North American Journal of Fisheries Management 11:305- 311, 1991

Use of a Habitat-Based Stream Classification System for Categorizing Trout Biomass

Timothy Modde

U.S. Fish and Wildlife Service, Utah Cooperative Fish and Wildlife Research Unit
Utah State University, Logan, Utah 84322, USA

Richard C. Ford

South Dakota Department of Game, Fish and Parks
3305 West South Street, Rapid City, South Dakota 57702, USA

Milton G. Parsons

Legislative Affairs, U.S. Forest Service
12th and Independence, SW, Washington, D.C. 20090, USA

Abstract.-A habitat-based system was evaluated as a means of classifying small watersheds. Streams from four land-type associations in the Black Hills National Forest were segregated qualitatively by means of physical characteristics determined from transect data and stratified by habitat type. The biomass of brown trout *Salmo trutta* could be categorized by habitat composition, but the biomass of brook trout *Salvelinus fontinalis* could not be. Segregating watersheds by both physical and biological characteristics of individual habitat units provides resource managers with a functional classification scheme. However, the usefulness of this approach depends on a consistent response of fish to habitat quality.

We examined the use of habitat types as defined by Bisson et al. (1982) to segregate streams of four small watersheds in the Black Hills of South Dakota. Treating habitat types as basic units of classification allows the use of rapid estimates of fish abundance and habitat area to characterize stream resources by watershed (e.g., Hankin and Reeves 1988). Timely categorization of stream resources improves the efficiency of managers as they define fisheries potential and prioritize management needs.

Our objectives were to determine whether physical characteristics could be used to segregate habitat units (i.e., individual habitat types) by watershed, and whether habitat composition within watersheds was associated with the distribution and abundance of brown trout *Salmo trutta* and brook trout *Salvelinus fontinalis*. Specifically, we asked three questions. Can instream characteristics measured from habitat units be segregated by watershed? Does habitat composition differ among watersheds? Can differences in habitat composition among watersheds be associated with biomass of brown trout and brook trout?

Study Area

The study area is in the Black Hills National Forest in west-central South Dakota and eastern Wyoming. The Black Hills are isolated, unglaciated mountains dominated by Ponderosa pine *Pinus ponderosa*. The forest is managed for multiple uses that include logging, mining, livestock grazing, wildlife habitat, and recreation. We selected streams in four land-type associations (Wertz and Arnold 1972; Figure 1): crystalline canyon (CC), gently dipping plateau (GDP), moderately rolling uplands (MRU), and limestone canyon (LC) (T. Svatos, J. Windsor, and F. Wild, U.S. Forest Service, unpublished). These land-type associations contain the major stream fishery resources in the Black Hills. The first three are in the Rapid Creek drainage, which drains the east slope of the mountain range; streams of the LC association drain the northern Black Hills by the way of Spearfish Creek. Each land-type association is unique within the Black Hills National Forest.

Elevation of the four land-type associations ranges from 1,200 to 2,070 m above mean sea level; average annual precipitation is 46-66 cm. The GDP association, found at the highest elevation in the Rapid Creek drainage, has broad ridges and valley bottoms, moderately sloping to steep side slopes (15-30%), and rock outcrops composed primarily of limestone with some shale and sandstone interspersed. The MRU association is similar in topography to the GDP but valley

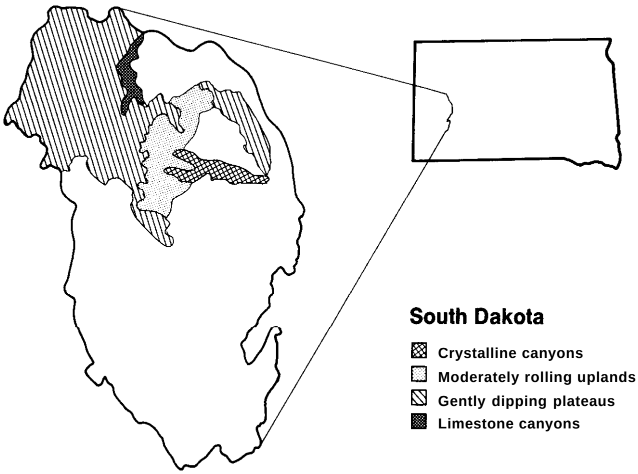

FIGURE 1.-Black Hills National Forest, including the four land-type associations studied.

widths are variable. The MRU bedrock consists largely of slate and mica schist. The CC association, found at the lowest elevation in the Rapid Creek drainage, has narrow ridges and valleys, very steep side slopes (> 40%), and outcroppings of slate and schist. The LC association is topographically similar to the CC except that bedrock consists primarily of limestone with some sandstone and shale.

Methods

In our study design we stratified soil type (21 types) within stream order within each land-type association. With one exception, soil types were unique to each land-type association. Within each sample stratum (i.e., soil type per stream order per land-type association), 1,000-m stream sections were delineated and a single section was randomly selected. In this manner, 53 sections were selected among the four land-type associations. Because of dewatering or physical disturbance to the stream site, only 36 sections were sampled from 1984 to 1986. Two contiguous stations were sampled per section, one station extending 100 m above and the other 100 m below the midpoint of each section. Sections from the Rapid Creek drainage were randomly sampled during 1984 and 198 5. An additional year of funding allowed sampling of the Spearfish Creek drainage in 1986. Sample stations from Spearfish Creek were randomly selected in the same manner as in 1984 and 1985. We sampled 242 individual habitat units within the 72 stations. Data were collected during the low-flow period (August-October).

We delineated stream orders by using the contour crenulation method (Gregory 1966) on 1:24,000 U.S. Geological Survey maps. The smallest permanent streams were fifth-order channels. Some streams lower in the Rapid Creek drainage were as high as eighth order, but streams of the GDP and LC did not exceed sixth order.

Sample stations were subjectively divided into habitat types as defined by Bisson et al. (1982). Habitat features (Table 1) were measured by the transect method (Platts et al. 1983); we used a minimum of three transects per habitat type, and distances between transects did not exceed 10 m. Transects were spaced uniformly the length of the habitat type. Water samples were collected from each station for analysis of alkalinity, pH, turbidity, conductivity, phosphate, nitrate, and sulfate. Alkalinity, pH, and turbidity were measured with a Hach field kit, whereas phosphate, nitrate and sulfate concentrations were determined by means of standard methods (USEPA 1974).

We used gasoline-powered backpack electroshockers to collect fish in individual habitats blocked with nets. A multiple-step, removal-depletion method (Platts et al. 1983) was used to estimate population size per habitat. Captured fish were measured and placed below the lower net. Only naturally reproduced fish or stocked fish that had overwintered in the creek were included in population estimates. Removal continued until the iterative removal sum was 80% of the first removal, or until five passes had been made. Numerical estimates of trout were calculated with Burnham's maximum-likelihood model (Platts et al. 1983).

Data on instream morphological variables (by

TABLE 1. -Results of analysis of covariance of stream variables among four land-type associations. Values are least-squares means; those within a row with a letter in common are not significantly different ($P > 0.05$). Asterisks indicate significant differences among soil types nested within land-type associations.

Variable	Crystalline canyon	Moderately rolling uplands	Gently dipping plateau	Limestone canyon
Width (m)*	4.84 zy	7.39 x	4.43 z	5.40 y
Maximum depth (cm)*	29.9 z	43.3 y	26.3 z	38.9 y
Mean depth (cm)*	19.0 z	20.4 z	14.7 z	18.7 z
Vegetation width (%)*	3.9 zy	26.3 x	5.2 yx	0.4 z
Bank angle (o)*	70.5 z	70.7 z	64.7 z	45.7 y
Bank undercut (cm)*	3.6 z	4.6 z	3.8 z	3.7 z
Vegetation overhang (cm)*	28.1 z	15.1 y	21.2 z	15.6 y
Bank water depth (cm)*	3.4 z	4.1 z	3.4 z	3.6 z
Boulder (%)*	13.8 z	21.1 z	15.3 z	37.3 y
Rubble (%)*	43.7 z	17.4 y	37.0 z	20.3 y
Gravel (%)*	20.6 z	5.0 x	14.2 zy	10.8 yx
Large fine sediment (%)*	4.1 z	5.5 y	6.9 y	13.3 y
Small fine sediment (%)*	15.9 z	51.9 y	25.6 z	19.9 z
Embeddedness*	3.6 z	2.9 y	3.7 z	5.3 x
Canopy cover (%)	39.2 z	17.2 y	8.9 y	22.3 y
Conductivity (μS/cm)*	149.0 z	294.8 y	236.6 y	171.3 z
Alkalinity (mg/L)*	152.6 z	235.2 y	174.3 x	222.2 w
pH*	8.2 z	8.4 z	8.6 y	8.5 y
Turbidity (NTU[a])*	2.0 z	1.7 z	6.4 y	4.1 x
Sulfate (mg/L)*	28.6 z	4.5 y	9.5 x	12.1 w
Nitrate (mg/L)*	0.11 z	0.13 z	0.11 z	0.11 z
Phosphate (mg/L)	0.015 zy	0.013 z	0.018 yx	0.022 x
Instream cover (%)*	9.9 z	30.6 y	15.3 z	10.4 z
Pool rating	2.4 zy	2.5 yx	1.8 z	4.1 x

[a] Nephelometric turbidity units.

habitat type) and water chemistry (by station) were separately grouped for analysis to test for differences among land-type associations. Physical instream variables were examined for differences with the general linear model of analysis of covariance (SAS Institute 1987); soil type was nested within land-type association and stream order was the covariate. Variables expressed as percentages-vegetative width, substrate, instream cover (sum of all cover from organic sources), and canopy-were subjected to arcsine transformation before analysis. Because some nonpercentage variables were not normally distributed, all nonpercentage variables were transformed [$\log_e(X + 1)$] to standardize variances. The general linear model of a two-factor analysis of covariance (SAS Institute 1987) was used to test for differences in trout biomass per unit area by land-type association and habitat type. Trout biomasses from beaver ponds and dammed ponds were combined in the analysis. Dependence of habitat ranking based on surface area among land-type associations was tested with Kendall's coefficient of concordance (Stoodley et al. 1980). Discrimination of habitat units among land-type associations was examined by stepwise discriminant analysis. Each observation consisted of mean variable scores from individual habitat types, including water chemistry variables. Discriminant functions were used to reclassify habitat types by land-type association. Unless otherwise indicated, the significance level used for all tests was $P = 0.05$.

Results

Habitat Comparisons

Significant differences were detected in all but 4 of the 24 instream morphometric and water quality variables tested among land-type associations (Table 1). Mean depth, bank undercut, bank water depth, and nitrate concentration showed no differences among land-type associations. Although differences occurred in most variables, we detected no elevational patterns within the Rapid Creek drainage (for CC, MRU, and GDP). The land-type associations most similar, as judged by the lack of significant differences, were streams from the top of the drainage (GDP) and the bottom of the drainage (CC). The MRU land-type association was wider and deeper with more fine sediment and instream cover. Streams in the LC land-type association had greater maximum depths, greater percentages of boulders, and higher pool ratings.

Rank-correlation analysis of habitat type area

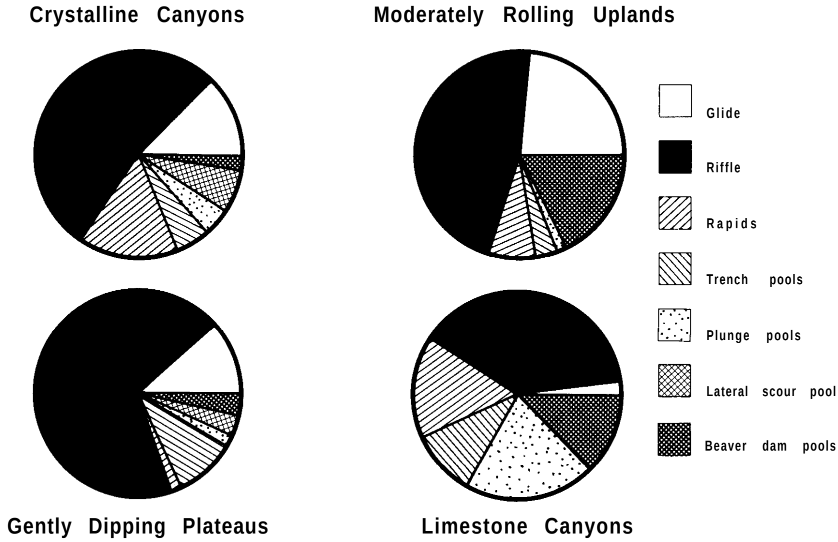

FIGURE 2.-Composition of instream habitat types among land-type associations studied within the Black Hills National Forest.

indicated independence among land-type associations (W = 0.469; α = 0.01; 4, 7 = 0.592) but not among stream orders (W = 0.737). Therefore, the composition of habitat types was distributed independently among land-type associations but not among stream orders. The difference in habitat ranking among land-type associations was greatest between the LC and the three land-type associations in Rapid Creek drainage, and between habitat types of fifth- and sixth-order streams and those of eighth-order streams. The percentage of pools was higher and the percent area of glides was lower in the LC land-type association than in the land-type associations in the Rapid Creek drainage (Figure 2). The total percent composition of pools was similar among the three land-type associations within the Rapid Creek drainage. However, pools caused by beaver dams represented 92% of the pool area in the MRU, whereas beaver dams made up a much smaller percentage of the total pool area in the other two land-type associations in the Rapid Creek drainage.

Stepwise discriminant analysis of morphometric and water chemistry variables produced a four-variable model that was moderately effective in segregating land-type associations. The four significant variables in the order of their entry into the model were sulfate, turbidity, bank angle, and vegetation overhang; Wilks' lambda values were 0.488, 0.263, 0.178, and 0.129, respectively. All variables were significant. The criterion for inclusion in the model was the subjective evaluation of the declining contribution to the explained variation. This model reclassified about 70% of all habitat units to the correct land-type association (Table 2). The largest number of misclassifications of habitat types occurred in streams of the Rapid Creek drainage. Segregation of land-type associations was most accurate for the CC streams.

Biomass Comparisons

The biomass of brown trout differed significantly among land-type associations (F = 4.03, P = 0.02) and habitat types (F = 3.57, P = 0.01), whereas no differences were observed among land-type associations (F = 1.99, P = 0.11) or habitat types (F = 1.56, P = 0.16) for brook trout biomass (Table 3). Brown trout biomass was greatest in pool habitats and the LC land-type association, which had the highest areal percentage of pools. The ratios of pool to riffle plus rapid were 1.59 for LC, 0.48 for MRU, 0.28 for CC, and 0.25 for GDP. Mean brown trout biomass was higher than that of brook trout biomass in all land-type associations and habitat types except for lateral scour pools. Brown trout biomass was greater in the MRU and LC landforms whose streams were wider and deeper. Although no significant differences were detected in brook trout biomass among land-type associations, the highest mean biomass occurred in the GDP association streams that had the lowest average width and depth among all land-type associations.

Comparisons of trout biomass distribution with

Table 2. -Reclassification by stepwise discriminant analysis of habitat types by land-type association in the Black Hills. Parenthetic values represent the portion (%) of the habitat units classified for each land-type association per cell.

Land-type association	Crystalline canyon	Moderately rolling uplands	Gently dipping plateau	Limestone canyon
Crystalline canyon	68 (88.3%)	5 (6.5%)	3 (3.9%)	1(1.3%)
Moderately rolling uplands	9 (16.7%)	38 (70.4%)	7 (13.0%)	0 (0.0%)
Gently dipping plateau	4 (6.6%)	8 (13.1%)	43 (70.5%)	6 (9.8%)
Limestone canyon	1 (2.2%)	5 (11.1%)	8 (17.8%)	31 (68.9%)

the areas of various habitat types were consistent with the trends observed from the analysis of variance (Figure 3). The total percent of brown trout biomass was greater than the total percent of pool habitats available. The highest biomass of brown trout relative to habitat availability occurred in plunge pools. Brown trout biomass in higher-velocity habitats was always relatively low. Brook trout biomass was also relatively high in most pool habitats, but its biomass in glides was also relatively high. In general, brown trout and brook trout used lower-velocity habitats at a greater rate and higher-velocity habitats at a lesser rate. The habitat type most preferred by brook trout-lateral scour pools- was the habitat least used by brown trout.

Discussion

Physical attributes of individual habitat types were used effectively to segregate streams among the four watersheds studied in the Black Hills. In addition, habitat composition was independent of land-type association. The ability to discriminate among watersheds was consistent with the functional concept of hierarchical classification. This approach allows a habitat-based inventory method (Hankin and Reeves 1988) to be incorporated into land-aquatic classification systems such as those proposed by Lotspeich and Platts (1982) and Frissel et al. (1986).

However, our use of habitat types as functional units in classification was only partly successful in linking fish biomass to watershed characteristics. One variable must respond consistently to another if it is to be categorized. The consistent use of specific habitat types by anadromous salmonids has been observed by Everest and Chapman (1972), Bisson et al. (1982), and Hankin and Reeves (1988). In our study, brown trout used pool habitats at a higher rate than nonpool habitats, but use was not similar among all pool types. Relative biomass of brown trout was highest in plunge pools, intermediate in trench and dammed pools, and lowest in lateral scour pools. The highest mean biomass of brown trout occurred in the LC land-type association, which had the greatest area of pool habitat. Bisson et al. (1982) observed differential use of pool types by cutthroat trout *Oncorhynchus clarki,* and Kozel(1987) documented it for brown trout. The use of specific habitat types in Black Hills streams was important in determining the distribution of brown trout among watersheds.

Whereas brown trout showed patterns of use among habitat types, brook trout did not. Greatest brook trout biomass per unit area occurred in lateral scour pools. However, the land-type association (CC) with the greatest area of lateral scour pools was relatively low in brook trout biomass. Using the habitat-based model cowfish, Shepard (1989) reported "reasonable estimates" of cutthroat trout, rainbow trout *0. mykiss,* and their hybrids ($r^2 = 0.65$) for streams in the Beaverhead National Forest, but he was unsuccessful in predicting brook trout numbers ($r^2 = 0.14$). In part, the lack of a pattern in habitat use by Black Hills brook trout could have resulted from their inter-

TABLE 3.-Results of analysis of covariance of Black Hills trout biomass, by land-type association and habitat type, with stream order. Values are biomass (kg/hectare); those within a column with a letter in common are not significantly different ($P > 0.05$).

	Brown trout		Brook trout	
Variable	Land-type association	Habitat type	Land-type association	Habitat type
Crystalline canyon	75.7 z		38.8 z	
Moderately rolling uplands	84.4 z		31.8 z	
Gently dipping plateau	69.7 z		62.0 z	
Limestone canyon	181.1 y		53.2 z	
Glide		78.5 z		46.6 z
Riffle		52.0 z		34.6 z
Lateral scour pool		73.1 z		151.5 z
Rapid		108.5 y		22.5 z
Trench pool		154.6 x		43.5 z
Plunge pool		138.7 w		37.4 z
Beaver dam pool		98.7 v		41.2 z

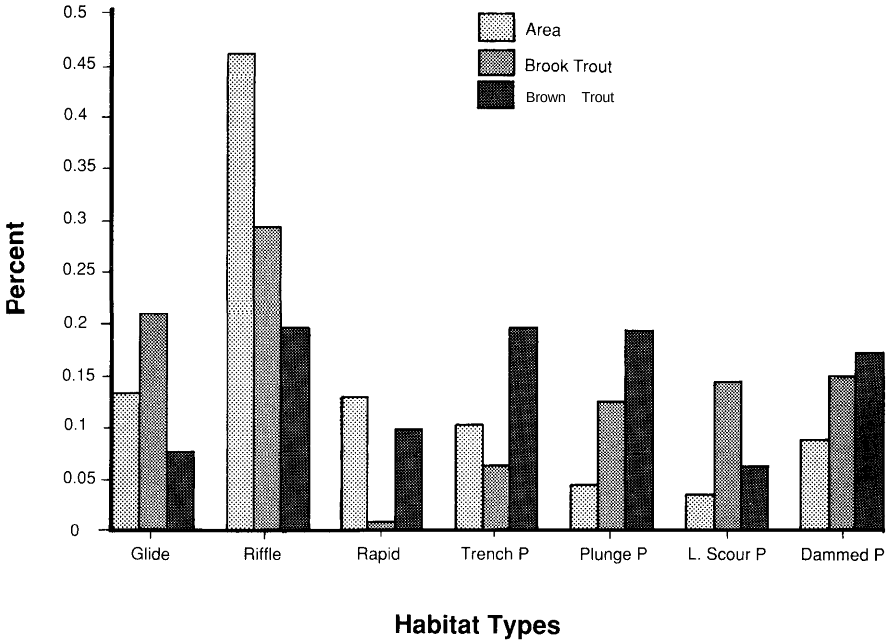

FIGURE 3.--Comparison of the total available area of habitat types with brown trout and brook trout biomasses from the four land-type associations within the Black Hills study area.

action with brown trout. Fechney (1988) observed that sympatric populations of brook and brown trout did not partition prey, and Fausch and White (198 1) and Cunjak and Power (1986) reported that both species used similar habitat. Kozel (1987) reported that the biomasses of brook and brown trout in the Medicine Bow National Forest were inversely correlated along an elevational gradient. Intermediate biomass in the land-type association with the greatest area of selected habitat, in addition to the inverse use of lateral scour pools, suggested some form of negative interaction between brown and brook trout in Black Hills streams.

We were able to distinguish four small Black Hills watersheds with physical, chemical, and brown trout biomass data collected from individual habitat units. The ability to categorize habitat resources by watershed in a timely and effective manner can assist resource managers in defining areas of high fishery potential or in planning habitat enhancement programs. However, the use of a hierarchical land-aquatic classification system for fishery resource management assumes that habitat has a major influence on the distribution and density of trout. In the Black Hills, brown trout density and distribution were consistently associated with habitat composition. Owing to competition or other factors, however, brook trout biomass was not associated with habitat composition among land-type associations. Thus, the habitat-based classification system represented an effective means of categorizing brown trout but provided little insight into the distribution and density of brook trout in Black Hills streams.

Acknowledgments

Funding for this study was provided by the Black Hills National Forest; South Dakota Department of Game, Fish and Parks; and the South Dakota Department of Water and Natural Resources. W. Lee Tucker and Jane Post offered guidance in statistical analysis. Constructive reviews of this manuscript were provided by Gordon Reeves and John Bissonette.

References

Bisson, P. A., J. L. Nielsen, R. A. Palmason, and L. E. Grove. 1982. A system of naming habitat types in small streams, with examples of habitat utilization by salmonids during low stream flow. Pages 62-73 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Cunjak, R. A., and G. Power. 1986. Winter habitat utilization of stream resident brook trout *(Salvelinus* *fontinalis)* and brown trout *(Salmo trutta).* Canadian Journal of Fisheries and Aquatic Sciences 43: 1970-1981.

Everest, F. H., and D. W. Chapman. 1972. Habitat selection and spatial interaction by juvenile chinook salmon and steelhead trout in two Idaho streams. Journal of the Fisheries Research Board of Canada 29:91-100.

Fausch, K. D., and R. J. White. 198 1. Competition between brook trout *(Salvelinusfontinalis)* and brown trout *(Salmo trutta)* for positions in a Michigan stream. Canadian Journal of Fisheries and Aquatic Sciences 38: 1220-l 227.

Fechney, L. R. 1988. The summer diet of brook trout *(Salvelinusfontinalis)* in a South Island high country stream. New Zealand Journal of Marine and Freshwater Research 22: 163-l 68.

Frissell, C. A., W. J. Liss, C. E. Warren, and M. D. Hurley. 1986. A hierarchical framework for stream habitat classification: viewing streams in a watershed context. Environmental Management 10: 199-214.

Gregory, K. J. 1966. Dry valleys and the composition of the drainage net. Journal of Hydrology 4:327-340.

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.

Kozel, S. J. 1987. Trends in habitat features and trout abundance among unaltered stream reaches on the Medicine Bow National Forest. Master's thesis. University of Wyoming, Laramie.

Lotspeich, F. B., and W. S. Platts. 1982. An integrated land-aquatic classification system. North American Journal of Fisheries Management 2: 138-l 49.

Platts, W. S., W. F. Megahan, and G. W. Marshall. 1983. Methods of evaluating stream, riparian, and biotic conditions. U.S. Forest Service General Technical Report INT 138.

SAS Institute. 1987. SAS/STAT guide for personal computers. SAS Institute, Cary, North Carolina.

Shepard, B. B. 1989. Evaluation of the U.S. Forest Service "COWFISH" model for assessing livestock impacts on fisheries in the Beaverhead National Forest, Montana. Pages 23-33 *in* R. E. Gresswell, B. A. Barton, and J. L. Kershner, editors. Practical approaches to riparian resource management. U.S. Government Printing Office, Washington, D.C.

Stoodley, K. D. C., T. Lewis, and C. L. S. Stainton. 1980. Applied statistical techniques. Wiley, New York.

USEPA (U.S. Environmental Protection Agency). 1974. Methods for chemical analysis of water and wastes. USEPA, Office of Technology Transfer, 16-74-003, Washington, D.C.

Wertz, W. A., and J. F. Arnold. 1972. Land systems inventory. U.S. Forest Service, Intermountain Region, Ogden, Utah.