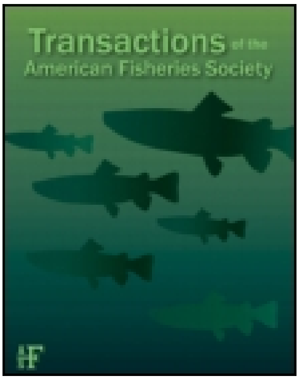

Transactions of the American Fisheries Society
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/utaf20

Geomorphic Influences on the Distribution of Yellowstone Cutthroat Trout in the Absaroka Mountains, Wyoming

Carter G. Kruse [a], Wayne A. Hubert [a] & Frank J. Rahel [b]

[a] U.S. Geological Survey Wyoming Cooperative Fish and Wildlife Research Unit, University of Wyoming, Laramie, Wyoming, 82071, USA

[b] Department of Zoology and Physiology, University of Wyoming, Larande, Wyoming, 82071, USA

Available online: 09 Jan 2011

Transactions of the American Fisheries Society 126:418–427, 1997

Geomorphic Influences on the Distribution of Yellowstone Cutthroat Trout in the Absaroka Mountains, Wyoming

CARTER G. KRUSE AND WAYNE A. HUBERT

U.S. Geological Survey, Wyoming Cooperative Fish and Wildlife Research Unit[1]
University of Wyoming, Laramie, Wyoming 82071, USA

FRANK J. RAHEL

Department of Zoology and Physiology, University of Wyoming
Laramie, Wyoming 82071, USA

Abstract.—Influences of large-scale abiotic, geomorphic characteristics on distributions of Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri* are poorly understood. We sampled 151 sites on 56 perennial streams in the Greybull–Wood river drainage in northwestern Wyoming to determine the effects of geomorphic variables on Yellowstone cutthroat trout distributions. Channel slope, elevation, stream size, and barriers to upstream movement significantly influenced the presence and absence of Yellowstone cutthroat trout. Wild populations of Yellowstone cutthroat trout were not found upstream of barriers to fish migration, at sites with channel slopes of 10% or greater, or at elevations above 3,182 m. Based on channel slope alone, logistic regression models correctly classified presence or absence of Yellowstone cutthroat trout in 83% of study sites. The addition of elevation and stream size in the models increased classification to 87%. Logistic models tested on an independent data set had agreement rates as high as 91% between actual and predicted fish presence. Large-scale geomorphic variables influence Yellowstone cutthroat trout distributions, and logistic functions can predict these distributions with a high degree of accuracy.

Yellowstone cutthroat trout *Oncorhynchus clarki bouvieri* inhabit a larger geographic range than any other cutthroat trout subspecies except coastal cutthroat trout *O. c. clarki* (Varley and Gresswell 1988). As in other interior stocks of cutthroat trout, hybridization (Leary et al. 1984; Campton and Utter 1985; Gresswell 1995) and competition with exotic fishes (Griffith 1988; Young 1995), as well as anthropogenic influences (logging, mining, agriculture, irrigation; Hanzel 1959; Allendorf and Leary 1988; Thurow et al. 1988; Gresswell 1995), have reduced the distribution of Yellowstone cutthroat trout by 70–90% since settlement by Europeans (Hadley 1984; Varley and Gresswell 1988; Behnke 1992; Young 1995).

Declines in Yellowstone cutthroat trout distributions have been most severe in high-order, low-elevation streams where human impacts are greatest (Hanzel 1959; Gresswell 1988; Young 1995). Limited access to remote, high-elevation drainages and public ownership of most of these systems have contributed to protection of Yellowstone cutthroat trout populations and their habitats (Gresswell 1995). Hanzel (1959), Behnke and Zarn (1976), Scarnecchia and Bergersen (1986), and Varley and Gresswell (1988) noted that most genetically pure populations of Yellowstone cutthroat trout occur in high-elevation headwaters in remote areas. Additionally, Behnke (1992) suggested the cutthroat trout may have a selective advantage over nonnative trout in these areas because they may function better in cold environments.

Persistence of fish species in a stream system is influenced by the ability of the fish to successfully use the habitat for cover, to acquire food, to interact with other fish in the community, and to reproduce (Bozek and Hubert 1992). Constraints imposed by physical habitat can limit species persistence; thus, identification of the abiotic factors that limit species distributions is important. Catastrophic events (Lamberti et al. 1991) and fish migration barriers (Stuber et al. 1988; Rieman and McIntyre 1993) can have major impacts on fish survival and distributions.

Habitat features that characterize trout distributions and abundance have been a common focus of research (e.g., Fausch et al. 1988; Nelson et al. 1992; Rieman and McIntyre 1995). As Yellowstone cutthroat trout populations continue to decline, it is imperative that fishery managers un-

[1] The Unit is jointly supported by the University of Wyoming, Wyoming Game and Fish Department, U.S. Department of the Interior, and Wildlife Management Institute.

derstand the environmental processes that control the habitat and, ultimately, fish populations in areas where native fish still persist. Until recently, biologists have attempted to characterize habitats through traditional, small-scale approaches such as stream reach or habitat unit inventories (Rieman and McIntyre 1995). But, as Nelson et al. (1992) and Rieman and McIntyre (1995) pointed out, it may be more important to understand trout distribution and response to habitat based on a spatially large-scale, geomorphic approach.

Trout habitat has been linked to large-scale geomorphic variables (Lanka et al. 1987; Hubert and Kozel 1993). Several researchers have shown that measures of elevation, channel slope, and stream size are useful indicators of trout occurrence (Platts 1979; Lanka et al. 1987; Kozel and Hubert 1989; Nelson et al. 1992; Rieman and McIntyre 1995). Incidence functions, based on these types of variables, that predict presence or absence of trout populations can be useful tools, particularly in areas where little detailed habitat or population information is available (Rieman and McIntyre 1995).

Although generalized distributions of Yellowstone cutthroat trout in Wyoming are known, accurate descriptions of their specific locations are not available. Several areas have been identified by the Wyoming Game and Fish Department as having high potential to contain remnant, genetically pure Yellowstone cutthroat trout populations, including the Greybull–Wood river drainage in northwestern Wyoming.

The purpose of this study was to determine the distribution of Yellowstone cutthroat trout in the Greybull–Wood river drainage and to determine whether geomorphic features and stream size affect these distributions. We developed logistic regression models based on large-scale geomorphic features and stream size to predict Yellowstone cutthroat trout distributions within the drainage.

Study Area

The Greybull River, including its primary tributary, the Wood River, is the third largest tributary to the Bighorn River. It drains more than 2,900 km^2 of the eastern Absaroka Range in northwestern Wyoming. The study area included that portion of the Greybull–Wood river drainage within the Shoshone National Forest (Figure 1). Fifty-six perennial tributaries (355 km of total stream length) occur in the 650-km^2 headwater drainage.

The Greybull River and its tributaries tend to be torrential, high-elevation mountain streams with high channel slopes, unstable substrates, and large fluctuations in discharge from spring to late summer (Hansen and Glover 1973). Elevations of streams in the study area range from 2,300 to 3,250 m above mean sea level. Channel slopes range from 0.5% to 25% with a mean of 8.5%, which is generally considered steep (Kondolf et al. 1991; Rosgen 1994). Snowmelt dominates the annual hydrograph and results in extremely high spring flows (Hansen and Glover 1973; Martner 1982; Zafft and Annear 1992). Wetted stream width of the mainstream Greybull River during late summer varies from 3.5 m at the glacial headwaters to 25 m at the Shoshone National Forest boundary with most tributary streams ranging 2.5–5 m in width.

The volcanicly derived watershed (Keefer 1972) is steep and rugged with uplifted peaks and deep valleys, resulting in mountain streams that have steep longitudinal profiles and low biological productivity. Stream substrates and banks are predominately erodible volcanic material (Hansen and Glover 1973; Zafft and Annear 1992), which, coupled with high spring flows and steep channel slopes, result in channels that shift regularly (Kent 1984), are strewn with large angular rocks, are poorly defined, and provide limited fish habitat.

The Greybull River, historic Yellowstone cutthroat trout range, is currently managed by the Wyoming Game and Fish Department as a native sport fishery for cutthroat trout. Mountain whitefish *Prosopium williamsoni*, mountain suckers *Catostomus platyrhynchus*, longnose dace *Rhinicthys cataractae*, and brook trout *Salvelinus fontinalis* are also present in the drainage (Yekel 1980). Rainbow trout *O. mykiss* were stocked in the drainage but are no longer present (electrophoretic analysis failed to detect rainbow trout alleles in the population). McBride Lake and LeHardy Rapids strains of Yellowstone cutthroat trout have been periodically stocked in four previously barren stream reaches above fish migration barriers since 1985 (Kruse 1995).

Anthropogenic influences on the Greybull River watershed are relatively minor. Fishing pressure is low because of limited access (Yekel 1980). The Greybull River drainage, especially the Wood River near Kirwin, has been prospected for minerals since the 1890s. Mining activity was highest between 1892 and 1907, but viable operations continued into the 1960s (Hansen and Glover 1973). Because of limited human influence, the Greybull River drainage is considered to be essentially unimpacted.

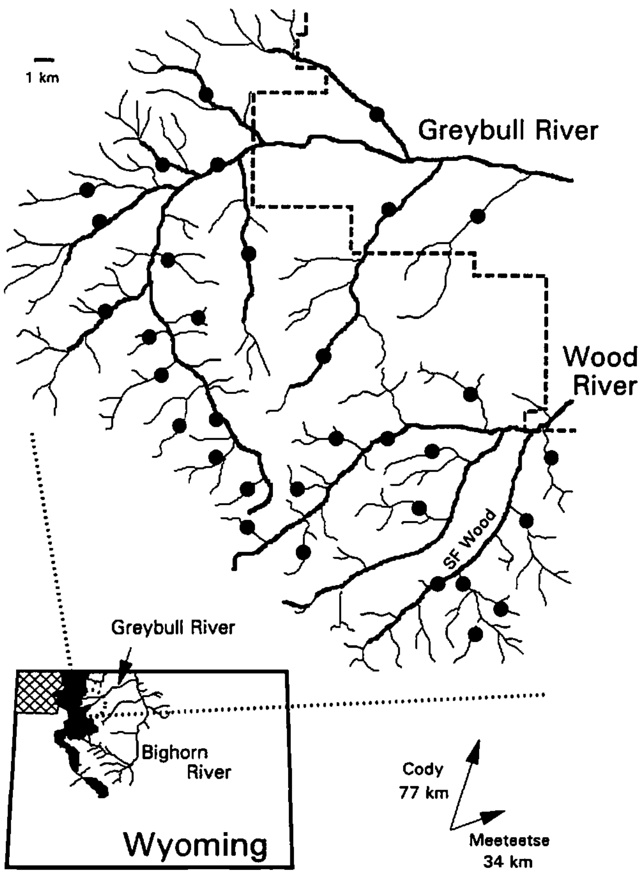

FIGURE 1.—The upper Greybull River drainage within the Shoshone National Forest (inset, blackened area) in northwestern Wyoming, east of Yellowstone National Park (inset, crosshatched area). Spots indicate streams on which at least one sample was taken. Dashed line indicates Shoshone National Forest boundary.

Methods

Study streams within the Greybull River drainage were selected by using two criteria: availability of permanent stream flow (based on U.S. Geological Survey [USGS] 1:24,000-scale topographic maps) and potential to support a trout population (Wyoming Game Fish Department, unpublished data). Perennial streams were sampled from June to September 1994 with Smith-Root 12-B programmable output waveform, battery-powered backpack electroshockers.

Sampling was initiated at the confluence of each tributary within the Greybull and Wood river drainage and progressed upstream at approximately 1-km intervals. At each location, a one-pass electrofishing run was performed across a 100-m stream reach. Additional stream reaches were sampled immediately downstream and upstream from permanent barriers to fish migration (Stuber et al. 1988; Rieman and McIntyre 1993) to assess barrier effects on fish presence. Barriers were defined as geologic structures at least 1.5 m high (Stuber et al. 1988) or reaches of very high channel slope or water velocity. Sampling progressed upstream until trout were no longer present; then an additional upstream site was sampled to ensure fish absence further upstream in the drainage and to obtain additional site information from areas where fish were not found. Sampling sites were grouped into four categories: (1) fish present with no downstream barrier to migration; (2) fish present above downstream barrier (s) to migration; (3) fish absent with no downstream barrier to migration; and (4) fish absent above a barrier to fish migration.

The locations (latitude, longitude) and elevations (meters) of sampling sites and barriers to fish migration were identified with global positioning units and USGS topographic maps. Barrier heights (nearest 0.1 m) and composition were recorded. Wetted stream width (nearest 0.05 m) was measured with a tape perpendicular to stream flow at four transects spaced equally within the 100-m reach. Channel slope (%) was estimated with a clinometer for the entire 100-m reach. Stream lengths (kilometers) were measured with an electronic map wheel from 1:24,000-scale USGS topographic maps.

Normal distributions of the data allowed use of a one-way analysis of variance (ANOVA) to test for differences in geomorphic and stream size features among the four categories. When significant differences were found, Tukey's multiple-comparison test was used to assess differences among categories. Pearson correlations were used to determine relations among channel slope, elevation, and wetted width (Krebs 1989). Logistic regression was used to develop incidence functions because of the binomial nature of the dependent variable (fish presence–absence) and because it provides a probabilistic prediction. To allow for independent testing of the model, the data set was divided by subdrainage and the logistic models were developed with sites from the Greybull River drainage and tested on sites from the Wood River drainage. Because barriers influence fish movement and distributions, we performed logistic regression analysis for only those sites unaffected by fish migration barriers (i.e., sites below barriers or sites with Yellowstone cutthroat trout above barriers). Models were also developed without sites having gradients higher than 10%. The logistic function form is

$$P = e^{u}/(1 + e^{u}),$$

where P = probability of Yellowstone cutthroat trout presence or absence, e = the inverse natural logarithm of 1, and u = linear model:

$$u = f + b_1X_1 + b_2X_2 + \ldots + b_nX_m,$$

where f = regression constant, b_n = regression coefficients, and X_m = independent variables. The maximum (−2) log-likelihood method was used to estimate regression coefficients (Hosmer and Lemeshow 1989).

Appropriateness of each model was evaluated with the (−2) log-likelihood statistic (hereafter referred to as the log-likelihood statistic); statistical significance was assessed with a chi-square test. Reductions in the log-likelihood indicate improved model fit because the statistic is analogous to the residual sums of squares in linear regression, and it measures observed value deviation from the model (Hosmer and Lemeshow 1989). Cutthroat trout presence–absence probabilities were predicted by the logistic models and compared with observed values. Predicted probabilities of 0.50 or greater indicated cutthroat trout were present, and probabilities less than 0.50 indicated absence. Kappa values were tested to determine whether trout classifications by logistic functions were significantly different than random classifications. The kappa statistic (Titus et al. 1984) expresses the proportion of sites correctly classified by the model after removing the effect of correct classification by chance (Beauchamp et al. 1992).

The logistic models from the Greybull River drainage were applied to an independent data set from the Wood River drainage to test model performance in predicting fish presence. Predicted probabilities of 0.50 or greater indicated probable fish presence, whereas probabilities less than 0.50 indicated fish absence. Statistical analyses were performed with SPSS/PC+ (SPSS 1991). Significance was determined at $P < 0.05$ for all tests.

Results

The distributions of Yellowstone cutthroat trout were described by using samples from 151 locations on 56 streams throughout the Greybull–Wood river drainage. Cutthroat trout were present in 15 of 33 Greybull River tributaries (58 of 89 sites) and in 7 of 23 Wood River tributaries (31 of 62 sites). Cutthroat trout were sampled from 116 of 236 km (49%) of perennial streams in the Greybull River drainage and from 44 of 119 km (37%) of streams within the Wood River drainage. Within the entire Greybull River drainage, 45% (160 km) of the 355 total km of perennial streams contained cutthroat trout, but the remaining 55% lacked fish because of barriers to fish migration or inadequate habitat associated with stream gradients steeper than 10%.

No wild cutthroat trout populations were found above fish migration barriers. Barriers to upstream migration of Yellowstone cutthroat trout were found on 17 of the 56 study streams. Fish were present in 15 of the 17 streams blocked by barriers; in 11 of these 15, fish were present up to the base of the barrier and absent upstream. The other four streams had recently been stocked with Yellowstone cutthroat trout above the barrier by the Wyoming Game and Fish Department. Introduced Yellowstone cutthroat trout upstream from barriers occupied 20 of 160 km (12.5%) of stream reaches where cutthroat trout were found.

Sites with cutthroat trout present had channel slopes less than 10% and were at elevations of 3,182 m or less. Elevations of the study sites

TABLE 1.—Physical habitat characteristics for the four categories of cutthroat trout presence or absence. Means along a row not sharing a common lowercase letter indicate significant difference among categories (Tukey, $P \leq 0.05$).

Stream characteristic and statistic	Fish present, no barrier	Fish absent, no barrier	Fish present above barrier	Fish absent, barrier present	P
Channel slope (%)					
Mean	4.4 z	9.6 x	4.0 zy	6.7 y	<0.001
SD	2.9	5.6	1.7	2.9	
Range	1–17	0.5–25	2–7.1	2–12.5	
N	73	38	15	23	
Elevation (m)					
Mean	2,437 z	2,768 y	2,774 y	2,657 y	<0.001
SD	216	197	111	237	
Range	2,096–3,182	2,356–3,146	2,569–2,996	2,321–3,206	
N	74	39	15	23	
Wetted width (m)					
Mean	4.90 z	3.05 y	4.15 zy	3.15 y	<0.001
SD	2.85	1.25	1.40	1.50	
Range	1.4–15.8	1.3–7.7	2.3–7.4	1.5–6.8	
N	74	39	15	23	

ranged from 2,096 to 3,206 m, channel slopes ranged from 0.5% to 25%, and wetted widths ranged from 1.3 to 15.8 m (Table 1). Cutthroat trout were found at one site with a channel slope of 17%. However, vertical falls were situated only 1.5 km upstream from this creek's confluence with the Greybull River, and only three adult cutthroat trout were collected, suggesting this was not a resident population. This site was dropped from the logistic regression analysis.

Mean elevation was significantly lower at sites where Yellowstone cutthroat trout were present without downstream barriers than at sites where Yellowstone cutthroat trout were stocked above barriers or where fish were absent (Table 1). Elevation did not differ among sites void of Yellowstone cutthroat trout, with or without barrier effects, and sites with stocked cutthroat trout upstream from barriers.

Channel slopes were significantly higher at sites where Yellowstone cutthroat trout were absent without influence from barriers to fish migration compared with both categories of fish presence. The proportion of sites occupied by Yellowstone cutthroat trout declined linearly with increasing channel slope from 0% to 10%.

Stream size, indicated by mean wetted width, was significantly greater at sites where Yellowstone cutthroat trout were present with no barrier than at sites where Yellowstone cutthroat trout were absent with or without a barrier (Table 1). However, mean width was highly variable among all sites sampled. Channel slope, elevation, and stream size all had significant effects on trout distributions; however, these variables were highly correlated, making it difficult to determine which characteristic had the greatest influence in predicting fish distributions (Figure 2).

Logistic models were developed by using stream variables observed to be significantly different between sites where fish were present and absent (Table 1). Models developed by using only channel slope classified 83% of the sites in the Greybull River drainage correctly when barrier influences were not considered (Table 2). High correct classification and the lowest log-likelihood values occurred with the inclusion of channel slope, elevation, and a measure of stream size in the model; however, the stream size regression coefficient was not significant in any model. Model 2 (Table 2) containing channel slope and elevation, correctly classified 87% of all sites and had a log-likelihood value only slightly higher than model 3. All models had significant chi-square values and predicted presence–absence of cutthroat trout with 80–87% overall correct classification.

Kappa values (Table 2) indicated that all models classified Yellowstone cutthroat trout presence significantly better than chance correct classifications. Classifications from all models were at least 32% better than chance alone, and most models were more than 50% better.

All logistic models except model 4 had high rates of agreement between actual and predicted fish presence when tested on sites from the Wood River drainage (Table 3). Although model 1, containing only channel slope, had a higher log-likelihood and lower overall correct classification than models 2 or 3 had, it had the highest agreement between actual and predicted fish presence (91%).

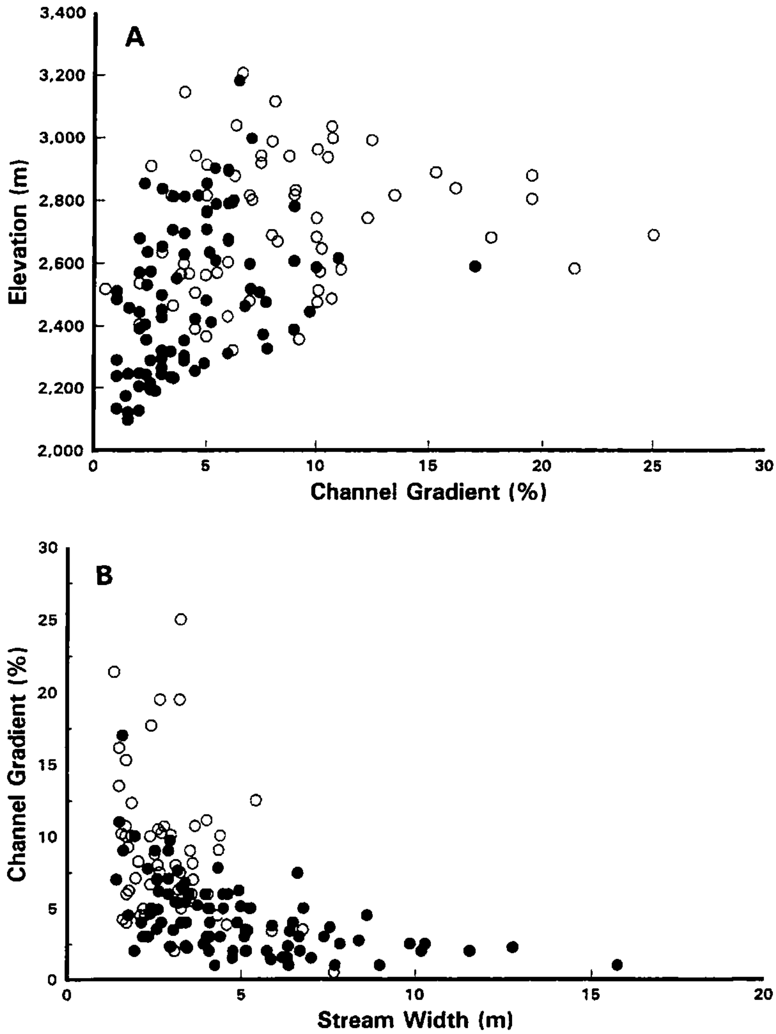

FIGURE 2.—Presence (●) and absence (○) of cutthroat trout in relation to (A) elevation and channel slope and (B) channel slope and stream size. All observations are included.

Discussion

Geologic barriers to fish migration influence distributions of Yellowstone cutthroat trout in the Greybull–Wood river drainage. We hypothesized that barriers might isolate genetically pure Yellowstone cutthroat trout from potential hybridization or competition; however, Yellowstone cutthroat trout did not appear upstream of barriers except in the four streams where Yellowstone cutthroat trout were stocked above barriers. If cutthroat trout naturally occurred above barriers, catastrophic events probably limited cutthroat trout persistence in these areas. Flood flows, severe drought (30–100-year cycles in Bighorn basin; Martner 1982), and debris torrents (Keefer 1972; Martner 1982; Lamberti et al. 1991) can locally decimate or extirpate trout populations. Swanson et al. (1987) suggest debris torrents are episodic events that may influence mountain streams every 50–200 years. Therefore, due to relatively short stream lengths above the barriers, poor habitat conditions, and relatively common occurrences of catastrophic events, it is probably difficult for Yellowstone cutthroat trout to persist in or to recolonize areas above barriers.

Yellowstone cutthroat trout distributions in the Greybull–Wood river drainage were significantly influenced by channel slope. Channel slope has been found to influence habitat (Chisholm and Hubert 1986; Bozek and Hubert 1992; Rosgen

TABLE 2.—Logistic regression analysis results with significance for parameters and model, correct classification, and kappa statistics of geomorphic and stream parameters predicitng Yellowstone cutthroat trout presence or absence in northwestern Wyoming. Differences are significant at $P \leq 0.05$.

Model and parameter	Value (SE)	*P*	Log-likelihood	Classification % (present/absent/overall)	Kappa (*P*)
Channel slope	−0.485 (0.12)	<0.0001			
Constant	3.840 (0.82)	<0.0001			0.580
Model 1		<0.0001	72.44	93/62/83	(<0.001)
Channel slope	−0.488 (0.15)	0.0012			
Elevation	−0.009 (0.00)	0.0004			
Constant	27.830 (7.17)	0.0001			0.688
Model 2		<0.0001	49.23	91/77/87	(<0.001)
Channel slope	−0.510 (0.19)	0.0074			
Elevation	−0.009 (0.00)	0.0004			
Mean width	−0.064 (0.33)	0.8445			
Constant	28.333 (7.66)	0.0002			0.688
Model 3		<0.0001	49.19	91/77/87	(<0.001)
Elevation	−0.008 (0.00)	<0.0001			
Constant	22.520 (5.46)	<0.0001			0.530
Model 4		<0.0001	69.14	89/62/80	(<0.001)

1994) and, therefore, distribution (Kozel and Hubert 1989) and abundance of trout (Chisholm and Hubert 1986) in other studies. Bozek and Hubert (1992) showed that channel slope was significantly related to cutthroat trout occurrence in high-elevation systems. Cutthroat trout occupied locations in streams with higher channel slopes than did other species of trout, but they were not found in streams with channel slopes greater than 8%. More than 60% of the stream sites in the Greybull River basin had channel slopes considered to be steep (>4%, Rosgen 1994), and 16% were very steep (>10% channel slope). Only one site where cutthroat trout were found had a channel slope greater than 10%, suggesting that channel slope is limiting Yellowstone cutthroat trout distributions in streams within the Greybull–Wood river drainage. In their discussion on presence of bull trout *Salvelinus confluentus* in relation to patch size, Rieman and McIntyre (1995) also observed a gradient threshold of about 10%.

Elevation significantly influenced cutthroat trout distributions in the study streams; however, elevation was also positively correlated with channel slope and not an independent influence on trout distribution. Because channel slope decreases with decreasing elevation, channel slope was probably the major variable influencing distributions (Figure 2). All study streams were at elevations above 2090 m and can be classified as high-elevation streams (Kozel and Hubert 1989). Bozek and Hubert (1992) found that elevation was a significant predictor of cutthroat trout locations within high-mountain streams of the central Rocky mountains. Elevation can be categorized as a predictor of climate (Bozek and Hubert 1992), which influences several stages of the cutthroat trout life history (Gresswell 1995). If a portion of the life cycle is incompatible with climatic conditions resulting from elevational differences, elevation would directly impact fish distribution. Similarly, Nelson et al. (1992) found that elevation, along with substrate embeddedness and streamflow, was a good discriminatory variable in distinguishing land classes (geologic), which in turn were related to trout distributions.

TABLE 3.—Agreement (percent) between actual and predicted fish presence when testing logistic models on sites in the Wood River drainage ($N = 43$ for all models).

Model	Number classified correctly	Agreement (%)
1	39	90.7
2	37	86.1
3	38	88.4
4	32	74.4

Mean wetted width was significantly greater in sites where Yellowstone cutthroat trout were present without barrier influence than in both site categories where fish were absent within the study area. Wetted width is a measure of stream size, but it is also related to climate and stream energy because larger streams tend to have lower gradients and occur at lower elevations (Bozek and Hubert 1992). Furthermore, stream size affects the availability and quality of physical habitat and abundance of trout species (Kennedy and Strange 1982; Chisholm and Hubert 1986; Bisson et al. 1988; Kozel and Hubert 1989; Heggenes et al. 1991). Several studies have found stream size, discharge, and variation in discharge to be important factors influencing fish distributions and abundance (Minshall et al. 1983; Kozel et al. 1989; Bozek and Hubert 1992; Fausch and Northcote 1992; Nelson et al. 1992). However, in the Greybull–Wood river drainage, stream size has only a minor influence on cutthroat trout distributions.

Modeling trout distributions based on habitat parameters is a common approach to understanding and managing fisheries; however, most modeling has been done on relatively small scales (e.g., stream reach level). Additionally, as Fausch et al. (1988) pointed out, these types of models are difficult to realistically apply in fisheries management because of a lack of generality or precision. More recently, with recognition of the link between large-scale geomorphology and stream habitat, distribution models have been developed on larger scales (Lanka et al. 1987; Nelson et al. 1992; Rieman and McIntyre 1995). For example, Rieman and McIntyre (1995) found consistent relationships between bull trout occurrence in a stream system and patch size and stream width in south central Idaho.

Whereas other models have employed a combination of geomorphic and stream size variables, our logistic functions indicated that fluvial Yellowstone cutthroat trout distributions in northwestern Wyoming can be predicted with a few geomorphic variables (Table 2). Although channel slope is a large-scale variable, we actually measured channel slope on a site-specific scale; however, this variable can easily be approximated by using longitudinal stream profiles derived from USGS 1:24,000-scale topographical maps. Comparisons between channel slope estimates derived on site with a clinometer and from topographical maps showed differences of less than 1% (D. Isaak, University of Wyoming, personal communication). Channel slope correctly classified 83% of all sites sampled (Table 2), and in conjunction with elevation, classification increased to 87% when the influence of barriers was removed. Although it is difficult to separate the independent effects of channel slope, elevation, and stream size on Yellowstone cutthroat trout distributions (Figure 2), channel slope appears to be the primary factor governing trout occurrence. Geomorphic variables were generally better at classifying Yellowstone cutthroat trout presence (89–93%) than absence (62–77%; Table 2), suggesting that additional factors may limit the ability of Yellowstone cutthroat trout to survive in a given system. After removal of sites influenced by channel slope greater than 10%, model prediction remained high, indicating that these variables can be used to classify cutthroat trout presence and absence across a relatively small range of channel slopes (1–9%).

Models including variables of elevation or stream size had slightly lower agreement rates (Table 3); however, they were actually better models as shown by lower log-likelihood values and higher correct classifications and kappa values (Table 2). Examination of sites that were incorrectly classified by models 1–3 indicated other anomalies present that influenced fish presence. Three of the four sites incorrectly classified by model 1 in the Wood River drainage were influenced by either a nonpermanent fish barrier (large-woody-debris jam) to upstream movement or inadequate stream flow (sinking into stream bed). Thus, agreement could be increased by eliminating unusual cases from the data set, but anomalies such as these and others (e.g., land use, upwellings, habitat changes) will complicate model application.

Additionally, it is important to remember, as Nelson et al. (1992) pointed out, habitat features affecting trout occurrence vary across broad land classes. Without additional testing and ground-truthing, application of our models to areas other than volcanic watersheds within native range of Yellowstone cutthroat trout is not advised.

Platts (1979) and Parsons et al. (1982) have shown that trout habitat on a stream reach basis can be related to drainage basin geomorphology; additionally, trout distributions are a function of the habitat. The ability to predict Yellowstone cutthroat trout distributions with some degree of certainty on the basis of geomorphic variables will be useful for fisheries managers. These large-scale models can be incorporated into geographic information system coverages, allowing managers to determine potential Yellowstone cutthroat trout distributions without extensive field surveys but with only a need for simple ground-truthing censuses. Models of this type provide managers predictive and diagnostic tools allowing for efficient watershed planning and management.

Acknowledgments

We thank C. Ewers, K. Harris, C. Griffith, K. Krueger, R. McLean, and M. Williams for assistance in collecting field data; and S. Mullner, R.

Wiley, M. Young, D. Zafft, and R. Zubik for critical review of the manuscript. This project was supported by the Wyoming Game and Fish Department and the U.S. Forest Service.

References

Allendorf, F. W., and R. F. Leary. 1988. Conservation and distribution of genetic variation in a polytypic species, the cutthroat trout. Conservation Biology 2:170–184.

Beauchamp, J. J., S. W. Christensen, and E. P. Smith. 1992. Selection of factors affecting the presence of brook trout (*Salvelinus fontinalis*) in Adirondack lakes: a case study. Canadian Journal of Fisheries and Aquatic Sciences 49:597–608.

Behnke, R. J. 1992. Native trout of western North America. American Fisheries Society, Monograph 6, Bethesda, Maryland.

Behnke, R. J., and M. Zarn. 1976. Biology and management of threatened and endangered western trouts. U.S. Forest Service General Technical Report RM-28.

Bisson, P. A., K. Sullivan, and J. L. Nielsen 1988. Channel hydraulics, habitat use, and body form of juvenile coho salmon, steelhead, and cutthroat trout in streams. Transactions of the American Fisheries Society 117:262–273.

Bozek, M. A., and W. A. Hubert. 1992. Segregation of resident trout in streams as predicted by three habitat dimensions. Canadian Journal of Zoology 70: 886–890.

Campton, D. E., and F. M. Utter. 1985. Natural hybridization between steelhead trout (*Salmo gairdneri*) and coastal cutthroat trout (*Salmo clarki clarki*) in two Puget Sound streams. Canadian Journal of Fisheries and Aquatic Sciences 42:110–119.

Chisholm, I. M., and W. A. Hubert. 1986. Influence of stream gradient on standing stock of brook trout in the Snowy Range, Wyoming. Northwest Science 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.

Fausch, K. D., and T. G. Northcote. 1992. Large woody debris and salmonid habitat in a small coastal British Columbia stream. Canadian Journal of Fisheries and Aquatic Sciences 49:682–693.

Gresswell, R. E., editor. 1988. Status and management of interior stocks of cutthroat trout. American Fisheries Society, Symposium 4, Bethesda, Maryland.

Gresswell, R. E. 1995. Yellowstone cutthroat trout. Pages 36–54 *in* M. K. Young, editor. Conservation assessment for inland cutthroat trout. U.S. Forest Service General Technical Report RM-256.

Griffith, J. S. 1988. Review of competition between cutthroat trout and other salmonids. Pages 134–140 *in* Gresswell (1988).

Hadley, K. 1984. Status report on the Yellowstone cutthroat trout (*Salmo clarki bouvieri*) in Montana. Report to Montana Department of Fish, Wildlife, and Parks, Helena.

Hansen, R. P., and F. Glover. 1973. Environmental inventory and impact analysis at Kirwin area, Park County, Wyoming, for America Climax, Inc. (AMAX). Rocky Mountain Center on Environment, Denver.

Hanzel, D. A. 1959. The distribution of the cutthroat trout (*Salmo clarki*) in Montana. Proceedings of the Montana Academy of Sciences 19:32–71.

Heggenes, J., T. G. Northcote, and A. Peter. 1991. Seasonal habitat selection and preferences by cutthroat trout (*Oncorhynchus clarki*) in a small, coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 48:1364–1370.

Hosmer, D. W., and S. Lemeshow. 1989. Applied logistic regression. Wiley, Toronto.

Hubert, W. A., and S. J. Kozel. 1993. Quantitative relations of physical habitat features to channel slope and discharge in unaltered mountain streams. Journal of Freshwater Ecology 8:177–183.

Keefer, W. R. 1972. The geologic story of Yellowstone National Park. U.S. Geological Survey Bulletin 1347.

Kennedy, G. J. A., and C. D. Strange. 1982. The distribution of salmonids in upland streams in relation to depth and gradient. Journal of Fish Biology 20: 579–591.

Kent, R. 1984. Fisheries management investigations in the upper Shoshone River drainage, 1978–1982. Wyoming Game and Fish Department, Fish Division Completion Report, Cody.

Kondolf, G. M., G. F. Cada, M. J. Sale, and T. Felando. 1991. Distribution and stability of potential salmonid spawning gravels in steep boulder-bed streams of the eastern Sierra Nevada. Transactions of the American Fisheries Society 120:177–186.

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

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

Krebs, C. J. 1989. Ecological methodology. Harper Collins, New York.

Kruse, C. G. 1995. Genetic purity, habitat, and population characteristics of Yellowstone cutthroat trout in the Greybull River drainage, Wyoming. Master's thesis. University of Wyoming, Laramie.

Lamberti, G. A., S. V. Gregory, L. R. Ashkenas, R. C. Wildman, and K. S. Moore. 1991. Stream ecosystem recovery following a catastrophic debris flow. Canadian Journal of Fisheries and Aquatic Sciences 48:196–208.

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. Transactions of the American Fisheries Society 116:21–28.

Leary, R. F., F. W. Allendorf, S. R. Phelps, and K. L.

Knudsen. 1984. Introgression between westslope cutthroat and rainbow trout in the Clark Fork River drainage, Montana. Proceedings of the Montana Academy of Sciences 43:1–18.

Martner, B. 1982. Wyoming climate atlas. University of Nebraska Press, Lincoln.

Minshall, G. W., and six coauthors. 1983. Interbiome comparison of stream ecosystem dynamics. Ecological Monographs 53:1–25.

Nelson, R. L., W. S. Platts, D. P. Larsen, and S. E. Jensen. 1992. Trout distribution and habitat in relation to geology and geomorphology in the North Fork Humboldt River drainage, northeastern Nevada. Transactions of the American Fisheries Society 121: 405–426.

Parsons, M. G., J. R. Maxwell, and D. Heller. 1982. A predictive fish habitat index model using geomorphic parameters. Pages 85–91 *in* N. B. Armantrout, editor. Acquisition and utilization of aquatic habitat inventory information. American Fisheries Society, Western Division, Bethesda, Maryland.

Platts, W. S. 1979. Relationships among stream order, fish populations, and aquatic geomorphology in an Idaho River drainage. Fisheries 4(2):5–9.

Rieman, B. E., and J. D. McIntyre. 1993. Demographic and habitat requirements for conservation of bull trout. U.S. Forest Service General Technical Report INT-302.

Rieman, B. E., and J. D. McIntyre. 1995. Occurrence of bull trout in naturally fragmented habitat patches of various size. Transactions of the American Fisheries Society 124:285–296.

Rosgen, D. L. 1994. A classification of natural rivers. Catena 22:169–199.

Scarnecchia, D. L., and E. P. Bergensen. 1986. Production and habitat of threatened greenback and Colorado river cutthroat trouts in Rocky Mountain headwater streams. Transactions of the American Fisheries Society 115:382–391.

SPSS. 1991. The SPSS guide to data analysis for SPSS/PC+, 2nd edition. SPSS Inc. Chicago.

Stuber, R. J., B. D. Rosenlund, and J. R. Bennett. 1988. Greenback cutthroat trout recovery program: management overview. Pages 71–74 *in* Gresswell (1988).

Swanson, F. J., and six coauthors. 1987. Mass failures and other processes of sediment production in Pacific Northwest forest landscapes. Pages 9–38 *in* E. O. Salo and T. W. Cundy, editors. Streamside management: forestry and fishery interactions. University of Washington, Institute of Forest Resources, Seattle.

Thurow, R. F., C. E. Corsi, and V. K. Moore. 1988. Status, ecology, and management of Yellowstone cutthroat trout in the upper Snake River drainage, Idaho. Pages 25–36 *in* Gresswell (1988).

Titus, K., J. A. Mosher, and B. K. Williams. 1984. Chance-correlated classification for use in discriminate analysis: ecological applications. American Midland Naturalist 111:1–7.

Varley, J. D., and R. E. Gresswell. 1988. Ecology, status, and management of the Yellowstone cutthroat trout. Pages 13–24 *in* Gresswell (1988).

Yekel, S. 1980. An evaluation of area fisheries in the Greybull River–Wood River drainages, Park County. Wyoming Game and Fish Department, Fish Division Administrative Report, Cody.

Young, M. K. 1995. Conservation assessment for inland cutthroat trout. U.S. Forest Service General Technical Report RM-256.

Zafft, D. J., and T. C. Annear. 1992. Assessment of stream fishery impacts and instream flow recommendations related to the Greybull Valley project. Wyoming Game and Fish Department, Fish Division Administrative Report, Cheyenne.

Received April 10, 1996
Accepted November 10, 1996