundary to 670 m at the upper limit; watershed elevation peaked at 1,128 m.

We surveyed 5.5 km of stream habitat within the Fish Camp Prong watershed, a tributary of Little River in the Great Smoky Mountains National Park (Figure 1). We started at the confluence of Fish Camp Prong and its tributary, Goshen Creek. Stream elevation in Fish Camp ranged from 1,006 to 1,219 m amsl, and the drainage peaked at 1,585 m.

We sampled 6.7 km of stream in the Rose River basin in Shenandoah National Park, Virginia (Figure 1). Our study area originated at the confluence of Rose River and Dark Hollow Creek. The drain-

age summit was about 1,036 m amsl, and the stream elevations ranged from 427 to 853 m in the sampled sections.

Survey techniques.—Habitat estimates were made by a single observer to maximize consistency and avoid the variability in habitat unit classification associated with multiple observers (Roper and Scarnecchia 1995). To keep our analysis as simple as possible, we chose a limited subset of habitat characteristics known to influence salmonid habitat quality and quantity, including habitat type, surface area, depth, and amount of large woody debris (LWD) within the bank-full channel of each habitat unit. For both the BVET and the RRET, we identified three habitat types: pools, riffles, and cascades (Dolloff et al. 1993). Pools had relatively deep water with low velocity, streambed gradients near zero, and concave streambed shapes. Riffles had shallow water with fast, turbulent flow, less than 12% channel slopes, and flat to convex streambed shapes. Cascades had alternating small falls and shallow pools, fast and turbulent flow and channel slopes greater than 12% (Platts et al. 1983; Hawkins, et al. 1993; McMahon et al. 1996). Counts of pieces of LWD in each of seven size-classes (Table 1) were recorded in each habitat unit sampled. We compared all habitat characteristics at both the stream segment and watershed scales (Figure 1).

Basinwide visual estimation technique.—The basic premise of the BVET is that if there is a strong, positive correlation between actual measurements and visual estimates, it should be possible to “correct” for observer bias by calculating and applying a simple calibration ratio to all estimates (Hankin and Reeves 1988). The BVET consists of two phases: estimation and verification (Hankin and Reeves 1988; Dolloff et al. 1993). During the estimation phase, a watershed is stratified into reaches (e.g., stream segments, Figure 1) based on natural features (e.g., change in stream order or change in gradient) or other criteria selected by the observer to ensure repeatability or to meet other specific objectives. Also during this phase, the stream is stratified by habitat type, and area and other features for each type are visually estimated. The verification phase of the BVET includes verification and calibration of the estimated habitat characteristics through measurements made with more accurate methods on a subsample of the habitat units.

The BVET surveys started at stream confluences or suspected barriers to upstream fish movement (typical stream segment boundaries) and pro-

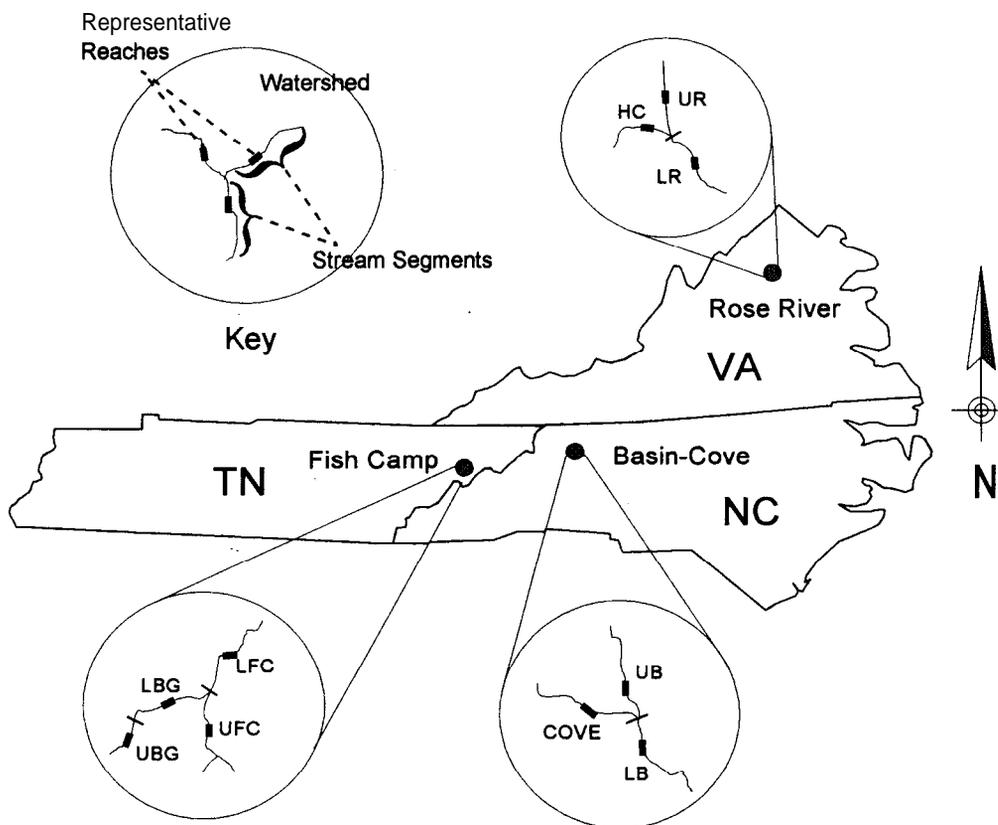


FIGURE 1.—Locations of the southern Appalachian watersheds and stream segments surveyed during 1989–1990. Rose River: LR = lower Rose River, UR = upper Rose River, and HC =Hogcamp Branch; Basin-Cove: LB = lower Basin Creek and UB = upper Basin Creek; and Fish Camp: LFC = lower Fish Camp Prong, UFC = upper Fish Camp Prong, LBG = lower Buckeye Gap, and UBG = upper Buckeye Gap. Size and location of representative reaches are approximate.

gressed either upstream (Basin Creek and Fish Camp Prong) or downstream (Rose River) to the end of the respective stream segment. Habitat type, distance from start points, estimated area, average and maximum depths, and LWD counts were re-

corded for every habitat unit in each stream segment.

TABLE I.—Size-classes of large woody debris used in the basinwide visual estimation and representative reach extrapolation techniques.

Class	Length (m)	Diameter (cm)
1	1-5	5-10
2		11-50
3		>50
4	>5	5-10
5		11-50
6		>50
7		Rootwad ^a

^a A mass of roots that remained intact when a tree or stump was uprooted (Maser and Sedell 1994).

Habitat units were sequentially numbered by habitat type. Distance (to 0.1 m) to each unit was recorded as the length along the thalweg as determined by hip-chain measurement. Average and maximum depths were estimated based on multiple measurements with a depth rod marked in 5-cm increments. Areas were accurately measured with a meter tape in a subset of units (about 20% of all pools and 10% of all riffles and cascades) to account for the bias of visual estimates. Areas were calculated as the product of length and average width. Separate calibrations were calculated for pools, riffles, and cascades within each stream segment and watershed. Estimates of habitat area, associated variances, and confidence intervals were calculated for each habitat type and stream segment with equations found in Dolloff et al. (1993).

Representative reach extrapolation technique.—The RRET is based on the assumption that trained biologists can select stream sections that will yield habitat estimates that are representative of the entire stream or watershed. The location, length, and number of representative reaches used for a particular watershed depends on the expected heterogeneity of stream habitat as assessed by professionals and on resources available for sampling (Platts et al. 1983; McMahon et al. 1996). Although recent research suggests that reach length should be a function of a natural feature such as mean stream width (Simonson et al. 1994), Armour et al. (1983) and others have recommended that reaches be at least 100 m in length. In the southern Appalachians, the Trout Committee of the Southern Division, American Fisheries Society, recommends a reach of 100 m for sampling a stream whose width is 10 m or less (“Standardized sampling guidelines for wadeable trout streams,” unpublished manuscript). In accordance with common practice in the southern Appalachians, we sampled one representative reach of about 100 m in each stream segment (Figure 1). Actual reach length varied to account for natural breaks between dissimilar habitat units. Three representative reaches were established in the Basin-Cove watershed; four reaches were sampled in the Fish Camp Prong basin; and three reaches were sampled in the Rose River.

To facilitate comparisons between estimates derived by the BVET and the RRET, we modified standard transect techniques (Platts et al. 1983) by identifying and measuring individual habitat units in each representative reach. We systematically located transects within each habitat unit rather than uniformly throughout the reach. Length of each habitat unit was measured along the thalweg, and width measurements were taken along transects located at one-quarter, one-half, and three-quarters of the habitat unit length measurement. Depth was measured at one-quarter, one-half, and three-quarters the distance across each of the three transects. Maximum depths of habitat units were not measured but were estimated by using the greatest depth measurement from all transects within a unit. Box and whisker plots (Ott 1984) were prepared to display the distribution of the average and maximum depths. Large woody debris in each habitat unit was classified and tallied.

The area of each habitat unit was calculated as the product of length and average width. Habitat areas and the number of units were summed by habitat type to obtain estimates of total area and

number of habitat units of each type within each representative reach. We then divided these estimates of habitat area and number of units by the length of the representative reach and multiplied by the length of the stream segment to obtain estimates of total habitat for each stream segment. We summed the estimates extrapolated from the RRET to obtain the total habitat area and the total number of units (by habitat type) for each watershed.

We were unable to statistically compare estimates derived from the two sampling techniques at the stream segment or watershed scales because we could not calculate variances and confidence intervals for habitat area as estimated by the RRET. However we compared RRET point estimates to the respective BVET 95% confidence intervals to illustrate how similar the extrapolated estimates and the statistically based estimates were.

Results

Comparisons of estimates of habitat by habitat type across the stream segments in each of the three watersheds revealed striking differences between the BVET and the RRET. With the RRET, 94% fewer habitat units were actually sampled than with the BVET. Extrapolation from three to four representative reaches in a watershed yielded variable estimates of the total number of habitat units when compared with the actual number of units counted in the watershed during the BVET survey. In general, when using the RRET, more pools and fewer cascades were estimated than with the BVET (Table 2). As an extreme example, use of the RRET showed no cascades in the Basin-Cove Watershed; however, cascades made up at least 8% of the habitat units and 5% of the surface area in two of the three stream segments.

Average areas of habitat units were more variable than numbers of habitat units (Table 2). Average areas estimated by the BVET for pools, riffles, and cascades were larger in 60%, 80%, and 70% of all stream segments, respectively, than similar estimates generated by the RRET. Sixty percent of the RRET pool : riffle area ratios were greater than those from the BVET.

At the watershed scale, estimates of total habitat area across all stream segments and habitat types were similar; extrapolations of RRET areas were within 0.167% of BVET estimates (Table 3). In contrast, eight out of nine RRET estimates of total habitat area by habitat type were outside the BVET 95% confidence intervals. Estimates of total pool area from the RRET were greater than BVET es-

TABLE 2.-Average habitat unit areas (m²) and pool : riffle ratios (P/R) for each stream segment within the Basin-Cove (North Carolina), Fish Camp prong (Tennessee), and Rose River (Virginia) watersheds sampled with the basinwide visual estimation technique (BVET) and the representative reach extrapolation technique (RRET) during 1989 and 1990. Total numbers of habitat units are in parentheses; RRET numbers are extrapolated.

Stream segment		Pools		Riffles		Cascades		P/R	
Name ^a	Length	BVET	RRET	BVET	RRET	BVET	RRET	BVET	RRET
Basin-Cove									
L. Basin Cove	2,398	130.8 (61)	102.6 (128)	225.1 (41)	153.6 (26)	0 (0)	0 (0)	0.9	3.3
U. Basin	2,742	32.5 (204)	36.6 (345)	59.5 (90)	32.7 (123)	25.0 (30)	0 (0)	1.2	3.1
Total	3,270	3 1.4 (355)	40.4 (170)	43.2 (97)	66.5 (97)	3 1.0 (40)	0 (0)	2.7	1.1
	8,410	41.5 (620)	50.7 (643)	82.0 (228)	58.8 (246)	28.4 (70)	0 (0)	1.4	2.3
Fish Camp Prong									
L. Fish Camp	1,623	40.1 (150)	40.5 (179)	7 1.2 (63)	41.5 (45)	59.7 (9)	7.9 (15)	1.3	3.9
U. Fish Camp	2,244	13.8 (209)	26.5 (257)	42.0 (120)	22.2 (99)	25.9 (75)	24.1 (20)	0.6	3.1
L. Buckeye	1,474	18.6 (127)	17.0 (142)	44.0 (57)	52.7 (65)	32.1 (64)	42.7 (26)	0.9	0.7
U. Buckeye	482	10.5 (42)	10.3 (68)	32.8 (22)	25.9 (21)	15.7 (19)	15.9 (17)	0.6	1.3
Total	5,823	22.1 (528)	26.6 (646)	47.8 (262)	34.9 (230)	28.9 (167)	25.4 (78)	0.9	2.1
Rose River									
L. Rose	2,652	36.0 (295)	29.3 (398)	43.2 (55)	37.7 (53)	39.1 (66)	28.0 (53)	4.5	5.8
U. Rose	2,256	19.0 (265)	13.9 (342)	29.2 (85)	21.4 (114)	33.2 (66)	15.4 (46)	2.0	2.0
Hogcamp	1,815	24.0 (150)	18.2 (189)	37.8 (32)	33.1 (57)	60.5 (58)	56.1 (19)	3.1	1.8
Total	6,723	27.1 (710)	21.3 (929)	35.1 (172)	28.2 (224)	43.6 (190)	27.5 (118)	3.2	3.1

^a L. = Lower; u. = Upper.

timates in the Basin-Cove and Fish Camp Prong watersheds; however, estimates from RRET and BVET in the Rose River basin were similar. Conversely, estimates of total riffle and cascade area from the RRET were less than BVET estimates, except for total riffle area in the Rose River.

At the stream segment scale, 70% of the RRET estimates of total habitat area across all habitat types were within the BVET 95% confidence intervals. However, 70%, 80%, and 88% of the individual pool, riffle, and cascade habitat area estimates, respectively, were outside the BVET confidence intervals. Of these, 86% of the pool estimates were greater and 63% of the riffle and 100% of the cascade estimates were less than the BVET confidence intervals.

The RRET mean average and mean maximum depths of habitat units were consistently smaller than BVET depths for all habitat types in all three watersheds, except for the mean maximum depth of cascades in the Fish Camp Prong watershed (Figure 2). However, maximum depths of habitat units were not purposely measured during RRET sampling; both the maximum and average depths were estimated from transect sampling.

Large woody debris counts extrapolated from the RRET data were less than the complete inventory obtained from the basinwide technique in the Fish Camp Prong and Basin-Cove watersheds and greater in the Rose River watershed (Figure

3). The estimated frequency distributions of LWD across size-classes were similar in Fish Camp Prong and Rose River watersheds (chi-square; $P > 0.05$), but not in the Basin-Cove watershed. Wood in size-classes 1 and 2 accounted for 60-80% of all LWD in the RRET estimate and 74-83% in the BVET estimate.

Discussion

Habitat estimates based on the BVET were a more accurate reflection of conditions existing in the three small southern Appalachian watersheds than estimates derived from the RRET. Although the estimates of total habitat area derived from the BVET and RRET were similar, the proportions of habitat area within each habitat type, as well as the numbers and average sizes of habitat units, were different. In general, RRET estimates of pool area were larger, and estimates of riffle and cascade areas were smaller than estimates based on the BVET.

The BVET is more likely to identify uncommon features, which may nonetheless be important components of fish habitat. For example, no cascades were found in some of the representative reaches, although cascades were present in the stream segments. The total habitat area estimates for the BVET and the RRET were similar in those stream segments, even though the RRET estimates were based on pools and riffles only. This suggests

TABLE 3.—Estimated areas (m²) of habitat units and 95% confidence intervals (in parentheses) for each stream segment within the Basin-Cove (North Carolina), Fish Camp Prong (Tennessee), and Rose River (Virginia) watersheds sampled using the basinwide visual estimation technique (BVET) and the representative reach extrapolation technique (RRET) during 1989 and 1990. The areas for the RRET are extrapolated.

Stream segment	Pools		Riffles		Cascades		Total	
	BVET	RRET	BVET	RRET	BVET	RRET	BVET	RRET
Basin-Cove								
Lower Basin	1,979 (542)	13,131	9,228 (1,388)	3,994	0.00	0.00	11,295 (902)	17,125
Cove	6,639 (330)	6,860	5,357 (363)	6,451	751 (124)	0.00	12,850 (591)	13,311
Upper Basin	11,146 (727)	12,638	4,190 (386)	4,028	1,240 (691)	0.00	16,767 (911)	16,666
Total	25,764 (1,038)	32,629	18,775 (1,019)	14,473	1,991 (300)	0.00	46,847 (1,416)	47,102
Fish Camp Prong								
Lower Fish Camp	5,727 (419)	7,252	4,665 (1,254)	1,858	506	119	11,193 (879)	9,229
Upper Fish Camp	3,162 (151)	6,830	4,617 (264)	2,195	1,956 (690)	481	9,756 (487)	9,506
Lower Buckeye	2,356 (181)	2,415	2,508 (211)	3,413	2,057 (416)	1,110	6,849 (341)	6,938
Upper Buckeye	440 (74)	703	722 (505)	554	299 a	270	1,386 (187)	1,527
Total	11,685 (467)	17,200	12,512 (928)	8,020	4,818 (700)	1,980	29,216 (1,074)	27,200
Rose River								
Lower Rose River	10,612 (639)	11,643	2,375 (152)	2,001	2,580 (550)	1,483	35,789 (898)	15,127
Upper Rose River	5,034 (233)	4,738	2,481 (172)	2,439	2,190 (104)	701	9,937 (332)	7,878
Hogcamp	3,598 (223)	3,438	1,176 (147)	1,872	3,511 (332)	1,060	8,560 (361)	6,370
Total	19,244 (702)	19,819	6,032 (212)	6,312	8,281 (550)	3,244	34,280 (1,019)	29,375

^a Insufficient sample size to compute confidence interval.

that underestimation of rare types within representative reaches and the subsequent failure to extrapolate to the stream segment or watershed scale may lead to an overestimation of the other types present.

The RRET is based on the premise that the habitat in a relatively small reach or set of reaches can be used to estimate habitat in a larger stream segment or basin. These smaller reaches are intensively sampled, and the resulting data used to make inferences about the quality and quantity of habitat in the larger reach. In contrast, habitat surveys based on the BVET yield complete inventories of all habitat units in a stream or watershed. Specific habitat attributes are estimated on all units, and only a subsample of the units are actually measured. This sampling scheme permits greater amounts of habitat to be surveyed with known accuracy and precision.

The most important feature of habitat in a rep-

resentative reach is how well it in fact "represents" the stream or watershed as a whole. The degree to which habitat in a reach reflects conditions at the larger scale depends on the judgment of the person selecting the reach. Reaches may be selected because they look "typical" (Kruskal and Mosteller 1979a) and appear to have the average width, depth, gradient, etc. of the entire stream. Or, selected reaches may appear to contain "good" trout habitat, which is more of an ideal than an average. Similarly, our reaches were selected based on one or more definitions of "representativeness," such as outlined by Kruskal and Mosteller (1979a, 1979b, 1979c).

We assessed representativeness not only in terms of typicalness but also as "coverage," (i.e., that most or all elements of interest in the population are at least present in the reaches regardless of quantities or proportions). Assuming that all elements of interest were identified prior to reach

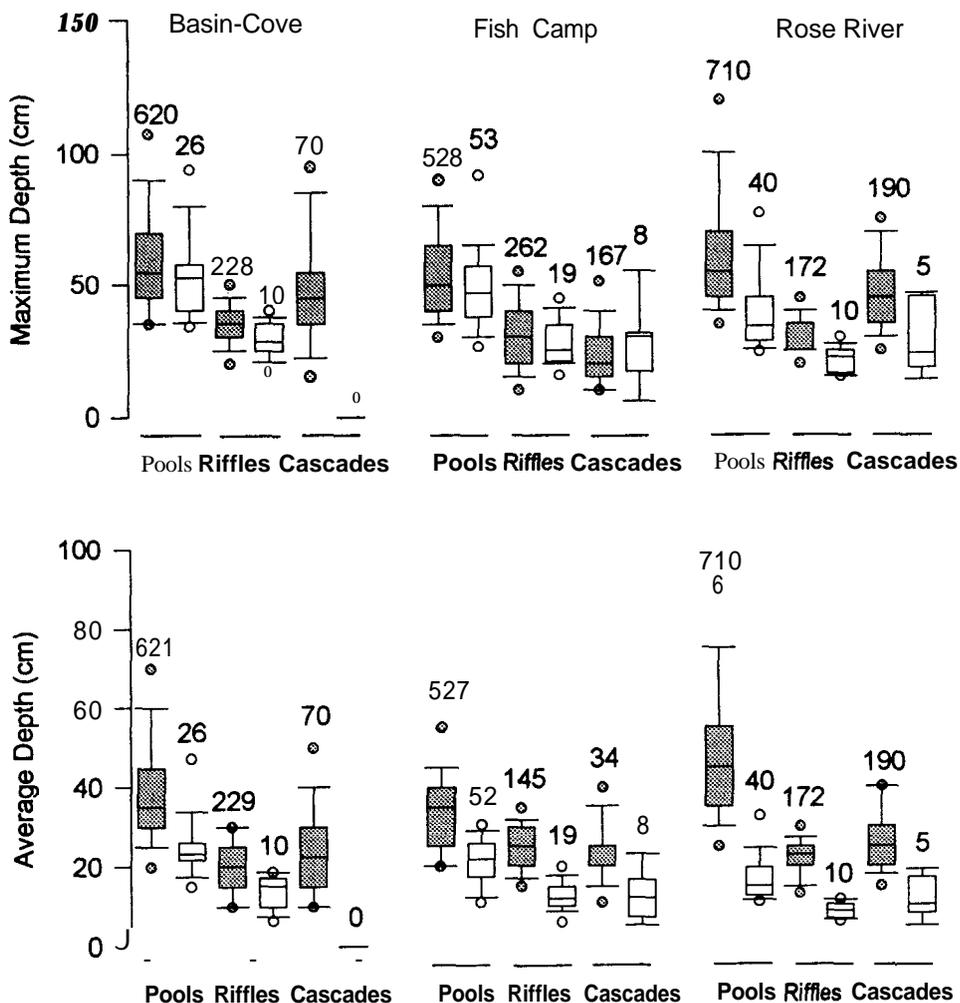


FIGURE 2.—Box and whisker plots of the distributions of maximum and average depths of habitat types sampled for the basinwide visual estimation (shaded boxes) and representative reach extrapolation (clear boxes) techniques within Basin-Cove (North Carolina), Fish Camp Prong (Tennessee), and Rose River (Virginia) watersheds during 1989-1990. Boxes encompass the 25th through the 75th percentiles, horizontal lines below and above the boxes represent the 10th and 90th percentiles, and circles represent data outside the 5th and 95th percentiles. Solid lines within boxes denote medians, and numbers above boxes are sample sizes.

selection, the heterogeneity of the population was then represented (Kruskal and Mosteller 1979b). We also considered the concept of a “miniature” of the population, in which exact proportions of habitat and habitat characteristics found in the population (stream) are present in the reach (Kruskal and Mosteller 1979a). The problem with viewing representativeness in this way is that the population values are not usually known, which is the reason a miniature replica of the population is desired. Conversely, purposively sampling a miniature replica of the population is difficult if the observer does not know the population values

beforehand, as in this case. Our results suggest that the reaches selected for the RRET were not representative; some of the reaches accurately described the habitat within a watershed, but some did not.

Highly complex interactions between riparian influences (e.g., forest stand age and density influences on in-channel large woody debris loading), stream hydraulics (e.g., flow regimes and peak flows), and geomorphic features (e.g., channel morphology and streambed material) are responsible for the formation of stream habitat. Very different reaches would likely be selected

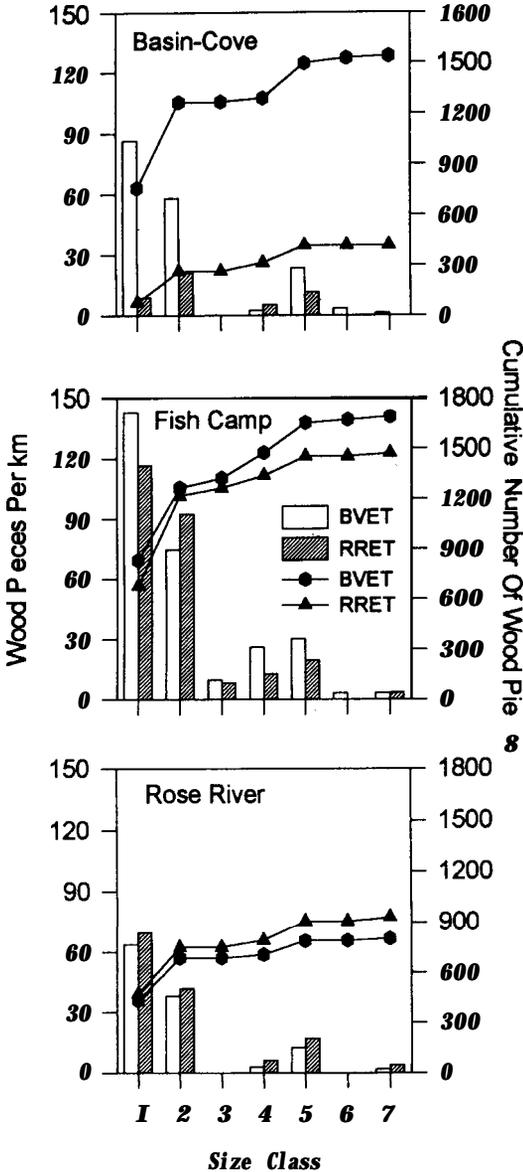


FIGURE 3.-Density (bars) and cumulative number of wood pieces (points) within each size-class as estimated from the basinwide visual estimation technique (BVET) and the representative reach extrapolation technique (RRET) within Basin-Cove (North Carolina), Fish Camp Prong (Tennessee), and Rose River (Virginia) watersheds during 1989-1990.

if selection depends upon particular attributes; "an approach that makes for typicalness of some characteristics-however defined-need not lead to typicalness for other characteristics" (Kruskal and Mosteller 1979c). For example, a reach that is truly representative of the total amount of pool

habitat in a stream segment may be completely unrepresentative of other characteristics such as gradient, large woody debris, or proportions of each habitat type. The importance of individual stream attributes such as these may be difficult to assess and, therefore, be unintentionally overlooked by the observer.

To expect a single reach to reflect the characteristics of an entire stream is unrealistic, unless that reach approaches the length of the stream. Increasing the length of a representative reach increases the likelihood of incorporating important features but also increases costs. Because of this, the representativeness of reaches is almost never verified with a sampling of the whole stream; the reaches are assumed to be typical or to be a miniature of the population simply because they look like they contain all the parts. Selection of truly representative reaches should be based on quantitative surveys designed to identify and sample the stream properties of interest. In this context, a BVET or other large-scale survey methodology could be designed to identify reaches that would address specific objectives.

A primary concern when designing a sampling program is how to minimize sampling variation at a reasonable cost (Deming 1950). Although Hankin (1984) developed methods to evaluate the relative efficiency of various sampling methods, variance estimators were not available for extrapolated estimates derived from the RRET. Without variance estimators, we have no way of evaluating the accuracy or precision of the data generated by the RRET at the stream segment or watershed scales and, subsequently, no way of evaluating the quality of the information, regardless of the cost.

Acknowledgments

We thank Gregg Chapman, Patricia Flebbe, Steve Moore, and Sherri Owen for assistance with field data collection. Don Orth and Eric Smith provided statistical advice, and Timothy Gregoire and Glenn Chen reviewed the manuscript in draft form. We also thank F. D. Shields, Jr., and an anonymous reviewer for thoughtful reviews that substantially improved the final presentation.

References

Armour, C. L., K. P. Burnham, and W. S. Platts. 1983. Field methods and statistical analyses for monitoring small salmonid streams. U.S. Fish and Wildlife Service FWS/OBS 83/33.
 Deming, W. E. 1950. Some theory of sampling. Wiley, New York.
 Dolloff, C. A., D. G. Hankin, and G. H. Reeves. 1993.

- Basinwide estimation of habitat and fish populations in streams. U.S. Forest Service General Technical Report SE-83.
- Etnier, D. A., and W. C. Starnes. 1993. *The fishes of Tennessee*. University of Tennessee Press, Knoxville.
- Everest, F. H., and five coauthors. 1986. Abundance, behavior, and habitat utilization by coho salmon and steelhead trout in Fish Creek, Oregon as influenced by habitat enhancement. Bonneville Power Administration, 1985 annual report, Portland, Oregon.
- Hankin, D. G. 1984. Multistage sampling designs in fisheries: applications in small streams. *Canadian Journal of Fisheries and Aquatic Sciences* 41:1575-1591.
- Hankin, D. G., and G. H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. *Canadian Journal of Fisheries and Aquatic Sciences* 45:834-844.
- Hawkins, C. P., and ten coauthors. 1993. A hierarchical approach to classifying stream habitat features. *Fisheries* 18(6):3-12.
- Jenkins, R. E., and N. M. Burkhead. 1994. *Freshwater fishes of Virginia*. American Fisheries Society, Bethesda, Maryland.
- Kruskal, W., and F. Mosteller. 1979a. Representative sampling I: non-scientific literature. *International Statistical Review* 47: 13-24.
- Kruskal, W., and F. Mosteller. 1979b. Representative sampling II: scientific literature, excluding statistics. *International Statistical Review* 47: 111-127.
- Kruskal, W., and F. Mosteller. 1979c. Representative sampling III: the current statistical literature. *International Statistical Review* 47:245-265.
- Maser, C., and J. R. Sedell. 1994. *From the forest to the sea: the ecology of wood in streams, rivers, estuaries, and oceans*. St. Lucie Press, Delray Beach, Florida.
- McMahon, T. E., A. V. Zale, and D. J. Orth. 1996. Aquatic habitat measurements. Pages 83-120 in B. R. Murphy and D. W. Willis, editors. *Fisheries techniques*, 2nd edition. American Fisheries Society, Bethesda, Maryland.
- Ott, L. 1984. *An introduction to statistical methods and data analysis*, 2nd edition. Duxbury Press, Boston.
- Platts, W. S., W. F. Megahan, and G. W. Minshall. 1983. *Methods for evaluating stream, riparian, and biotic conditions*. U.S. Forest Service General Technical Report INT-138.
- Roper, B. B., and D. L. Scarnecchia. 1995. Observer variability in classifying habitat types in stream surveys. *North American Journal of Fisheries Management* 15:49-53.
- Simonson, T. D., J. Lyons, and P. D. Kanel. 1994. Quantifying fish habitat in streams: transect spacing, sample size, and a proposed framework. *North American Journal of Fisheries Management* 14: 607-615.

