Quantitative Relations of Physical Habitat Features to Channel Slope and Discharge in Unaltered Mountain Streams

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ABSTRACT

Two habitat gradients--channel slope and stream size--are important determinants of physical habitat features among streams in the central Rocky Mountains. Among 48 stream reaches in 15 streams in southeastern Wyoming, 35 habitat features were assessed for their relation to channel slope and stream size. Simple-regression analysis identified 21 habitat features significantly related to channel slope and 12 related to stream size. Multiple-regression analysis demonstrated that both channel slope and stream size significantly accounted for variation in 15 habitat features. Among the 35 habitat variables, 32 were significantly related to channel slope or stream size.

INTRODUCTION

Heede and Rinne (1990) described the importance of considering streamflow, sediment transport, and channel morphology when determining the interactions between physical and biological processes. Stream energy is a function of channel slope and discharge (Petts and Foster 1985) and is a determinant of sediment transport in streams. Linkage of these processes to definable habitat features important to trout has not been clearly defined.

Several studies in the central Rocky Mountains have shown that variation in channel slope (Chisholm and Hubert 1986, Lanka et al. 1989, Kozel et al. 1990) or stream size (Lanka et al. 1989, Kozel and Hubert 1989a, 1989b) affect standing stocks of trout in mountain streams. These studies suggest that habitat features vary with channel slope and stream size, but they do not describe quantitative relations of physical habitat features to variation in channel slope or stream size.

Kozel et al. (1989) described how physical habitat features differed between two classes of stream reaches based on channel slope. They found that reaches with low channel slopes (<1.5%) were deeper and narrower, possessed more overhanging bank and trench pools, and had smaller substrate particles, while reaches with moderate channel slopes had more woody debris with more plunge pools and dammed pools. They did not assess quantitative changes over the range of channels slopes or the simultaneous effects of variation in stream size on physical habitat features.

We suggest that two definable habitat gradients--channel slope and discharge--are major determinants of physical habitat features in streams. Streams in southeastern Wyoming that have been minimally influenced by human activity were studied to demonstrate the relations between physical habitat features, channel slope, and stream size. The lack of anthropogenic influences on the

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study streams enabled natural variation among streams to be evaluated. Our objectives were to determine if variation in physical habitat features was related to gradients of channel slope and stream size, and to quantitatively describe such relations when they were found.

METHODS

All study streams were in the Medicine Bow National Forest, south of Wyoming Highway 130 on the Snowy Range and east of the Continental Divide on the Sierra Madre. No endemic salmonids occurred in the study area, but brook trout Salvelinus fontinalis and brown trout Salmo trutta have been introduced. Populations are maintained by natural reproduction.

Potential study streams between 2350 and 3000 m above mean sea level were selected from U.S. Forest Service records and U.S. Geological Survey topographic maps. About 8% of all stream channels in the study area have a channel slope of 0.1-1.4%, and 90% have slopes of 1.5-4.0%. Fifteen watersheds (0.7 - 100 km^2) were selected that had been minimally affected by human activity; that is, they had no history of clearcut logging, overgrazing, or mining.

The transect method was used to measure stream habitat features over the 200-m reaches during late summer and early autumn (Platts et al. 1983). In 1985, transects were spaced 2 m apart, and point measurements were made at 0.3-m intervals not including the banks. In 1986, the transects were 4 m apart, and point measurements were made at seven equally spaced locations not including the banks. At each transect wetted width was measured. Bankfull width, defined by the mark left on both banks during the peak spring flow, was measured at five transects equally spaced over the reach. At each point across a transect, we visually determined the dominant substrate, embeddedness, microhabitat, and cover. Substrate was classified into six categories (after Platts et al. 1983; diameter in parentheses): small fine sediment ($\leq$0.8 mm), large fine sediment (0.9-4.7 mm), gravel (4.8-76.0 mm), cobble (77-304 mm), small boulder (305-609 mm), and large boulder ($\geq$610 mm). Embeddedness (amount of fine sediment surrounding the underlying substrate particles) was visually rated from zero to 100% (Platts et al. 1983). Habitat types were classified according to Bisson et al. (1982). Cover was classified into three categories: boulder, woody debris, or aquatic vegetation. Undercut bank and overhanging vegetation were measured at each bank. Over the length of each reach, stream sinuosity was determined as the ratio of the reach length to the straight line distance over the reach. The number of log dams in each reach was determined.

Channel slope was measured over a representative 30-m section of each reach using a surveyor's level (Platts et al. 1993). Discharge was estimated using a current meter at one transect at the lower end of each reach (Buchanan and Somers 1969). Discharge during late summer or early fall was the measure of stream size selected for use in this analysis.

Summary statistics for 35 habitat variables at each sampling reach were developed from the field measurements to assess the relations of channel slope and discharge to the physical habitat features. Simple- and multiple-regression analyses were used to determine relations among the measured variables. All statistical relations were accepted as significant at $P \leq 0.05$. Computations were done using STATISTIX 3.1 (Analytical Software 1990).

RESULTS

Forty-eight stream reaches were sampled in 1985 and 1986 (Table 1). Elevation of the study reaches extended from 2,377 to 2,975 m above sea level. Discharge during late summer or early fall ranged from 0.003 to 2.12 m^3/s, while channel slope varied from 1.16% to 7.12%. Substantial variation also occurred in the 35 habitat features describing the 48 stream reaches (Table 1).

Table 1. Means and ranges of habitat variables in 48 study reaches in 15 streams of southeastern Wyoming.

Variable	Mean	Range
Channel slope (%)	2.05	0.16 - 7.16
Discharge (m^3/second)	0.334	0.003 - 2.12
Mean bankfull width (m)	3.52	0.58 - 11.48
Mean wetted width (m)	3.00	0.40 - 9.25
CV wetted width	40.0	16.6 - 66.9
Mean water depth (cm)	16	8 - 34
CV water depth	63	39 - 100
Mean width-to-depth ratio	9.4	2.0 - 23.5
Sinuosity	1.38	1.01 - 2.22
Large boulders (%)	3.0	0.0 - 27.5
Small boulders (%)	9.3	0.0 - 28.6
Cobble (%)	37.3	2.6 - 67.6
Gravel (%)	39.7	7.6 - 77.4
Large sediment (%)	5.8	0.0 - 36.7
Small sediment (%)	4.9	0.0 - 53.1
Embeddedness (%)	40.5	14.7 - 97.5
CV embeddedness	97.2	11.9 - 166.7
Riffle (%)	35.0	7.7 - 61.6
Rapid (%)	1.3	0.0 - 10.7
Cascade (%)	0.1	0.0 - 1.8
Secondary channel pool (%)	0.6	0.0 - 4.9
Backwater pool (%)	12.3	0.0 - 28.1
Trench pool (%)	13.4	0.0 - 67.0
Plunge pool (%)	2.8	0.0 - 17.3
Lateral scour pool (%)	2.2	0.0 - 11.6
Dammed pool (%)	17.4	0.5 - 48.9
Boulder cover (%)	0.6	0.0 - 6.6
Woody cover (%)	4.1	0.0 - 13.9
Aquatic vegetation cover (%)	6.3	0.0 - 62.7
Pools with boulder cover (%)	0.9	0.0 - 12.0
Pools with woody cover (%)	6.6	0.0 - 18.5
Pools with aquatic vegetation cover (%)	5.6	0.0 - 55.4
Pools $\geq$ 30 cm deep (%)	24.1	0.0 - 87.3
Maximum pool depth (cm)	61	31 - 107
Undercut bank (%)	35.1	7.9 - 90.2
Overhanging vegetation (%)	34.5	4.0 - 77.9
Log dams (number/100 m)	1.3	0.0 - 6.6

Simple-regression analysis identified that channel slope significantly accounted for variation in 21 of 35 habitat features (Table 2). As channel slope increased there were increases in the extent of variation in water depth and embeddedness, the amount of large substrate particles, and the extent of riffles, cascades, plunge pools, and dammed pools. However, as channel slope increased there were decreases in sinuosity, the abundance of gravel substrate, the extent of trench pools and lateral scour pools, the depth of pools, and the amount of undercut banks.

Significant simple-regression models were found for 12 of the 35 variables where discharge accounted for variation in the habitat feature (Table 2). As discharge increased there were increases in stream width, water depth, width-to-depth ratio, and abundance of rapids among the 48 stream reaches. Similarly, as discharge increased there were declines in the extent of variation in wetted width, abundance of woody cover and overhanging vegetation, and frequency of log dams.

When multiple-regression analysis was applied using channel slope and discharge as independent variables, both variables significantly accounted for variation in 15 habitat features (Table 2). These features included measures of water depth, discriptors of bottom substrate, four kinds of microhabitat, boulder cover, and undercut bank.

Among the 35 habitat variables that were assessed, variation was significantly accounted for among 32 from knowledge of channel slope, discharge, or the two in combination. The only habitat features that did not have statistically significant relations with channel slope or discharge were abundance of secondary channel pools, amount of aquatic vegetation cover, and extent of pools with aquatic vegetation.

DISCUSSION

Consideration of stream size as a habitat gradient affecting physical habitat features in mountain streams was stimulated by the "River Continuum Concept" which describes changes in structure and function through lengths of river systems (Vannote et al. 1980). The concept suggests that the physical structure of the channel coupled with the hydrological cycle and energy inputs results in a consistent pattern of community structure and function along the length of a stream (Schlosser 1982). In mountain streams, the concept focuses largely on riparian vegetation and its influence on physical and biological processes (Murphy and Meehan 1991). We observed that riparian features varied with changes in stream size and channel slope among the study reaches in southeastern Wyoming. Reaches with higher channel slopes occurred in coniferous forests, where little riparian vegetation occurred. Physical habitat in these reaches was greatly influenced by the presence of large woody debris and underlying rock (Andrus et al. 1988, Marcus et al. 1990, Hicks et al. 1991).

Among our study reaches, low channel slopes occurred in areas of alluvial deposits. Meander processes (Hasfurther 1985) were the primary means by which stream habitat features were formed in these reaches. Willows (Salix) and sedges (Carex) in riparian areas tended to stabilize the banks of small streams and contributed to the formation of trench pools and undercut banks, habitat features important to trout (Wesche et al. 1987a, 1987b). As stream size increased among low-gradient reaches, there was more bank erosion and fewer trench pools and undercut banks. Trench pools and associated undercut banks provide cover for trout and substrate for aquatic invertebrates important as food for trout (Rhodes and Hubert 1991).

Table 2. Simple- and multiple-regression models in which channel slope (S), discharge (D), or the two in combination, significantly account for variation in habitat features in 48 study reaches in southeastern Wyoming.

Independent variable	Equation	r^2 or R^2	P
	Channel slope		
Mean water depth	= - 2.572 S + 21.58	0.47	< 0.0001
CV water depth	= 4.260 S + 53.76	0.27	0.0001
Sinuosity	= 0.107 S + 1.59	0.37	< 0.0001
Large boulders	= 1.877 S - 0.88	0.34	< 0.0001
Small boulders	= 1.756 S + 5.71	0.11	0.0212
Cobble	= 5.183 S + 26.66	0.22	0.0009
Gravel	= - 5.639 S + 51.24	0.18	0.0024
CV embeddedness	= 6.405 S + 84.01	0.08	0.0476
Riffles	= 4.064 S + 26.68	0.23	0.0006
Cascades	= 0.117 S - 0.10	0.24	0.0004
Trench pools	= - 4.032 S - 21.63	0.16	0.0053
Plunge pools	= 1.523 S - 0.29	0.50	< 0.0001
Lateral scour pools	= - 0.786 S + 3.82	0.18	0.0029
Dammed pools	= 2.876 S + 11.52	0.21	0.0009
Boulder cover	= 0.365 S - 0.12	0.23	0.0006
Pools with boulder cover	= 0.651 S - 0.37	0.24	0.0004
Pools with woody cover	= 1.094 S + 4.31	0.08	0.0461
Pools ≥ 30 cm deep	= - 7.714 S + 39.98	0.32	< 0.0001
Maximum pool depth	= - 4.438 S + 70.38	0.13	0.0121
Undercut bank	= - 4.322 S + 44.00	0.12	0.0182
Log dams	= 0.607 S + 0.02	0.41	< 0.0001
	Discharge		
Mean bankfull width	= 3.422 D + 2.38	0.52	< 0.0001
Mean wetted width	= 3.072 D + 1.97	0.61	< 0.0001
CV wetted width	= - 6.021 D +38.00	0.10	0.0315
Mean water depth	= 8.209 D +13.56	0.60	< 0.0001
Mean width-to-depth ratio	= 3.980 D + 8.06	0.18	0.0028
Rapids	= 1.480 D + 0.79	0.12	0.0147
Woody cover	= - 2.470 D + 4.88	0.14	0.0088
Pools with woody cover	= - 3.500 D + 7.73	0.11	0.0226
Pools ≥ 30 cm deep	= 28.772 D +14.53	0.56	< 0.0001
Maximum pool depth	= 19.377 D +54.79	0.31	< 0.0001
Overhanging vegetation	= - 19.190 D +40.93	0.21	0.0011
Log dams	= - 0.909 D + 1.57	0.12	0.0173
	Channel Slope and Discharge		
Mean wetted width	= - 1.763 S + 6.459 D +17.77	0.79	< 0.0001
Small boulders	= 2.301 S + 4.353 D + 3.14	0.18	0.0101
Cobble	= 6.701 S + 12.115 D +19.50	0.35	0.0001
Large sediment	= - 2.203 S - 4.976 D +12.00	0.16	0.0180
Small sediment	= - 2.360 S - 6.084 D +11.81	0.15	0.0271
CV embeddedness	= 8.792 S + 19.064 D +72.74	0.16	0.0180
Embeddedness	= - 5.380 S - 14.902 D +56.53	0.21	0.0045
Riffles	= 4.935 S + 6.953 D +22.57	0.30	0.0003
Rapids	= 0.427 S + 1.904 D - 0.23	0.19	0.0079
Backwater pools	= 1.318 S + 3.767 D + 8.35	0.12	0.0511
Trench pools	= - 5.179 S - 9.163 D +27.05	0.25	0.0017
Boulder cover	= 0.452 S + 0.693 D - 0.52	0.32	0.0002
Pools with boulder cover	= 0.788 S + 1.092 D - 1.02	0.32	0.0002
Pools ≥ 30 cm deep	= - 4.694 S + 24.111 D +25.72	0.67	< 0.0001
Undercut bank	= - 6.138 S - 14.497 D +52.57	0.26	0.0012

Our analysis supports the hypothesis that much of the variation in physical habitat features among mountain streams is a function of change along two habitat gradients: channel slope and stream size. The quantitative relations described in this paper can be used by ecologists and managers to identify trends in physical habitat features with variation in channel slope or stream size among streams in the central Rocky Mountains. Consideration of these two habitat gradients can provide a simplified basis for developing and assessing models that assess habitat quality or predict standing stocks of trout from measured habitat features. The seemingly unrelated models that have been developed, such as those described by Fausch et al. (1988), have many similarities when viewed within this framework.

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LITERATURE CITED

Analytical Software. 1990. STATISTIX manual. Analytical Software, Saint Paul, Minnesota.

Andrus, C. W., B. A. Long, and H. A. Froehlich. 1988. Woody debris and its contribution to pool formation in a coastal stream 50 years after logging. Can. J. Fish. Aq. Sci. 45: 2080-2086.

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.

Buchanan, T. J., and W. P. Somers. 1969. Techniques of water-resources investigations of the United States Geological Survey. U.S. Government Printing Office, 2401-0498, Washington, D.C.

Chisholm, I. M., and W. A. Hubert. 1986. Influence of stream gradient on standing stock of brook trout in the Snowy Range, Wyoming. Northwest Sc. 60: 137-139.

Fausch, K. D., C. L. Hawkes, and M. G. Parsons. 1988. Models that predict standing crop of stream fish from habitat variables: 1950-85. U.S. Forest Service General Technical Report PNW-213.

Hasfurther, V. R. 1985. The use of meander parameters in restoring hydrologic balance to reclaimed stream beds. Pages 21-40 in J. A. Gore (ed). The Restoration of Rivers and Streams. Butterworth Publishers, Boston.

Heede, B. H., and J. N. Rinne. 1990. Hydrodynamic and fluvial morphologic processes: implications for fisheries management and research. No. Amer. J. Fish. Manage. 10: 249-268.

Hicks, B. J., J. D. Hall, P. A. Bisson, and J. R. Sedell. 1991. Responses of salmonids to habitat changes. Amer. Fish. Soc. Spec. Publ. 19: 483-518.

Kozel, S. J., and W. A. Hubert. 1989a. Factors influencing the abundance of brook trout (Salvelinus fontinalis) in forested mountain streams. J. Freshwater Ecol. 5: 113-122.

Kozel, S. J., and W. A. Hubert. 1989b. Testing of habitat assessment models for small trout streams in the Medicine Bow National Forest, Wyoming. No. Amer. J. Fish. Manage 9: 458-464.

Kozel, S. J., W. A. Hubert, and M. G. Parsons. 1989. Habitat features and trout abundance relative to gradient in some Wyoming streams. Northwest Sci. 63: 175-182.

Kozel, S. J., W. A. Hubert, and M. G. Parsons. 1990. Relations of habitat features to brown trout abundance in unimpacted drainages on the Medicine Bow National Forest, Wyoming. Pages 38-44 In J. C. Borawa, (ed). Brown Trout Workshop: Biology and Management. American Fisheries Society, Southern Division, Asheville, North Carolina.

Lanka, R. P., W. A. Hubert, and T. A. Wesche. 1987. Relations of geomorphology to stream habitat and trout standing stock in small Rocky Mountain streams. Trans. Amer. Fish. Soc. 116: 21-28.

Marcus, M. D., M. K. Young, L. E. Noel, and B. A Mullan. 1990. Salmonid-habitat relationships in the western United States: a review and indexed bibliography. U.S. Forest Service General Technical Report RM-188.

Murphy, M. L., and W. R. Meehan. 1991. Stream ecosystems. Amer. Fish. Soc. Spec. Publ. 19: 17-46.

Petts, G., and I. Foster. 1985. Rivers and landscape. Edward Arnold, London.

Platts, W. W., 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.

Rhodes, H. A., and W. A. Hubert. 1991. Submerged undercut banks as macroinvertebrate habitat in a subalpine meadow stream. Hydrobiologia 213: 149-153.

Schlosser, I. J. 1982. Fish community structure and function along two habitat gradients in a headwater stream. Ecol. Monographs 52: 395-414.

Vannote, R. L., G. W. Minshall, K. W. Cummins, J. R. Sedell, and C. E. Cushing. 1980. The River Continuum Concept. Can. J. Fish. Aq. Sci. 37: 130-137.

Wesche, T. A., C. M. Goertler, and C. B. Frye. 1987a. Contribution of riparian vegetation to trout cover in small streams. No. Amer. J. Fish. Manage. 7: 151-153.

Wesche, T. A., C. M. Goertler, and W. A. Hubert. 1987b. Modified habitat suitability index model for brown trout in southeastern Wyoming. No. Amer. J. Fish. Manage. 7:232-237.

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