AN ABSTRACT OF THE THESIS OF

Caleb Frederick Zurstadt for the degree of Master of Science in Fisheries Science presented on March 7, 2000. Title: Relationships Between Relative Abundance of Resident Bull Trout (*Salvelinus confluentus*) and Habitat Characteristics in Central Idaho Mountain Streams.

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Abstract approved: ______________________

William J. Liss

Resident bull trout (*Salvelinus confluentus*) may be particularly vulnerable to human related disturbance, however very few studies have focused on resident bull trout populations. The abundance of bull trout is one measure of the strength and potential for persistence of a population. Habitat characteristics may influence resident bull trout abundance to differing degrees and by varying means at multiple spatial scales. We used day and night snorkel counts to assess relative bull trout abundance. A modification of the Forest Service R1/R4 Fish and Fish Habitat Inventory was used to assess habitat characteristics associated with resident bull trout. Logistic and multiple linear regression were used to assess the relationships between resident bull trout abundance and habitat characteristics at the patch (1 to 5 km), reach (0.5 to 1 km) and habitat unit (1 to 100 m) scales. Site categorical variables were used along with quantitative habitat variables to explain among-site and across-site variation in the data. The significance of both quantitative habitat variables and categorical site variables at various spatial scales suggest that relationships between bull trout abundance and habitat characteristics are complex and in part dependent on scale. The characteristics of individual habitat units explained little of the variation in bull trout presence/absence (logistic regression; Somers' D = 0.44) and density (multiple linear regression; adjusted $R^2 = 0.08$) in habitat units, however there were habitat characteristics that were significantly ($P \leq 0.05$) correlated to bull trout presence/absence and density in habitat units. The relationships between habitat characteristics and bull trout presence/absence and density varied between habitat unit types. There was a strong quadratic relationship between bull trout abundance and mean summer water temperature at the reach ($P = 0.004$) and patch scales ($P = 0.001$). The mean temperature of patches appears to explain some of the variation in bull trout density at smaller spatial scales, such as reaches and habitat units. An appreciation of the complex nature of scale dependent interactions between bull trout abundance and habitat characteristics may help resource managers make wiser decisions regarding conservation of resident bull trout populations.

Relationships Between Relative Abundance of Resident Bull Trout (*Salvelinus confluentus*) and Habitat Characteristics in Central Idaho Mountain Streams

by

Caleb Frederick Zurstadt

A THESIS

submitted to

Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Presented March 7, 2000
Commencement June 2000

Master of Science in Fisheries Science thesis of Caleb Frederick Zurstadt presented on March 7, 2000

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Caleb Frederick Zurstadt, Author

ACKNOWLEDGMENT

I would like to thank Kathy Golden, Mike Kaylor, Jay Lewellyn, Jenny Nyme, Duncan Oswald, and Isaac Sanders for collecting monotonous habitat data and snorkeling in icy streams, often groveling on hands and knees, during the day and at night. Without their positive attitudes and hard work the data would never have been collected. The personnel of the Lowman Ranger District provided the platform from which this project was carried out. I would like to thank Bill Liss, Susie Adams, Tim Burton, Jason Dunham, Joe Ebersole, Bob Gresswell, Wesley Jones, Fred Ramsey, Gordon Reeves, Bruce Rieman, Russ Thurow, and Don Zurstadt for reviewing and providing helpful insights at various stages of this project. Jason Dunham in particular showed great generosity with his time. The USDA Forest Service, including the Boise National Forest and Rocky Mountain Research, provided funding for fieldwork. I am grateful to Fritz and Henrietta Zurstadt for funding a large portion of my tuition. I would like to give special thanks to my boss and friend Justin Jimenez. This project could not have been completed without his positive energy, support in the office and field, and smiles.

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INTRODUCTION

Until recently very little was known about bull trout (*Salvelinus confluentus*) ecology. It was only during the last two decades that a general consensus could be reached on the classification of bull trout as a unique char species (Cavender 1978; Hass and McPhail 1991). Bull trout are increasingly recognized as a species sensitive to anthropogenic habitat alteration, population isolation, and displacement by introduced exotic fishes such as brook trout (*S. fontinalis*) (Rieman and McIntyre 1993; Rieman and McIntyre 1995; Dunham and Rieman 1999). On June 10, 1998, the US Fish and Wildlife Service listed the Columbia River Basin distinct population segment of bull trout as threatened under the Endangered Species Act (SP# 1-4-98-SP-225).

Bull trout display three major life history patterns. Adfluvial (residing in lakes and using streams or rivers for spawning and rearing), fluvial (residing in large rivers and using smaller tributaries for spawning and rearing), and resident (residing in small streams for their entire lives) (Goetz 1989; Rieman and McIntyre 1993). Migratory and resident bull trout spawn and rear in water with average summer temperatures between 6.0 and 9.0 °C (Goetz 1989; Adams 1994; Lowman Ranger District, unpublished data). In many streams adult and juvenile bull trout are the only fish species present presumably because water temperatures are below the thermal tolerance of other potential inhabitants (Adams 1994; Dambacher and Jones 1997; Lowman Ranger District, unpublished data).

The majority of studies on bull trout involve highly migratory adfluvial populations. These adfluvial populations characteristically are composed of large migratory adults that return to natal areas to spawn in the fall. Juveniles tend to emigrate from rearing streams to lakes by age four (Goetz 1989). It may not be appropriate to extrapolate data on adfluvial bull trout habitat relationships to populations that have resident life histories. Because of their large size (total length 400-875 mm) migratory bull trout tend to spawn in larger streams than resident fish.

Adult resident bull trout on the Lowman Ranger District, Idaho, range in size from approximately 140 to 200 mm total length and tend to spawn and rear in headwater streams with average widths and depths of 2.8 and 0.19 m respectively (Lowman Ranger District, unpublished data). In some cases genetic differences distinguish resident and migratory populations (Northcote 1992). The stenothermal requirement of bull trout often restricts resident forms to small isolated patches of habitat. Small population size, isolation, and dependence on headwater streams during all life history phases and seasons may make resident bull trout particularly vulnerable to natural and anthropogenic habitat alterations.

The abundance of bull trout influences long term persistence of populations for several reasons. Large bull trout populations are less likely to succumb to stochastic or deterministic events, such as forest fires, random population fluctuations, and effects of land use practices (Rieman and McIntyre 1993). Large, persistent populations also are more likely to serve as sources for colonization of neighboring patches of habitat. This increase in dynamic flow of bull trout between various patches of habitat may aid in the long term persistence of populations by enhancing genetic diversity and spreading the risk of extinction over several sub-populations (Rieman and McIntyre 1993). Rieman and McIntyre (1993) list five habitat characteristics that are particularly important for bull trout: channel stability, substrate composition, cover, temperature, and migratory corridors. In various ways these five characteristics influence or are associated with survival, growth, and distribution of juvenile and adult bull trout. However, few researchers have investigated the relationships between resident bull trout abundance and habitat characteristics.

Habitat characteristics may influence resident bull trout abundance at multiple spatial scales. A watershed can be viewed as a hierarchy in which the interactions of physical and biological systems direct or constrain physical and biological processes at subsequently finer scales of resolution (Frissell et al. 1986; Schlosser 1991; Schlosser 1995). The climate, geology and geomorphic processes of a region control the processes influencing upland and riparian biotic communities within a watershed. Stream ecosystems are constrained by physical processes which sculpt stream geomorphology (e.g., pool and riffle formation) and by connectivity and interaction with upland and riparian biotic communities (e.g., input of organic materials such as large wood and leaves) (Beschta and Platts 1986; Gregory et al. 1991; Schlosser 1995). More specifically, fish ecology in headwater streams is a function of the temporal evolution of physical and biological processes that shape the expression of fish habitat characteristics over lateral and longitudinal spatial scales (Schlosser 1991). Thus physical and biological processes at various spatial scales influence fish abundance.

Microhabitat scale studies have shown that bull trout exhibit some common behavioral patterns across a wide range of geographic regions. Bull trout tend to position themselves in close proximity with the streambed, and with areas of low water velocity especially during early life stages (Pratt 1984; Bonneau 1994; Adams 1994; Jakober 1995; Sexauer and James 1997). Juvenile bull trout tend to use shallow stream margins (Goetz 1991; Saffel and Scarnecchia 1995). Bull trout also tend to associate closely with cover, although the form of cover may vary. Large woody debris (LWD) appears to be a particularly important form of cover for juvenile and adult bull trout (Goetz 1991; Jakober 1995).

Ziller (1992) sampled 30 m sites in four streams located in the Sprague River subbasin of Oregon and found that resident bull trout were more prevalent at higher elevations, in streams with cold water and steep gradients. Saffel and Scarnecchia (1995) investigated the relationship between juvenile adfluvial bull trout abundance and physical habitat characteristics in 100 m sample sites. They found strong relationships between juvenile abundance and both the number of pocket pools and average temperatures.

Recently fisheries researchers have begun to analyze bull trout presence/absence trends in relation to habitat characteristics at basin-wide and region-wide scales. Results from these large scale studies suggest the importance of metapopulation dynamics in influencing the presence or absence of bull trout (Rieman and McIntyre 1995; Rich 1996; Dunham and Rieman 1999). Presence and absence studies have revealed relationships between bull trout distribution and habitat characteristics, such as LWD, shade, pool depth, and stream gradient. (Rich 1996; Dambacher and Jones 1997; Watson and Hillman 1997).

Watson and Hillman (1997) investigated the relationship between bull trout presence and relative abundance, and physical habitat characteristics at multiple spatial scales (e.g., basin, stream, reach). Their results suggest that bull trout distribution may be primarily determined by obligate life history requirements (e.g., temperature requirements), while densities are determined by facultative, adaptive responses to the prevailing habitat conditions (e.g., habitat complexity). Therefore, to varying degrees, management protocols must be tailored to the unique relationships between bull trout populations and habitat characteristics in the landscape of concern.

In summary, microhabitat studies and large-scale presence/absences studies have shown that migratory and resident bull trout are often associated with certain habitat characteristics such as LWD, number of pools, gradient, and water temperature. Broad scale physical and biological processes interact at progressively finer scales of resolution to ultimately influence resident bull trout populations. However, most of the research on bull trout abundance-habitat relationships has been conducted at single spatial scales and has been limited largely to migratory populations. By limiting sampling to relatively small sections of study streams, researchers risk overlooking the larger scale processes which could be influencing fish abundance.

My goal was to increase understanding of the relationship between resident bull trout abundance and habitat characteristics at multiple spatial scales. To achieve this goal I pursued three major objectives: 1) measure the habitat characteristics of individual habitat units, stream reaches, and stream patches during summer base flow in 9 streams 2) estimate the number and length of bull trout in each habitat unit, stream reach, and stream patch 3) relate habitat characteristics and resident bull trout abundance at the habitat unit scale, stream reach scale, and stream patch scale.

METHODS

Study Area Description

The study area is located within US Forest Service land in the Boise and Salmon River Mountains of West Central Idaho (Figure 1). The study area falls within the boundaries of the Lowman Ranger District, which is part of the Boise National Forest. The geology underlying the study area is part of the enormous region (approximately 39,896 km^2) dominated by an igneous complex known as the Idaho Batholith Granitics. The most prominent features of the landscape have been shaped by glaciation, cryoplanation, plutonic intrusions, localized block faulting, and fluvial processes including mass wasting (Arnold 1975). One of the most significant traits of the Idaho Batholith geology is that the weathering characteristics of the granitic bedrock and soils lead to high natural and anthropogenically related sedimentation rates (Wendt et al. 1973; Arnold 1975).

Wet winters and dry summers characterize the local climate. Most of the annual precipitation results from cyclonic storms that move in from the Pacific Ocean with the Aleutian low and drop snow from November through March (Wendt et al. 1973). Average annual precipitation in the area ranges from 37 to 82 cm depending on the elevation and topography. Peak stream flows correspond with spring and early summer snowmelt, which begins around March and can extend into early July. Less predictable and less dramatic spikes in the annual discharge record occur during late summer when isolated, high intensity thundershowers (i.e., microbursts) drop heavy rainfall over relatively small areas. Average annual temperatures range from 1.4 to 6.8°C depending on elevation and topography (Western Regional Climate Center Web site 1998).

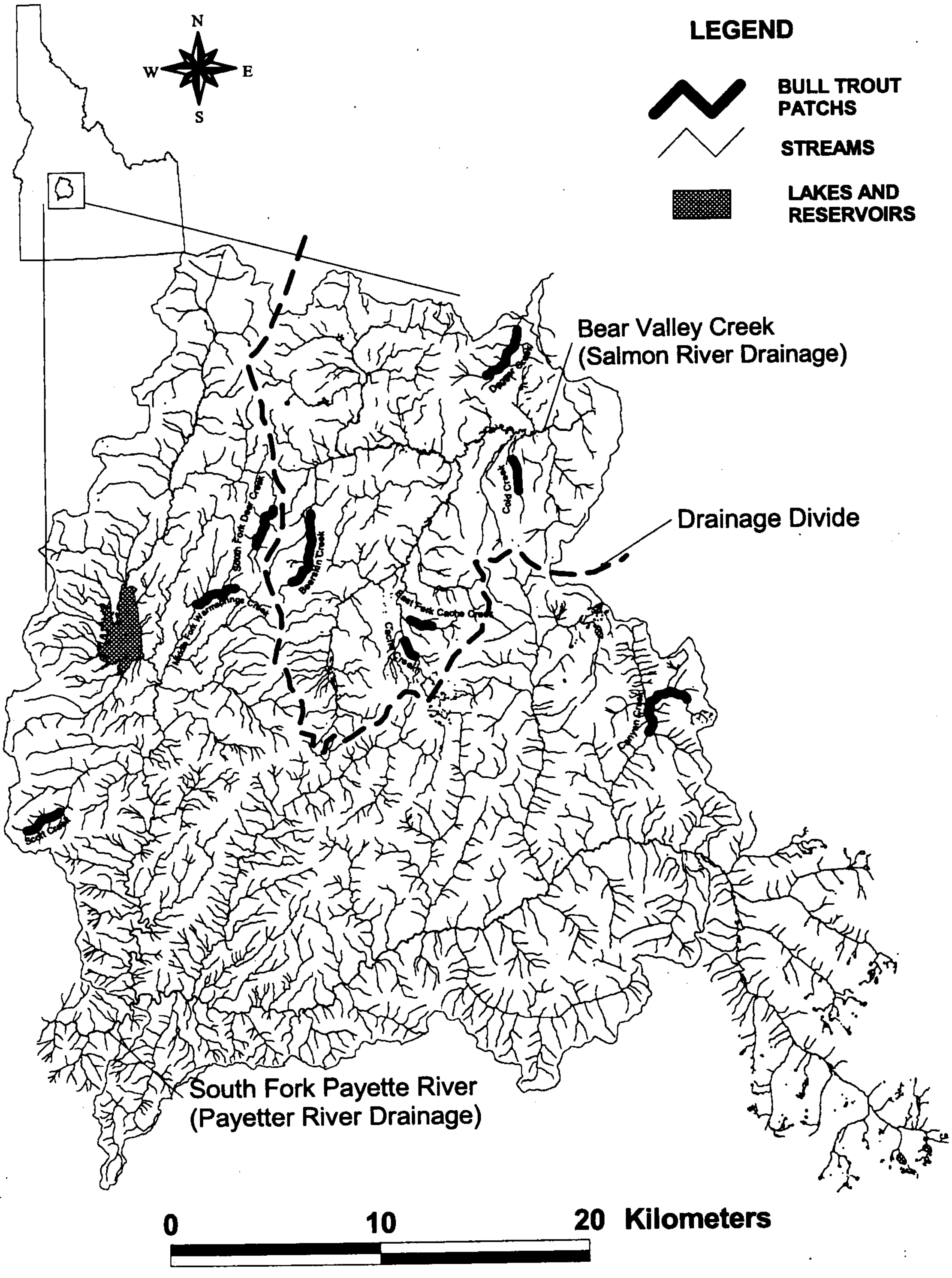

Figure 1. Lowman Ranger District streams and bull trout patches.

There are two major drainages within the study area (Figure 1). Four of the study streams flow into Bear Valley Creek, a tributary of the Middle Fork of the Salmon River. A fifth stream (Dagger Creek) flows directly into the Middle Fork Salmon River. Four of the streams in this study drain into the South Fork of the Payette River. The bull trout populations from these two major drainages are isolated from one another by impassable dams. All of the streams in the study area are small first or second order (Strahler system) streams. Several of the streams originate or are partially fed by lakes and marshes while the remaining streams are fed by springs and small seeps.

The streams that flow into the Middle Fork Salmon originate in heavily cryoplanated rolling hills and meander into deeply filled glacial valleys that often accumulate cold air. The elevation of the patches surveyed in this drainage range from 1936 to 2171 meters. Willow (*Salix* spp.), sedge (*Juncus* spp.), and rushes (*Carex* spp.) characterize the vegetation types along the meadow reaches of these patches. Various combinations of lodgepole pine (*Pinus contorta*), subalpine fir (*Abies lasiocarpa*), and Douglas fir (*Pseudotsuga menziesii*) habitat types occur adjacent to and upslope of the patches depending on the specifics of the site (Arnold 1975; Wendt et al. 1973). In addition to bull trout, fish species found in the Bear Valley Creek drainage include ESA listed spring/summer Snake River chinook salmon (*Onchorhynchus tshawycha*), resident and anadromous forms of redband rainbow trout (*O. mykiss*), westslope cutthroat trout (*O. clarki lewisi*), brook trout, mountain whitefish (*Prosopium williamsoni*), and sculpin (*Cottus* spp.). Of these fish species only redband rainbow trout, westslope cutthroat trout, brook trout, and sculpin were observed within the stream sections surveyed. Human related disturbance in the area has historically included intensive sheep and cattle grazing, road construction, dredge mining, logging, and fire suppression. Currently the Forest Service allows tightly controlled cattle grazing, very limited logging, and practices fire suppression. Recreational and Native American subsistence fishing have a long history in the drainage and continue today.

The streams that flow into the South Fork Payette River occupy strongly and moderately dissected granitic fluvial lands and canyon lands. Elevations of stream sections surveyed range in elevation from 1756 to 2079 meters. Douglas fir and subalpine fir habitat types dominate with vigorous patches of pondorosa pine (*P. ponderosa*) and Engleman spruce (*Picea engelmannii*) in many areas. Alder (*Alnus* spp.) frequently dominates the understory vegetation adjacent to the streams. Willow is common in the less shaded sections of stream at higher elevations. Many fish species have been introduced into the South Fork Payette drainage, however only a few species were found in the sections we surveyed. These include non-anadromous redband rainbow trout, sculpin, and the occasional cutthroat trout and brook trout that disperse from lakes where the Idaho Department of Fish and Game has introduced them. Historically, human related disturbance in the area has included logging, dredge and other forms of mining, livestock grazing, road construction, water diversion and damming, and fire suppression. Current activities include logging, small-scale suction dredge mining, water diversion and damming, controlled burning, and fire suppression. Recreational fishing is very popular in some areas.

Larval and adult tailed frogs (*Ascaphus truei*) are common in many of the patches surveyed in both drainages. River otters (*Lutra canadensis*) and belted kingfisher (*Ceryle alcyon*) are the most common fish predators in the sections we surveyed. Beaver (*Castor canadensis*) are a common resident of many of the patches surveyed, especially in the Bear Valley Creek drainage.

Data Collection

Four streams were sampled during August and early September 1996 and six additional streams were sampled during late July through August 1997. We tried to select a variety of streams that expressed the diversity of environments found on the district. Each stream surveyed contained one patch (Figure 2), and the entire patch was surveyed when possible. We defined a patch as an area within a stream where all life-history stages of resident bull trout tend to occur at higher frequencies than in other portions of the stream (Figure 2). For example a patch on the Lowman Ranger District would tend to be located in the headwaters of a stream (1st -2nd order) that contained reproducing bull trout. The total length of a patch is variable.

Our goal was to sample each patch using the upper limits and lower limits of juvenile bull trout occurrence as rough starting and ending points. A survey began when divers observed several juvenile bull trout within roughly 100 m of one another. We classified bull trout ≤ 140 mm total length as juveniles. The 140 mm cutoff was used because the majority of the bull trout observed exhibiting spawning behavior on the Lowman Ranger District have been larger than 140 mm in total length (Lowman Ranger District, unpublished report). A survey ended when bull trout became very scarce (e.g., < one fish per 100 m) or when snorkeling became very ineffective due to small stream size. Sampling only streams with bull trout insured that we were not including information from streams that were lacking bull trout for reasons unrelated to habitat characteristics such as historic overfishing or disease outbreak. Concentrating our efforts on streams that have bull trout populations also allowed us to increase our sample size given our time constraints.

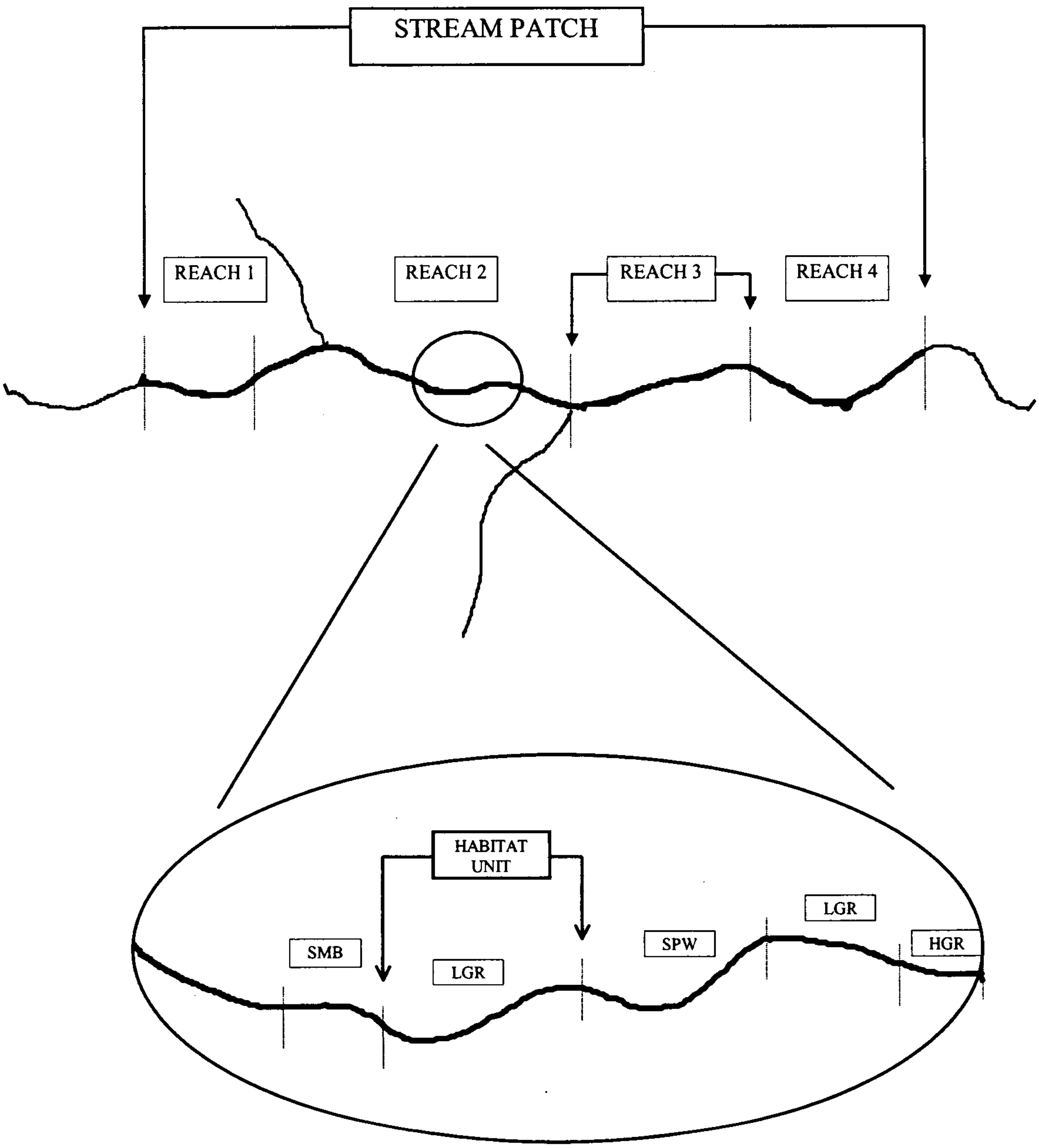

Figure 2. Hierarchical organization of a stream patch, stream reaches, and habitat units.

Habitat characteristics were measured based on a modification of the Forest Service Region 1/Region 4 protocol for stream habitat inventories (Overton et al. 1997). The surveyed patch of each stream was divided into individual reaches while in the field (Figure 2). Reaches were delineated based on several features. The features included how the channel fit into three broad catagories of channel confinement (e.g., unconfined channels are more susceptible to lateral channel migration and have larger floodplains than moderately and highly confined channels), average stream gradient, cover group (i.e., wooded vs. meadow riparian zone), and confluences with tributaries that significantly altered habitat characteristics (i.e., temperature, discharge) (Overton et al. 1997). Individual habitat units (Figure 2) were delineated based on a hierarchical classification system (Overton et al. 1997). Habitat units are "quasi-discrete areas of relatively homogeneous depth and flow that are bounded by sharp physical gradients" (Hawkins et al. 1993). Habitat units are categorized based on fluvial geomorphic descriptors including flow patterns, formative features, and channel bed shape (e.g., low gradient riffle, mid-channel scour pool, wood formed dam pool etc.) (Hawkins et al. 1993; Overton et al. 1997). We differentiated two major categories of habitat units; fast water units (average velocity > 0.30 m/sec), and slow water units. Fast water units were sub-classified as either low gradient riffles (gradient < 4%), or high gradient riffles (gradient > 4%). The slow water units were sub-classified as either dam or scour pools. Dam and scour pools were further sub-classified by formative feature (i.e., wood, boulder, meander, other). Scour pools were further sub-classified into plunging, and non-plunging.

Habitat characteristics and fish abundance were measured and recorded continuously along the entire length of each patch. Sampling took place during base flows from late July to early September. We based our decisions on which habitat parameters to measure on two criteria: 1) the usefulness of the parameter as a measure of four of the habitat characteristics Rieman and McIntyre (1993) list as critical for bull trout (channel stability, substrate composition, cover, and temperature) and 2) the need to measure parameters for monitoring and management on the Lowman Ranger District.

Some parameters were sub-sampled (measured every 5^{th} time a habitat unit type occured rather than in every habitat unit) within the patch. We based our decision on which parameters to sub-sample on three factors. The first factor was the within-stream and across-streams variability of a parameter. For example, LWD has been shown to be highly variable. In order to characterize the amount of LWD in a reach it was necessary to count all the LWD. We determined which parameters are likely to be highly variable by referring to Overton et al. (1995) as well as our own observations on the Lowman Ranger District. The second factor was the influence of a within-habitat unit variable on other habitat units throughout the stream. For example, bank instability in one habitat unit can lead to increases in surface fines within units downstream. The third factor was the amount of time it would take to measure the parameter weighed against factors one and two.

Data Collection for Objective One (measure the habitat characteristics of individual habitat units, stream reaches, and stream patches during summer base flow in 10 streams)

Habitat Unit Scale

Habitat unit dimensions: Every habitat unit was classified into various types of fast and slow water habitat unit types (e.g., low gradient riffle, wood formed plunge pool, etc.). We followed the methods in Overton et al. (1997) for measuring habitat unit dimensions. The width of fast and slow water habitat units was measured across a transect of the habitat unit where the width appeared to be representative of the average unit width. The mean depth in fast water units was calculated by measuring the water depth at ¼, ½, and ¾ the distance across the channel and dividing the sum of the three depths by four. Transects for measuring the mean depth of slow water units were located by finding a point in the thalweg that was equal to the average of the maximum depth and maximum crest depth. Maximum depth and maximum crest depth were measured in slow water units only. In 1996 the maximum depth, maximum crest depth, mean depth, and width were measured every 5th time a particular habitat unit occurred within the stream channel. The protocol was changed in 1997 to accommodate the needs of fish biologists on the Lowman Ranger District and improve the accuracy of the calculated mean depth and mean width of reaches and patches. In 1997 the mean depth and width were measured every 5th time a particular type of fast water habitat unit occurred, and visually estimated for the remaining units. In 1997 the crest depth, mean depth, and width were measured every 5th time a particular type of slow water habitat unit occurred, and the mean depth, and width were visually estimated in all remaining units. Our intent was that by increasing the sample size the visual estimates would help improve the accuracy of calculated mean depths and mean width for reaches and patches where the sample sizes of measured units were small. The individual who was collecting habitat unit dimensions continually checked the estimates against actual measurements, thus improving the accuracy of the estimates. The maximum depth was measured in every slow water habitat unit. The total length of every habitat unit was measured in both 1996 and 1997.

Channel stability: Channel stability was measured in every habitat unit by visually estimating the total percent of bank length that is stable. A stream bank was determined to be stable when there was no evidence of active erosion, breakdown, shearing, or tension cracking. Undercut banks were considered stable unless tension fractures were observed on the ground surface at the back of the undercut.

Substrate composition: The dominant and subdominant classes of substrate were ocularly estimated in every 5th habitat unit. Substrate classes were as follows: fines (< 2 mm), pea-gravel (2-8 mm), gravel (8-64 mm), rubble (64-128 mm), cobble (128-256 mm), small boulder (256-512 mm), boulder (>512 mm), and bedrock (solid rock) (Overton et al. 1997). The percentage of surface fines was ocularly estimated in every habitat unit. For every 10th habitat unit the percentage of surface fines was measured with a metal grid to calibrate the ocular estimate (Overton et al. 1997).

Cover: The number of single pieces of large woody debris (LWD), LWD aggregates, and LWD root wads was counted in every habitat unit. For every 5th habitat unit the following underwater estimates of cover were made: percent of the habitat unit volume filled with submerged woody cover, percent of the waters surface protected by overhead cover, percent of the habitat units banks that were undercut, percent of the stream bed covered with large substrate, and percent of the stream bed covered with submerged vegetation. Within every habitat unit the number of lateral habitat areas was recorded. Lateral habitats are shallow areas along the stream margin with little or no current velocity (Moore and Gregory 1988). In order to be counted as lateral habitat, areas must be less than 20 cm deep, have a current velocity of less than 4 cm/s, and be at least 0.5 m wide. Backwater pools were counted as lateral habitat. Backwater pools are areas of low water velocity in which access to the main channel is restricted to small openings or gaps in rocks or debris. The number of pocket pools and the average depth of the pocket pools were recorded whenever they were present. Pocket pools are small, bed depressions formed around channel obstructions within fast water habitat types (Overton et al. 1997).

Temperature: Air and water temperatures were recorded with hand held thermometers once every two hours while collecting habitat data. The amount of stream surface area that was shaded was classified as low (0-25% shaded), medium (26-75% shaded), or high (76-100% shaded) in every 5th habitat unit. The percent of shade that was provided by coniferous trees as opposed to understory was recorded every 5th time a particular habitat unit type occurred (e.g., every 5th time a low gradient riffle occurred).

Reach Scale

Habitat variables were summarized across each reach. For example, total numbers of LWD pieces, mean stream width, and mean percent surface fines were calculated for each reach. The visually estimated mean widths and depths were used along with the measured values to obtain the mean widths and depths of the reaches. Stream gradients and reach elevations were taken from USGS 1:24,000 topographic maps. The mean channel gradient was calculated by dividing the length of the reach by the change in elevation. Continuously recording thermographs were placed in each reach roughly 0.8 km apart and set to record the water temperature at approximately 2-hour intervals throughout the summer. The mean water temperature was calculated for each reach.

Patch Scale

Habitat variables were summarized across each patch just as they were in reaches as discussed above. The temperatures recorded by the thermographs located within each patch were averaged to obtain the summer mean temperatures for each patch.

Data Collection for Objective Two (estimate the number and length of bull trout in each habitat unit, stream reach, and stream patch)

To estimate abundance and habitat utilization of bull trout, every habitat unit throughout the entire patch of each stream was snorkeled using Thurow's (1994) methodology for snorkeling. Thurow recommended snorkeling when water temperatures are at least 9°C, however we snorkeled when temperatures were at or above 8°C because some of the streams rarely warm to 9°C. Divers recorded the species of fish and estimated total fish lengths to the nearest 10 mm. Divers measured fish with PVC cuffs marked with 10 mm increments. When divers could not directly measure the length of the fish, they compared the fish to a nearby object such as a rock and measured the object. During the summer of 1997 night snorkeling was used to assess the precision of day counts. For every 1000 m of stream that was snorkeled during the day a 50 m section was randomly selected to be snorkeled again after dark. Simple linear regression (Ramsey and Schafer 1997) was used to assess the consistency between the difference in day and night counts.

Statistical Analysis for Objective Three (relate habitat characteristics and resident bull trout abundance at the habitat unit scale, stream reach scale, and stream patch scale)

Habitat Unit Scale

Many of the habitat units had bull trout densities of zero. Therefore, the response variable did not approximate a normal distribution. Consequently there was not a single regression technique appropriate for all of the data. To address this problem we conducted the analysis in two steps. For step one we used logistic regression procedures (SAS Release 6.12) with bull trout presence or absence as the response variable. Step two included only habitat units that had densities above zero. For this analysis we used multiple linear regression procedures (SAS Release 6.12) with the natural logarithm of bull trout density per habitat unit as the response variable.

All habitat variables were screened for outliers and normality. When appropriate, natural logarithm transformations were used to improve a variable's approximation of a normal distribution. Several variables collected were not used in the analysis because of strong correlation ($-0.50 > r > 0.50$) with other independent variables, which can drastically effect standard error estimates (Ramsey and Schafer 1997).

Step One: Bull trout presence or absence in habitat units as the response variable

The initial logistic regression models included all habitat units from all streams. A model that included habitat characteristic variables as explanatory variables was used to investigate how certain habitat characteristics affected the likelihood of bull trout presence in habitat units. Subsequent models included patch, reach, or habitat unit type as categorical variables. These models were used to investigate how location (i.e., patch or reach) or habitat type affected the likelihood of bull trout presence in a habitat unit (Dunham and Vinyard 1997; Ramsey and Schafer 1997). Somers' D, Akaike Information Criterion (AIC), and the –2 Log likelihood statistic were used to assess model adequacy and to compare the performance of different models. Models with higher Somers' D values have better predictive ability. Models with lower AIC and -2 Log likelihood values fit the data better than models with higher values. A low *P*-value for the -2 Log likelihood statistic provides evidence that at least one of the regression coefficients for an explanatory variable is nonzero (SAS Logistic Regression Examples). For ease of interpretation, parameter estimates were multiplied by a value that was typical of what the explanatory variable would range over, then exponentiated and thus converted to odds ratios. If, for example, the odds ratio for an explanatory variable is 2.4, then the odds of bull trout being present in a habitat unit increases 2.4 fold for each unit increase in the explanatory variable. The definition of a "unit increase" was determined by the scale of the explanatory variable. For example, a unit increase in percent of shade provided by overstory was 35 while 0.20 represents a unit increase in mean habitat unit depth. An odds ratio less than one denotes a negative relationship while an odds ratio of greater than one shows a positive relationship. An odds ratio near one suggests a weak relationship. Drop-in-deviance tests were used to test the statistical significance of the categorical site variables (Ramsey and Schafer 1997).

Step Two: Bull trout density for each habitat unit as the response variable

For habitat units with bull trout densities greater than zero, and where habitat unit length and mean width were measured, multiple linear regression procedures were used with bull trout density as the response variable (SAS Release 6.12). Bull trout density (fish per 100 m^2) per habitat unit was calculated by dividing the number of bull trout found in a given habitat unit by the area of the unit. Models were created with habitat variables as explanatory variables. These models were used to investigate how certain habitat characteristics were correlated with bull trout density in habitat units. Other models were constructed that included patches, reaches, or habitat unit type as categorical factors. These models were used to detect patch, reach, or habitat unit type effects on the density of bull trout in individual habitat units (Dunham and Vinyard 1997). Extra-sum-of-squares F-tests were used were used to test the statistical significance of the categorical site variables (Ramsey and Schafer 1997).

Reach Scale: Average Bull Trout Density of each Reach as the Response Variable

Bull trout density (fish per 100 m^2) was calculated by dividing the total number of bull trout counted within a reach by the area of water within the reach. Multiple linear regression models were constructed with mean bull trout density in each reach as the response variable and individual patches as categorical variables. Additional multiple linear regression models included the averages or total sums of selected habitat variables within each reach as explanatory variables. Extra-sums-of-squares F-tests were used to test for the significance of explanatory variables (Ramsey and Schafer 1997).

Patch Scale: Average Bull Trout Density of each Patch as the Response Variable

Bull trout density (fish per 100 m^2) was calculated by dividing the total number of bull trout counted within a patch by the area of water within the patch. The average density (fish per 100 m^2) of bull trout over an entire patch was used as a response variable in a multiple linear regression model with selected habitat variables as explanatory variables (SAS Release 6.12). These models were used to search for relationships between bull trout density over entire patches and patch scale habitat characteristics.

RESULTS

Fish Counts: Day vs. Night and Size Distribution

The total number of bull trout counted in 50 m long sections of stream during the day was positively correlated with the total number of bull trout counted in the same stations at night (Figure 3; F-test, $P = 0.0129$, $R^2 = 0.39$). Although day counts were proportional to night counts, the day counts of bull trout numbers were lower than night counts. The slope of the least squares line was 0.43, therefore on average about twice as many bull trout were counted at night. In day snorkel counts there was an increasing trend of bull trout concealment from divers for fish that are less than approximately 110 mm in total length (Figure 4).

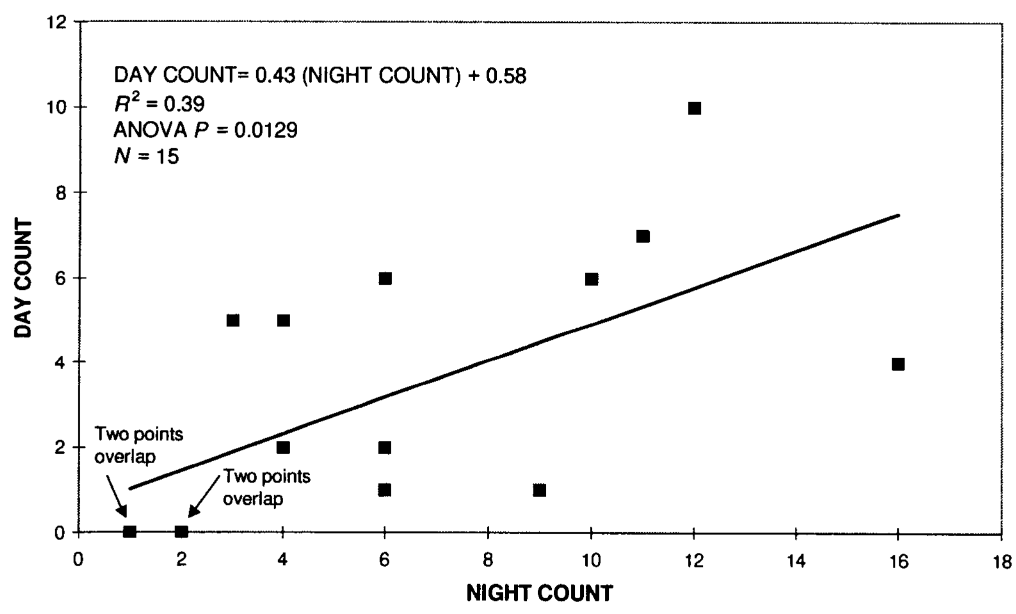

Figure 3. Daytime bull trout snorkel counts in 50 m sections vs. nighttime snorkel counts.

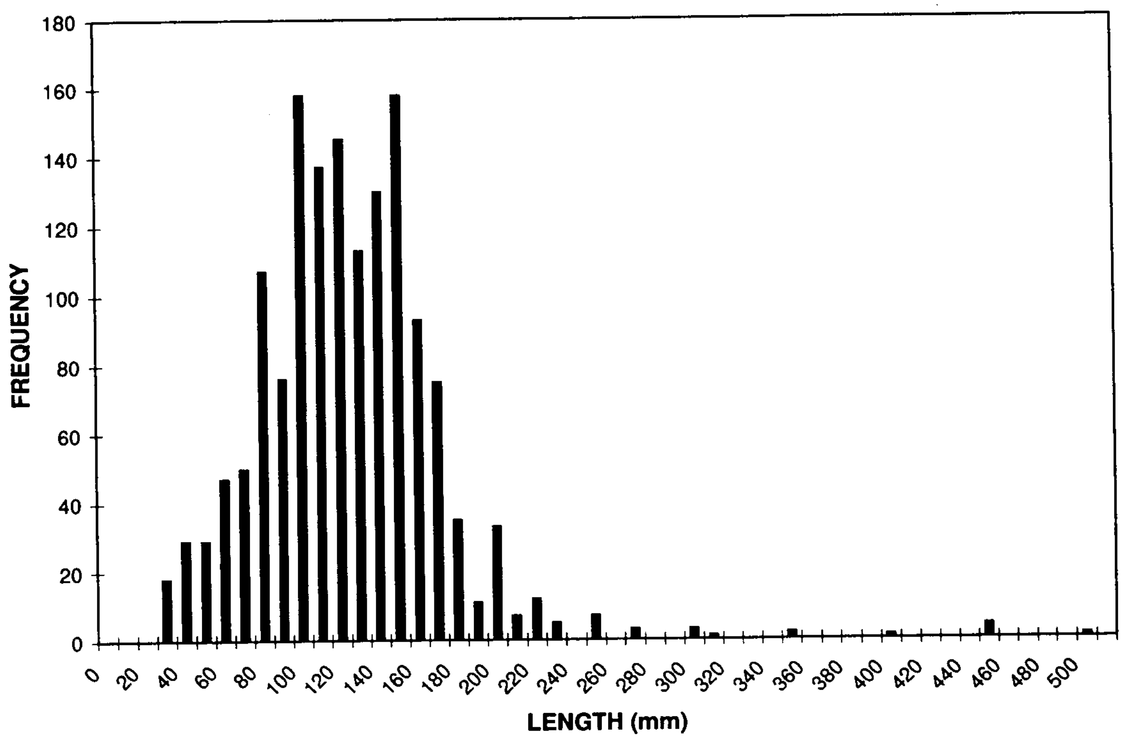

Figure 4. Frequency distribution for estimated length of bull trout observed during snorkel surveys.

Habitat Unit Analysis

Step One: Bull trout presence or absence in each habitat unit as the response variable

The model fit the data poorly (Somers' D = 0.44) and half of the variables had statistically insignificant parameter estimates (Table 1; $P > 0.05$). Eight exceptions were habitat unit length, mean depth, percent surface fines, total amount of large woody debris, percent submerged vegetation, percent of shade provided by overstory, and brook trout and rainbow trout presence.

Table 1. Results from logistic regression of bull trout presence/absence in habitat units on the habitat characteristics of the units. Odds ratio is the factor by which the odds of bull trout presence increases or decreases for every unit increase in the explanatory variable.

N = 552, -2 Log L *P* = 0.001, AIC = 633.32, Somers' D = 0.44				
Variable (ln = natural log transformation)	**Parameter Estimate**	**Odds Ratio**	**95% Confidence Interval for Odds Ratio**	**Probability > Chi-Square**
Length (m)	**0.05**	**1.72**	**1..34 – 2.21**	**0.0001**
Width (m)	0.10	1.11	0.92 – 1.32	0.27
Mean depth (m)	**5.06**	**2.75**	**1.59 – 4.75**	**0.0003**
Dominant substrate*	-0.01	0.99	0.85 – 1.14	0.85
Sub-dominant substrate*	-0.02	0.98	0.84 – 1.15	0.79
ln % Surface fines	**-0.28**	**0.44**	**0.19 – 0.99**	**0.05**
% stable bank	-0.004	1.00	0.98 – 1.01	0.62
ln Total large woody debris per 100 m	**0.16**	**1.71**	**1.08 – 2.69**	**0.02**
ln Lateral habitat areas per 100 m	0.13	1.40	0.95 – 2.07	0.09
ln % Undercut bank	0.08	1.20	0.79 – 1.83	0.38
ln % Submerged vegetation	**-0.35**	**0.40**	**0.25 – 0.65**	**0.0002**
ln % Overhead cover	0.10	1.37	0.77 – 2.46	0.29
Shade **	0.08	1.08	0.80 – 1.46	0.60
% Shade provided by overstory	**-0.01**	**0.73**	**0.59 – 0.89**	**0.002**
Presence of redband rainbow trout	**-0.59**	**0.55**	**0.31 – 0.96**	**0.04**
Presence of brook trout	**1.13**	**3.09**	**0.98 – 9.58**	**0.05**

*Substrate classes were put into numeric classes for analysis: Sand/silt = 1, peagravel = 2, gravel = 3, rubble = 4, cobble = 5, small boulder = 6, boulder = 7, bedrock = 8.
** Shade classified as high, medium, or low. For analysis high = 3, medium = 2, and low = 1.

The odds of a bull trout being present in a given habitat unit increased by a factor of 1.72 for every unit increase in unit length (χ^2, P = 0.0001), 2.75 for every unit increase in mean depth (χ^2, P = 0.0003), by a factor of 1.71 for every unit increase in large woody debris (χ^2, P = 0.02), and by a factor of 3.06 when a brook trout was present in the same habitat unit (χ^2, P = 0.05). The odds of a bull trout being present in a given habitat unit decreased by a factor of 0.44 for every unit increase in percent surface fines (χ^2, P = 0.05), by 0.40 for every unit increase in percent submerged vegetation (χ^2, P= 0.0002), by 0.73 for every unit increase in the percent of shade provided by overstory (χ^2, P= 0.002), and by 0.55 when a redband rainbow trout was present in the habitat unit (χ^2, P = 0.04).

Analyzing all of the habitat units at once from all of the streams surveyed allowed us to investigate within-site variation in bull trout presence/absence. Adding site catagorical variables (i.e., patch, reach, and habitat unit type) allowed us to investigate across-site variation in bull trout presence/absence. As evidenced by highly significant drop in deviance tests, lower AIC, and higher Somers'D values; patch, reach, and habitat unit type categorical site variables improved the fit of the logistic regression model over that with habitat characteristic variables alone (Table 2).

Table 2. Comparison of models with habitat variables alone, and models with habitat variables and patch, reach, or unit catagorical variables.

Variable	Drop -in-Deviance Test for Site Effect Probability > Chi-Square	-2 Log Likelihood Statistic Probability > Chi-Square	Akaike Information Criterion	Somers' D
Habitat variables		0.001	633.32	0.44
Habitat variables +Patch	0.0001	0.0001	615.16	0.53
Habitat variables +Reach	0.0001	0.0001	625.21	0.61
Habitat variables +Unit type (Fast/Slow)	0.01	0.0001	622.19	0.48

Although the categorical variables perform poorly alone in the regression model as evidenced by high AIC and very low Somers'D scores (Table 3), patch or reach categorical variables alone performed similarly to a model with habitat characteristic variables alone.

Table 3. Comparison of models with only patch, reach, or unit type catagorical variables and models with habitat variables alone.

Variable	-2 Log Likelihood Statistic Probability > Chi-Square	Akaike Information Criterion	Somers' D
Habitat variables	0.001	633.32	0.44
Patch alone	0.0001	704.22	0.41
Reach Alone	0.0001	706.92	0.50
Unit type (Fast/Slow) alone	0.008	760.14	0.11

Habitat variables with significant parameter estimates differ for fast and slow water habitat unit types (Table 4). The one exception is percent of shade provided by overstory canopy, which has a significant negative correlation to the odds of bull trout presence in fast and slow water habitat unit types (fast water units χ^2, $P = 0.005$; odds ratio = 0.50, slow water units χ^2, $P = 0.006$, odds ratio = 0.70). The number of pocket pools per 100 m was included in the fast water units model because pocket pools only exist in fast water units. The parameter estimate for pocket pools is statistically significant (χ^2, $P = 0.03$) and the odds ratio is 3.32. The habitat unit length (χ^2, $P = 0.0001$, odds ratio = 2.23) and, total large woody debris per 100 m (χ^2, $P = 0.01$, odds ratio = 4.95) are the other two habitat variables that were significant in the model for fast water units. In slow water units mean depth had a strong positive relationship (χ^2, $P = 0.01$, odds ratio = 2.33) to the odds of bull trout presence in a habitat unit. The percent surface fines (χ^2, $P = 0.05$, odds ratio = 0.40), percent submerged vegetation (χ^2, $P = 0.003$, odds ratio = 0.40) and presence of rainbow trout (χ^2, $P = 0.03$, odds ratio = 0.47) all had negative correlations with the odds of bull trout presence in slow water habitat units.

Table 4. Logistic regression models for the presence/absence of bull trout in fast water habitat units and slow water habitat units.

FAST WATER UNITS				
***N* = 197, -2 Log L *P* = 0.001, AIC = 186.50, Somers' D = 0.71**				
Variable (ln = natural log transformation)	**Parameter Estimate**	**Odds Ratio**	**95% Confidence Interval for Odds Ratio**	**Probability > Chi-Square**
ln Pocket pools per 100 m* **	**0.37**	**3.32**	**1.13 – 8.16**	**0.03**
Length (m)	**0.08**	**2.23**	**1.48 – 3.35**	**0.0001**
Width (m)	0.001	1.0	0.68 – 1.43	0.99
Mean depth (m)	-3.50	0.50	0.24 – 1.01	0.49
Dominant substrate*	0.13	1.15	0.83 – 1.61	0.4
Sub-dominant substrate*	-0.51	0.95	0.65 – 1.36	0.77
ln % Surface fines	0.43	3.63	0.46 – 28.77	0.24
% Stable bank	0.009	1.01	0.98 – 1.06	0.58
ln Total large woody debris per 100 m	**0.48**	**4.95**	**1.55 – 15.84**	**0.01**
ln Lateral habitat areas per 100 m	0.009	1.02	0.38 – 2.79	0.94
ln % Undercut bank	-0.10	0.79	0.32 – 1.97	0.62
ln % Submerged vegetation	-0.22	0.56	0.21 – 1.52	0.21
ln % Overhead cover	-0.04	0.88	0.23 – 3.42	0.87
Shade **	0.10	1.11	0.56 – 2.15	0.78
% Shade provided by overstory	**-0.02**	**0.50**	**0.34 – 0.72**	**0.005**
Presence of redband rainbow trout	-0.71	0.49	(0.12 – 1.76)	0.3
Presence of brook trout	1.66	5.31	(0.21 – 68.97)	0.22

Table 4, Continued

SLOW WATER UNITS N = 355-2 Log L P = 0.0002, AIC = 448.60, Somers' D = 0.40				
Variable (ln = natural log transformation)	**Parameter Estimate**	**Odds Ratio**	**95% Confidence Interval for Odds Ratio**	**Probablility> Chi-Square**
Length (m)	0.01	1.11	0.48 – 2.52	0.66
Width (m)	0.15	1.17	0.92 – 1.47	0.18
Mean depth (m)	**4.23**	**2.33**	**1.20 – 4.51**	**0.01**
Dominant substrate*	-0.03	0.97	0.82 – 1.14	0.7
Sub-dominant substrate*	0.009	1.01	0.84 – 1.21	0.95
ln % Surface fines	**-0.31**	**0.40**	**0.15 – 1.05**	**0.05**
% Stable bank	-0.01	0.99	0.97 – 1.01	0.27
ln Total large woody debris per 100 m	0.02	1.07	0.65 – 1.75	0.69
ln Lateral habitat areas per 100 m	0.13	1.41	0.87 – 2.27	0.16
ln % Undercut bank	0.11	1.29	0.78 – 2.12	0.32
ln % Submerged vegetation	**-0.35**	**0.40**	**0.21 – 0.76**	**0.003**
ln % Overhead cover	0.03	1.10	0.55 – 2.21	0.75
Shade **	0.01	1.02	0.72 – 1.45	0.92
% Shade provided by overstory	**-0.01**	**0.70**	**0.49 – 1.01**	**0.006**
Presence of redband rainbow trout	**-0.75**	**0.47**	**0.24 – 0.89**	**0.02**
Presence of brook trout	0.92	2.53	0.68 – 9.74	0.16

*Substrate classes were put into numeric classes for analysis: Sand/silt = 1, peagravel = 2, gravel = 3, rubble = 4, cobble = 5, small boulder = 6, boulder = 7, bedrock = 8.
** Shade classified as high, medium, or low. For analysis high = 3, medium = 2, and low = 1.
***Pocket pools were not measured in slow water units.

There was a significant positive relationship between habitat unit length (χ^2, P = 0.0001, odds ratio = 1.62), total amount of large woody debris per 100 m (χ^2, P = 0.01, odds ratio = 1.82) and the odds of juvenile bull trout presence in a habitat unit (Table 5). The percent of submerged vegetation (χ^2, P = 0.005, odds ratio = 0.50), the percent of shade provided by overstory (χ^2, P = 0.02, odds ratio = 0.70), and the presence of redband rainbow trout (χ^2, P = 0.03, odds ratio = 0.51) were negatively correlated to the odds of bull trout presence in habitat units. The presence of bull trout > 140 mm in total length (adult bull trout) was not statistically significant (χ^2, P = 0.32).

Table 5. Results for logistic regression of juvenile bull trout presence/absence in habitat units on the habitat characteristics of the units.

N = 552, - 2 Log L P = 0.0001, AIC = 614.74, Somer's D = 0.40				
Variable (ln = natural log transformation)	**Parameter Estimate**	**Odds Ratio**	**95% Confidence Interval for Odds Ratio**	**Probability > Chi-Square**
Presence of bull trout > 140 mm in total length	0.37	1.46	0.65 – 2.97	0.32
Length (m)	**0.04**	**1.62**	**1.34 – 1.94**	**0.0001**
Width (m)	0.11	1.12	0.94 – 1.36	0.23
Mean depth (m)	2.39	1.61	0.78 – 3.33	0.1
Dominant substrate*	0.00	1	0.87 – 1.16	0.98
Sub-dominant substrate*	-0.02	0.98	0.84 – 1.17	0.84
ln % Surface fines	-0.17	0.60	0.25 – 1.44	0.21
% Stable bank	0.00	1	0.98 – 1.02	0.96
ln Total large woody debris per 100 m	**0.18**	**1.82**	**1.14 – 2.91**	**0.01**
ln Lateral habitat areas per 100 m	0.05	1.14	0.69 – 1.87	0.44
ln % Undercut bank	0.14	1.38	0.93 – 2.04	0.1
ln % Submerged vegetation	**-0.26**	**0.50**	**0.30 – 0.86**	**0.005**
ln % Overhead cover	0.06	1.21	0.71 – 2.07	0.43
Shade **	-0.06	0.94	0.69 – 1.28	0.69
% Shade provided by overstory	**-0.01**	**0.70**	**0.70 – 0.71**	**0.02**
Presence of redband rainbow trout	**-0.67**	**0.51**	**0.26 – 0.89**	**0.03**
Presence of brook trout	1.05	2.86	0.91 – 9.22	0.07

*Substrate classes were put into numeric classes for analysis: Sand/silt = 1, peagravel = 2, gravel = 3, rubble = 4, cobble = 5, small boulder = 6, boulder = 7, bedrock = 8.
** Shade classified as high, medium, or low. For analysis high = 3, medium = 2, and low = 1.

Step Two: Bull trout density of each habitat unit as the response variable

The multiple linear regression model of the natural logarithim of bull trout density (per 100 m^2) in habitat units on habitat characteristic variables explained very little of the variance in bull trout density (adjusted $R^2 = 0.08$), however several parameter estimates were statistically significantly larger than zero. Of the variables that were significant ($P \leq 0.05$), only mean unit depth ($\beta = 1.71$) and the percent surface fines ($\beta = -0.23$) had a parameter estimate that were substantial.

Including patch categorical variables in the model did not improve the model significantly (lack-of-fit F-test, $P = 0.13$). Reach categorical variables improved the model fit significantly (lack-of-fit F-test, $P = 0.006$), however the overall model fit explained little of the variance in bull trout density (adjusted $R^2 = 0.23$). A model that accounted for across-habitat unit type (fast or slow water unit type) variance fit the data significantly better than one that accounted for within-site variance alone. With habitat characteristic variables alone the adjusted $R^2 = 0.09$, and after adding unit type as a categorical variable the adjusted $R^2 = 0.45$. In other words the habitat unit type explained significantly more of the variance in bull trout density than the specific characteristics of the habitat units alone. In fact a model with habitat unit type catagorical variables alone performed better than a model that included quantitative habitat characteristics. Separate multiple linear regression models for fast water units and slow water units fit the data very poorly.

The fit of the multiple linear regression of the natural logarithm of juvenile bull trout density (per 100 m^2) in habitat units on habitat characteristic variables was poor (adjusted $R^2 =$ 0.37). However, the density of juvenile bull trout in a given habitat unit had a significant ($P =$ 0.0001) negative correlation ($\beta = -0.67$) with the density of adult bull trout in that same habitat unit.

Reach Analysis

The saturated (i.e., contains all available variables) model of bull trout density (per 100 m^2) in reaches on quantitative habitat characteristic variables fit the data poorly (ANOVA, P = 0.11, adjusted R^2 = 0.34) and none of the parameter estimates were significantly larger than zero. A reduced model was obtained by systematically removing insignificant variables (P > 0.05) until the highest adjusted R^2 value was achieved (Table 6). Of the variables remaining in the reduced model only mean summer water temperature had a large parameter estimate. However, mean summer water temperature was only significant when a quadratic term was included in the model. The rest of the variables that remained in the model had parameter estimates that were very small but were significantly larger than zero ($P \leq 0.05$). One exception was the percent undercut bank, which did not have a statistically significant parameter estimate, but dropping it from the model decreased the model fit to the data.

Models with either TEMP (TEMP= mean summer water temperature + [mean summer water temperature]^2) or patch site variables alone explained approximately the same amount of variance (Table 7; adjusted R^2 = 0.39 and 0.38 respectively). A model with both TEMP and patch variables (adjusted R^2 = 0.41) explained approximately the same amount of variance as the models with either TEMP or patch alone.

Overall model fit of multiple linear regression for juvenile bull trout density (per 100 m^2) in reaches on quantitative habitat characteristic variables was moderate (adjusted R^2 = 0.45) for a saturated model, however none of the parameter estimates were substantially larger than zero. A model with a reduced set of habitat variables was obtained by systematically removing variables with insignificant parameter estimates until the adjusted R^2 value was maximized (Table 8). All of the remaining habitat variables had parameter estimates significantly different from zero ($P \leq 0.05$) except for density of redband rainbow trout (T-test, P = 0.06), the density of brook trout (T-test, P = 0.48) and the percent of undercut bank (T-test, P = 0.13). Despite the statistical significance of the parameter estimates most of them were very small (Table 8). Mean water temperature and density of adult bull trout were two exceptions. Mean summer water temperature was not significant without a quadratic term included in the model. Juvenile bull trout density in reaches was positively correlated with adult bull trout densities (parameter estimate = 0.53, T-test, P = 0.05).

Table 6. Results of the best fit multiple linear regression model of (ln) bull trout density on the habitat characteristic of the reaches.

N = 32, R^2 = 0.67, Adjusted R^2 = 0.59, ANOVA P = 0.0001			
Variable (ln = natural log transformation)	**Parameter Estimate**	**95% Confidence Interval for Parameter Estimate**	**Probability > T Statistic**
Mean summer water temperature (°C)	5.24	2.89 - 7.59	0.0001
(Mean summer water temperature)^2 (°C)	-0.35	-0.50 - (-0.20)	0.004
Mean dominant substrate	-0.15	-0.32 - 0.01	0.07
% Surface fines	-0.02	-0.03- (-0.01)	0.005
% Undercut bank	0.02	-0.01 - 0.05	0.23
ln % Submerged vegetation	-0.02	-0.03 - (-0.01)	0.002

Table 7. Comparison of fit for models with mean summer water temperature alone, patch alone, and mean summer water temperature and patch together.

Explanatory Variables	**R^2 and Adjusted R^2**	**ANOVA F-Test**	**Lack-of-Fit F-Test**
TEMP*	R^2 = 0.43, Adj. R^2 = 0.39	P = 0.0002	
PATCH	R^2 = 0.53, Adj. R^2 = 0.38	P = 0.008	
TEMP + PATCH	R^2 = 0.59, Adj. R^2 = 0.41	P = 0.01	PATCH P = 0.007 TEMP P > 0.1

*TEMP = mean summer water temperature + (mean summer water temperature)^2

Table 8. Results of the best fit multiple linear regression model of (ln) juvenile bull trout density on the habitat characteristic of the reaches.

N = 32, R^2 = 0.76, adjusted R^2 = 0.62, ANOVA P = 0.0005			
Variable (ln = natural log transformation)	**Parameter Estimate**	**95% Confidence Interval for Parameter Estimate**	**Probability > T Statistic**
Density of bull trout with > 140 mm total length	0.53	0.01 - 1.05	0.05
Mean summer water temperature (°C)	3.78	0.67- 6.90	0.02
(Mean summer water temperature)^2 (°C)	-0.24	-0.45 - (-0.04)	0.02
% Surface fines	-0.01	-0.03 - (-0.002)	0.03
Total large woody debris per 100 m	0.02	0.002 - 0.05	0.04
ln Lateral habitat areas per 100 m	-0.18	-0.37 - (-0.003)	0.05
% Undercut bank	0.03	-0.01 - 0.07	0.13
% Overhead cover	-0.02	-0.03 - (-0.01)	0.004
ln % Submerged vegetation	-0.02	-0.03 - (-0.01)	0.007
% Shade provided by overstory	-0.01	-0.01 - 0.001	0.07
Density of redband rainbow trout per 100 m^2	-0.26	-0.53 - 0.01	0.06
Density of brook trout per 100 m^2	-0.28	-1.10 - 0.54	0.48

Patch Analysis

Various combinations of quantitative habitat variables were added and removed from a multiple linear regression model of bull trout density in patches on habitat characteristics until a final model was constructed which explained the most variance in the data. The final model contained stream gradient, and TEMP (TEMP= mean summer water temperature + [mean summer water temperature]^2) as explanatory variables and fit the data well (Table 9; adjusted R^2 = 0.74). After accounting for gradient there is a strong quadratic relationship between bull trout density and mean summer water temperature. Table 10 gives the results from multiple linear regression of juvenile bull trout density on gradient and mean summer water temperature. Again various combinations of quantitative habitat variables were added and removed from the model until a final model was constructed that explained the most variance in the data. The final model included the same explanatory variables as the model with juvenile and adult bull trout as the response variable, however the model with juvenile bull trout density as the response variable explained more of the variance (adjusted $R^2 = 0.87$). After accounting for gradient there was a strong quadratic relationship between juvenile bull trout density and mean summer water temperature.

Table 9. Results of multiple linear regression of bull trout density in patches on the habitat characteristics of the patches.

$N = 9$, $R^2 = 0.84$, adjusted $R^2 = 0.74$, ANOVA $P = 0.02$			
Variable (ln = natural log transformation)	**Parameter Estimate**	**95% Confidence Interval for Parameter Estimate**	**Probability > T Statistic**
Gradient	0.17	0.01 – 0.33	0.04
Mean summer water temperature (°C)	8.87	1.77 – 15.97	0.02
(Mean summer water temperature)^2 (°C)	-0.6	-1.06 – (-0.15)	0.02

Table 10. Results of multiple linear regression of juvenile bull trout density in patches on the habitat characteristics of the patches.

$N = 9$, $R^2 = 0.92$, adjusted $R^2 = 0.87$, ANOVA $P = 0.004$			
Variable (ln = natural log transformation)	**Parameter Estimate**	**95% Confidence Interval for Parameter Estimate**	**Probability > T Statistic**
Gradient	0.11	0.02 – 0.19	0.02
Mean summer water temperature (°C)	9.64	5.79 – 13.50	0.001
(Mean summer water temperature)^2 (°C)	-0.63	-0.88 – (-0.39)	0.001

DISCUSSION

Fish Counts: Day vs. Night and Size Distribution

Overall the day counts of bull trout were proportional to night counts of bull trout, which indicates that day counts were precise enough for comparisons of relative abundance. The day snorkel counts were lower than the number of bull trout counted at night (Figure 3). The tendency for bull trout to conceal during the day and emerge from cover at night is highly variable from stream to stream and from age class to age class. Several authors reported higher counts of bull trout during night snorkel counts than during day snorkel counts (Jakober 1995; Goetz 1997; Sexauer and James 1997). Others could not find statistically significant differences in day versus night snorkel counts of bull trout (Thurow and Schill 1996; Adams 1994). As water temperature warms above about 7°C, daytime bull trout counts tend to increase (Bonneau et al. 1995; Jakober 1995). Goetz (1997c) found that diel patterns in bull trout concealment vary with age class. Thurow and Schill (1996) and Adams (1994) snorkeled at temperatures above 9 and 8°C respectively and could not find significant differences in night and day counts. Baxter and McPhail (1997) documented a diel habitat shift in juvenile bull trout held in a laboratory stream where temperatures were below 9°C.

In addition to detecting fewer bull trout than night surveys, the daytime surveys were biased towards bull trout that were approximately 110 mm in total length and larger. The downward sloping left leg of the bell-shaped frequency histogram displayed in Figure 4 indicates that bull trout less than approximately 110 mm in total length remain concealed from divers. The tendency for small bull trout, especially young of the year, to go undetected by surveyors is not unique to our streams or to day snorkeling methods. In a survey of recent literature that included length-frequency histograms I found similar bell-shaped patterns even when the sampling method was night snorkeling or multiple pass electrofishing (Hemmingsen et al. 1996; Thurow and Schill 1996; Hunt et al. 1997; Sexauer and James 1997; Stelfox 1997). The frequency of the bell-shaped pattern in bull trout length-frequency histograms highlights the tendency of juveniles to often remain in contact with the substrate or concealed within some form of cover (Pratt 1984; Adams 1994; Bonneau 1994; Jakober 1995; Baxter and McPhail 1997; Sexauer and James 1997; Thurow 1997). We can conclude that there are site specific differences in temporal, age class, and temperature related patterns in bull trout concealment behavior. These site-specific logistic challenges should be recognized when designing sampling methodologies or analyzing demographic data.

Patterns at Multiple Spatial Scales

The significance of habitat characteristic and site categorical variables in logistic and multiple linear regression models indicate that the habitat characteristics of individual habitat units as well as factors evaluated at larger spatial scales are related to bull trout presence/absence and density in habitat units.

The significance of habitat variables differed between fast and slow water habitat units, suggesting that there are complex relationships between habitat characteristics and bull trout abundance. The characteristics of habitat units, such as cover, velocity breaks, food availability, and other features necessary for survival of individuals, can directly influence fish presence and density. The statistically significant positive correlation between habitat unit length and bull trout presence in fast water habitat units is logical. The longer the habitat unit (some fast water habitat units were ~ 100 m long) the higher the likelihood a bull trout will be present because a greater amount of area has been searched. The mean depth of slow water habitat units had a strong positive correlation to bull trout presence in habitat units. Several authors have documented the bull trout's affinity for low velocity habitat (Pratt 1984; Adams 1994; Bonneau 1994; Jakober 1995; Rich 1996; Sexauer and James 1997). Pools and low velocity runs were often the deepest habitat units in our study area. Therefore, the strong positive correlation between unit depth and bull trout presence and density may be related to their preference for pools and other low velocity units. When fast and slow water habitat units were analyzed separately, mean depth was only significant in slow water units indicating the importance of pool depth. One reason bull trout may prefer deep habitat units is that they may provide cover from terrestrial predators (Lonzarich and Quinn 1995).

The positive correlation between bull trout presence and total large woody debris is consistent with other reports of strong associations between bull trout and large woody debris (Goetz 1991; Jakober 1995; Dambacher and Jones 1997). When slow and fast water habitat units were analyzed separately, LWD was only significant in fast water units. Large woody debris in fast water units may provide velocity breaks that affords holding areas for bull trout in otherwise high velocity areas.

Pocket pools are found only in fast water habitat units. The number of pocket pools had a strong positive correlation to the presence of bull trout in habitat units. In fact 32 % of the bull trout in fast water habitat units were observed holding in pocket pools, while only 17 % of redband rainbow trout observed in fast water units were in pocket pools. Saffel and Scarnecchia (1995) also found a positive correlation between juvenile adfluvial bull trout density and the number of pocket pools.

The percent surface fines in slow water habitat units had a strong negative correlation to bull trout presence in slow water habitat units. There was not a relationship between percent surface fines and bull trout presence or density in fast water units. Bjornn and others (1977) found that higher levels of sediment resulted in reduced densities of fish in laboratory and natural stream pools, but could not find significant correlations in riffles. Fine sediment can fill interstitial spaces between bed material that would otherwise be used by bull trout for cover from predators (Bjornn et al. 1977; McPhail and Murray 1979; Baxter and McPhail 1997;

Thurow 1997). Pratt (1984) reported that juvenile bull trout defended territories over the streambed. When interstitial areas in the streambed are filled with sediment, bull trout may be forced into positions within the water column where they must defend territories or leave the area. One of the most common themes in the literature on migratory and resident bull trout involves the importance of substrate as cover (Pratt 1984; Adams 1994; Bonneau 1994; Jakober 1995; Baxter and McPhail 1997; Sexauer and James 1997; Thurow 1997).

The significance of substrate related habitat characteristics in this study support the growing evidence found in the literature. In this study divers repeatedly commented on the tendency for bull trout (especially juveniles) to remain motionless in direct contact with the substrate when disturbed. This behavior is similar to sculpin behavior and is in contrast to redband rainbow trout and brook trout that tend to flee rather than lie motionless. I noticed that bull trout were easier to detect when they were lying motionless in smaller substrates, such as sand and silt. Road construction, logging, livestock grazing, mining and other management activities can contribute directly to increased sediment levels and consequent embeddedness in stream channels (Bjornn et al. 1977). The soils of the Idaho Batholith are particularly susceptible to erosion (Wendt et. al 1973; Arnold 1975), which may increase the risk to bull trout because of their potential sensitivity to alterations of substrate size class structure.

There are two likely reasons for the negative correlation between bull trout presence and the percent of submerged vegetation. Fish may be avoiding detection by the divers by hiding in the thick vegetation. Another possibility is that the high percent of submerged vegetation is indirectly associated with warmer water temperatures, which has a parabolic correlation to bull trout densities at larger spatial scales.

The percent of shade provided by overstory does not indicate the total amount of stream shade, instead it gives an estimate of what percent of the stream shade is provided by large coniferous trees as opposed to small alder, willow, and herbaceous plants (understory).

The negative correlation between juvenile and adult bull trout presence in habitat units and the percent of shade provided by overstory may be related to a lack of understory rather than the amount of overstory. Alder and willow often hang over the stream providing shade as well as cover from terrestrial predators.

The negative correlation between redband rainbow trout presence and bull trout presence may be related to competitive displacement or differences in temperature preferences between the two species. Divers observed very few aggressive interactions between the two species, however the two species are known to segregate spatially across a temperature gradient (Ziller 1992; Adams 1994; Lowman Ranger District unpublished data). Brook trout are considered a threat to bull trout population persistence through hybridization and potential competitive interactions (Rieman and McIntyre 1993). The positive correlation between the brook trout presence and the presence of bull trout in a habitat unit may be due in part to similar preferences for habitat types. Also there were very few units with brook trout that did not have bull trout because of the larger overlap in the temperature preferences of the two congeners.

Bull trout had higher densities in slow water habitat than in fast water units. In fact habitat type (fast or slow) had a stronger correlation to bull trout density than the habitat characteristics of the habitat units such as the amount of large woody debris, mean depth, percent surface fines, and so on. The significance of the habitat unit type categorical variable indicates that factors associated with fast and slow units that we did not measure are influencing bull trout presence/absence and density in addition to the variables we measured. These factors may include water velocity, which was not directly measured in each habitat unit. It is also possible that snorkeling counts are biased to some degree in fast water units because they are often shallow and therefore difficult to snorkel effectively.

Reach categorical variables were highly significant at the habitat unit scale indicating that factors at the reach scale were influencing bull trout presence and density in habitat units. Of the habitat variables included in reach scale multiple linear regression models, mean summer water temperature and a quadratic term for mean summer water temperature were the only coefficients with large values that were statistically significant. Thus, mean summer water temperature is likely one of the key factors at the reach scale that is influencing bull trout densities. Decreasing stream sizes may confound the parabolic relationship between bull trout density and mean summer water temperature. In other words, the decrease in bull trout densities in reaches with mean summer water temperatures below about 7°C may in part result because the reaches with the coldest temperatures are often near the source of the stream where the small channel size limits the suitability of the habitat. Saffel and Scarnecchia (1995) found a decreasing trend in the density of juvenile adfluvial bull trout in 100 m reaches with the coldest maximum summer stream temperatures. I failed to find any literature documenting bull trout physiological performance at extremely cold temperatures. Patch categorical variables were also very significant. In fact patch categorical variables explained the variation in bull trout density equally as well as summer mean water temperature.

The high significance and large proportion of variance explained by the patch categorical variables in the reach scale model suggests factors at the patch scale have a strong relationship to the density of bull trout in reaches. In other words, bull trout density in reaches within patches are not entirely independent. Mean summer water temperature is a likely factor influencing bull trout density at the patch scale. Other potential unmeasured factors that may be contributing to the remaining variation in bull trout density (i.e., not explained by temperature) include differences in stream productivity, random bull trout population fluctuations, and sampling error. Gradient had a positive correlation to bull trout density in patches, however the relationship was a weak one. After accounting for stream temperature, bull trout may be less abundant in lower gradient streams because of lack of large substrate and other forms of cover often associated with complex moderate to high gradient streams. Rich (1996) found a strong negative correlation between bull trout presence and gradient, however his sample was not confined to habitat that was known to be occupied by bull trout. My results apply only to habitat characteristics within patches occupied by bull trout

The highest densities of bull trout in this study were in reaches with mean summer stream temperatures between 7 and 8.5°C (Figure 5). It is clear from laboratory and field evidence that cold temperatures are crucial for juvenile bull trout growth and survival (McPhail and Murray 1979; Saffel and Scarnecchia 1995; Goetz 1997a). We also found temperature to be highly significant in patch scale models with juvenile bull trout as the response variable.

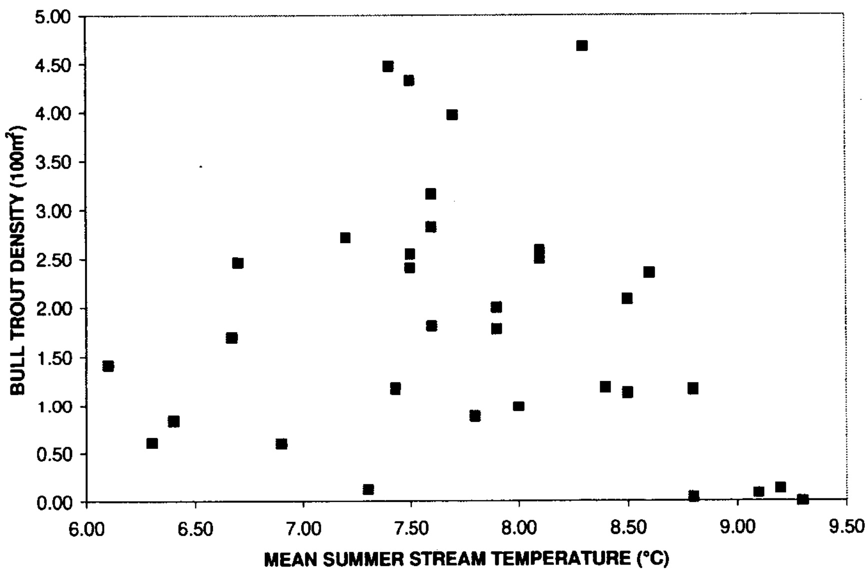

Figure 5. Scatter plot of bull trout density in reaches vs. the mean summer stream temperature.

There is also some evidence that the species segregation that is commonly found in streams with bull trout and other salmonids is in part the result of a shift in competitive dominance at various temperatures. Adams (1994) found juvenile and adult bull trout in a meadow stream that reached 20.5°C at least three days in a row. I observed bull trout feeding and cruising in a stream that was 23.5°C and likely over 24°C during the warmest part of the day. In both circumstances bull trout were the only salmonid species observed. Bull trout distribution may be confined to colder streams when other salmonid species are present because their ability to compete for resources improves. Further research is needed on the physiological performance of bull trout over a wide temperature gradient and in the presence of various other salmonid competitors. Knowing the maximum and minimum temperature tolerances of all age classes of bull trout may be a helpful tool in predicting bull trout occurrence.

Juvenile bull trout presence in habitat units was not significantly correlated in any way with the presence of adult bull trout, however the density of juvenile bull trout in a habitat unit had a strong negative correlation with the density of adult bull trout in the unit. Bull trout are highly piscivorous and often cannibalistic (Goetz 1989; Goetz 1997b; author's personal observation). When densities of adult bull trout are high in a habitat unit, juvenile bull trout may conceal themselves or leave the unit. At the reach scale, the density of juvenile bull trout was positively correlated to adult bull trout density. These results contradict the negative correlation found between juvenile bull trout density in habitat units. These results underscore the importance of scale in fish habitat relationships. Interactions between bull trout within a stream may directly effect their distribution within specific habitat units, but have little effect on the overall density of the population at larger spatial scales such as reaches.

Large-scale factors may constrain the effectiveness of small-scale habitat projects such as adding LWD to streams. For example the mean temperature of a patch may be the limiting factor that constrains the density of bull trout in individual reaches and habitat units, but temperature is partly controlled by large-scale watershed attributes, such as aspect and elevation, which are beyond the control of managers. Adding LWD to a stream that is too warm for bull trout will not likely increase the abundance of bull trout.

One important implication of large scale controlling factors in fish populations is that the controlling factors act on the population as a whole. For example, as long as fish have freedom to move, distribution and density in habitat units and reaches (or whatever spatial unit one chooses) within a stream are not independent of one another (Gowan et al. 1993). In our study, temperature may be a large-scale factor that is contributing to fish distribution and density within habitat units and reaches throughout patches. Recent work on bull trout populations has emphasized the potential role of metapopulation dynamics in population persistence (Rich 1996; Dunham and Rieman 1999). To the degree that metapopulation dynamics are operating, bull trout distribution and density may be linked across patches within watersheds or even entire basins. Stream temperature within a given patch of bull trout habitat has the potential to affect the population dynamics in adjacent patches.

Dunham and Rieman (1999) and Rich (1996) documented strong relationships between the area of suitable habitat and the presence of bull trout. Both papers stated the importance of conservation of core bull trout areas. When designating core areas for protection, large-scale factors that constrain bull trout populations should be considered. It would be wise to consider features of the landscape beyond catchment or basin size that will influence bull trout population size. For example, does the patch have the characteristics necessary to produce and maintain water temperatures that will contribute to strong bull trout populations?

Within certain constraints bull trout can inhabit a diversity of habitat types. Indeed bull trout could not have obtained their current distribution without having strong tendencies to colonize new habitat and recolonize previously occupied habitat. With these traits in mind managers should remain optimistic about restoring and conserving bull trout populations.

This study was observational in nature. Therefore we cannot infer that the linear correlations between resident bull trout density and the explanatory variables we measured and found to be statistically significant are direct cause and effect relationships. Controlled experiments are needed to test for causal relationships between the habitat characteristics we found to be significant, such as temperature, and bull trout distribution and density.

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APPENDIX

Table A.1. Results for multiple linear regression of (ln) bull trout density per 100 m^2 in habitat units on the habitat characteristics of the habitat units.

N = 165, R^2 = 0.17, Adjusted R^2 = 0.08, ANOVA P = 0.0132			
Variable (ln = natural log transformation)	**Parameter Estimate**	**95% Confidence Interval for Parameter Estimate**	**Probability > T Statistic**
Mean depth (m)	1.71	0.34 – 3.09	0.02
Dominant substrate*	-0.08	-0.16 – 0.00	0.05
Sub-dominant substrate*	-0.006	-0.09 – 0.08	0.89
ln % Surface fines	-0.23	-0.38 – (-0.08)	0.003
% Stable bank	-0.01	-0.02 – 0.00	0.03
ln Total large woody debris per 100 m	0.09	0.01 – 0.17	0.03
ln Lateral habitat areas per 100 m	-0.01	-0.09 – 0.07	0.77
ln % Undercut bank	0.01	-0.08 – 0.11	0.81
ln % Submerged vegetation	0.06	-0.11 – 0.12	0.89
ln % Overhead cover	0.07	-0.03 – 0.17	0.18
Shade**	0.1	-0.04 – 0.25	0.16
% Shade provided by overstory	0	-0.003 – 0.003	0.99
Presence of redband rainbow trout	-0.11	-0.44 – 0.21	0.5
Presence of brook trout	-0.14	-0.72 – 0.43	0.63

*Substrate classes were put into numeric classes for analysis: Sand/silt = 1, peagravel = 2, gravel = 3, rubble = 4, cobble = 5, small boulder = 6, boulder = 7, bedrock = 8.

** Shade classified as high, medium, or low. For analysis high = 3, medium = 2, and low = 1.

Table A.2. Separate multiple linear regression models for the (ln) density of bull trout in fast water habitat units and slow water habitat units.

	FAST WATER UNITS ANOVA F-Test $P = 0.16$, $R^2 = 0.44$, Adjusted $R^2 = 0.15$, $N = 45$		**SLOW WATER UNITS** ANOVA F-Test $P = 0.007$, $R^2 = 0.24$, Adjusted $R^2 = 0.14$, $N = 120$	
Variable (ln = natural log transformation)	**Parameter Estimate (95 % C.I.)**	**Probability > T Statistic**	**Parameter Estimate (95 % C.I.)**	**Probability > T Statistic**
ln Pocket pools per 100 m	0.03 (-0.15 – 0.21)	0.73		
Mean depth (m)	-3.9 (-9.5 – 1.68)	0.16	-0.55 (-1.67 – 0.57)	0.33
Dominant substrate*	-0.19 (-0.36 – (-0.02))	0.03	0.02 (-0.05 – 0.08)	0.61
Sub-dominant substrate*	-0.003 (-0.19 – 0.18)	0.97	0.04 (-0.04 – 0.11)	0.31
ln % Surface fines	-0.41 (-0.86 – 0.04)	0.07	-0.1 (-0.22 – 0.01)	0.08
% Stable bank	0.005 (-0.02 – 0.03)	0.61	-0.01 (-0.02 – (-0.003)	0.007
ln Total large woody debris per 100 m	0.26 (0.02 – 0.49)	0.03	0.05 (-0.01 – 0.11)	0.08
ln Lateral habitat areas per 100 m	-0.11 (-0.29 – 0.06)	0.19	0.02 (-0.04 – 0.09)	0.44
ln % Undercut bank	-0.18 (-0.37 – 0.01)	0.07	0.03 (-0.05 – 0.11)	0.41
ln % Submerged vegetation	0.08 (-0.26 – 0.42)	0.64	0.04 (-0.05 – 0.13)	0.33
ln % Overhead cover	-0.06 (-0.34 – 0.21)	0.64	0.1 (0.02 – 0.18)	0.01
Shade**	0.08 (-0.22 – 0.37)	0.59	0.06 (-0.06 – 0.18)	0.31
% Shade provided by overstory	-0.004 (-0.004 - 0.003)	0.22	0.001 (-0.001 – 0.005)	0.26
Presence of redband rainbow trout	-0.26 (-0.89 – 0.35)	0.39	-0.05 (-0.32 – 0.22)	0.71
Presence of brook trout	-0.34 (-2.17 – 1.48)	0.7	-0.07 (-0.51 – 0.36)	0.73

*Substrate classes were put into numeric classes for analysis: Sand/silt = 1, peagravel = 2, gravel = 3, rubble = 4, cobble = 5, small boulder = 6, boulder = 7, bedrock = 8.

** Shade classified as high, medium, or low. For analysis high = 3, medium = 2, and low = 1.

Table A.3. Results for multiple linear regression of (ln) juvenile bull trout density in habitat units on the habitat characteristics of the units.

N =165, R^2 = 0.43, Adjusted R^2 = 0.37, ANOVA P=.0001			
Variable (ln = natural log transformation)	**Parameter Estimate**	**95% Confidence Interval for Parameter Estimate**	**Probability > T Statistic**
Density of bull trout > 140 mm in total length per 100 m^2	-0.67	-0.83 – (-0.52)	0.0001
Mean depth (m)	1.6	-11 – 3.30	0.07
Dominant substrate*	-0.05	-0.15 – 0.04	0.26
Sub-dominant substrate*	-0.02	-0.13 – 0.08	0.66
ln % Surface fines	-0.18	-0.36 – 0.003	0.05
% Stable bank	-0.01	-0.03 – 0.001	0.03
ln Total large woody debris per 100 m	0.08	0.01 – 0.17	0.09
ln Lateral habitat areas per 100 m	-0.01	-0.11 – 0.08	0.77
ln % Undercut bank	0.07	-0.04 – 0.18	0.21
ln % Submerged vegetation	-0.01	-0.15 – 0.12	0.83
ln % Overhead cover	0.06	-0.05 – 0.18	0.28
Shade**	0.05	-0.12 – 0.22	0.54
% Shade provided by overstory	0.002	-0.002 – 0.01	0.31
Presence of redband rainbow trout	-0.15	-0.53 – 0.24	0.45
Presence of brook trout	-0.21	-0.88 – 0.45	0.53

*Substrate classes were put into numeric classes for analysis: Sand/silt = 1, peagravel = 2, gravel = 3, rubble = 4, cobble = 5, small boulder = 6, boulder = 7, bedrock = 8.
** Shade classified as high, medium, or low. For analysis high = 3, medium = 2, and low = 1.

Table A.4. Results of multiple linear regression of (ln) bull trout density in reaches on the habitat characteristics of the reaches.

N = 32, R^2 = 0.71, Adjusted R^2 = 0.34, ANOVA P = 0.11			
Variable (ln = natural log transformation)	**Parameter Estimate**	**95% Confidence Interval for Parameter Estimate**	**Probability > T Statistic**
Gradient	0.04	-0.07 – 0.14	0.48
Mean summer water temperature (°C)	4.10	-0.42 – 10.41	0.07
(Mean summer water temperature)^2 (°C)	-0.33	-0.68 – 0.01	0.06
Mean depth (m)	0.02	-3.97 – 4.01	0.99
Mean dominant substrate*	-0.13	-0.65 – 0.39	0.60
Mean sub-dominant substrate*	0.01	-0.33 – 0.36	0.93
% Surface fines	-0.01	-0.04 – 0.01	0.32
% Stable bank	0.003	-0.03 – 0.04	0.88
Pocket pools per 100 m	-0.001	-0.04 – 0.04	0.97
Total large woody debris per 100 m	-0.002	-0.04 – 0.03	0.92
ln Lateral habitat areas per 100 m	-0.03	-0.47 – 0.40	0.88
% Undercut bank	0.02	-0.05 – 0.09	0.57
ln % Submerged vegetation	-0.02	-0.05 – 0.002	0.07
% Overhead cover	-0.01	-0.04 – 0.02	0.68
Mean shade**	-0.18	-0.91 – 0.54	0.60
% Shade provided by overstory	0.0006	-0.01– 0.01	0.90
Density of redband rainbow trout per 100 m^2	-0.12	-0.59 – 0.35	0.59
Density of brook trout per 100 m^2	-0.12	-1.49 – 1.24	0.85

*Substrate classes were put into numeric classes for analysis: Sand/silt = 1, peagravel = 2, gravel = 3, rubble = 4, cobble = 5, small boulder = 6, boulder = 7, bedrock = 8.

** Shade classified as high, medium, or low. For analysis high = 3, medium = 2, and low = 1.

Table A.5. Summary of habitat characteristics found in bull trout patches on the Lowman Ranger District.

Habitat Variables	Sample Size (*N*)	Mean	Standard Deviation	Mode	Minimum Value	Maximum Value
Length	2736	9.04	10.89	4.0	0.6	140.8
Width	1456	2.87	1.39	2.0	0.45	14.5
Mean. depth	1433	0.20	0.10	0.15	0.02	0.82
Max. depth	972	0.49	0.16	0.40	0.12	1.27
Crest depth	961	0.17	0.08	0.20	0.02	0.50
Pocket pools per 100m^2	2735	9.34	21.73	0	200.00	0
Mean pocket pool depth	718	0.26	0.07	0.30	0.05	0.57
Dominant substrate	1427	3.2	1.7	3.00	1	8
Subdominant substrate	1427	3.0	1.4	3.00	1	10
% Surface fines	2446	26	23.0	10.0	0	100
% Stable bank	2720	93	14.3	100	0	100
Total large woody Debris per 100m^2	2735	25.2	28.0	0	0	233.3
Total aggregates per 100m^2	2734	11.4	17.3	0	0	200.0
Lateral habitat areas per 100m^2	2735	7.3	14.7	0	0	151.5
Shade (High = 3, Med. = 2, Low = 1)	649	2.0	0.8	2.0	1.0	3.0
% Overstory	651	56.9	36.7	100	0	100
% Undercut bank	622	6.4	9.6	0	0	90
% Overhead cover	626	25.7	25.3	5.0	0	95
% Submerged cover	626	7.3	10.1	0	0	60
% Submerged vegetation	626	7.0	14.0	0	0	90
% Large substrate	626	17.0	20.4	0	0	90
% Bubble cover	323	4.9	10.4	0	0	80
Gradient*	34	3.9	3.8	1.0	0.1	18.6
Elevation (m)*	34	1977	104.7	1951	1756	2168
Mean daily Temperature (°C)*	33	7.8	0.8	7.5	6.1	9.3
Mean daily maximum Temperature (°C)*	33	10.0	1.3	9.0	8.1	12.6

*Values calculated by taking the mean of all the stream reaches.

Table A.6. Summary of habitat characteristics found in reaches.

Stream	Reach	Gradient	Elevation (m)	Daily Mean Temp. (°C)	Mean Daily Maximum Temp. (°C)	Total Habitat Units	Total # Pools	% Pools	Pools per 100m
North Fork Canyon Creek	1	3.6	1832	7.5	9.0	142	75	53	3.7
	2	5.0	1905	7.4	9.0	27	16	59	5.3
	3	6.5	1924	7.5	9.1	69	36	52	5.1
	4	18.6	1970	7.6	9.2	64	29	45	5.1
Canyon Creek	1	3.7	1773	NA	NA	39	8	21	0.9
Scott Creek	1	5.9	1845	6.1	8.4	107	50	47	3.6
	2	3.5	1927	6.3	8.2	35	18	51	7.0
	3	3.9	1939	6.4	8.1	39	18	46	6.4
Middle Fork Warmspring Creek	1	4.9	1756	8.0	9.5	149	87	58	7.3
	2	6.6	1817	7.9	9.4	98	52	53	7.5
	3	5.9	1856	7.2	8.7	134	65	49	5.8
	4	9.7	1933	6.7	8.3	91	50	55	8.9
South Fork Deer Creek	1	0.7	2012	9.3	12.6	80	42	53	5.5
	2	0.9	2015	8.8	12.0	68	41	60	6.04
	3	1.8	2049	7.6	10.5	225	144	64	9.2
	4	2.3	2067	6.9	9.7	100	82	82	15.2
Bearskin Creek	1	3.1	1994	8.5	11.3	61	33	54	3.0
	2	2.5	2034	7.9	10.6	122	85	70	6.5
	3	0.9	2061	8.4	11.3	103	68	66	6.4
	4	0.5	2067	8.3	10.5	26	11	42	2.56
	5	5.6	2073	8.1	9.4	102	59	58	6.8
Cache Creek	1	1.2	2084	9.1	10.8	126	76	60	7.9
	2	7.0	2096	9.2	10.9	76	35	46	6.4
East Fork Cache Creek	1	1.0	2159	8.1	10.9	35	15	43	3.6
	2	1.0	2162	7.7	10.5	52	33	63	10.7
	3	1.0	2171	7.3	10.8	37	18	49	7.3
Dagger Creek	1	1.0	1936	8.8	12.1	64	26	41	3.7
	2	1.0	1945	8.6	11.5	39	15	38	4.0
	3	3.7	1951	7.8	9.7	124	56	45	5.7
	4	4.5	1986	7.6	9.2	104	64	62	11.5
	5	12.0	2024	7.5	8.9	89	54	61	10.7
Cold Creek	1	0.5	2951	8.5	11.5	39	20	51	5.3
	2	0.1	1963	7.4	9.0	89	45	51	6.4
	3	1.0	1973	6.6	8.2	81	47	58	9.0

Table A.6, Continued.

Stream	Reach	Total Length (m)	Mean Unit Length (m)	Mean Unit Width (m)	Mean Unit Depth (m)	Mean Pool Max. Depth (m)	Mean Pool Crest Depth (m)
North Fork Canyon Creek	1	2013.1	14.18 (18.04)	4.92 (1.54)	0.20 (0.05)	0.62 (0.16)	0.20 (0.08)
	2	299.6	11.10 (13.87)	3.36 (1.02)	0.21 (0.08)	0.55 (0.08)	0.23 (0.06)
	3	706.2	10.23 (13.42)	3.47 (1.25)	0.20 (0.08)	0.53 (0.13)	0.21 (0.03)
	4	574.4	8.98 (11.86)	3.58 (0.86)	0.18 (0.04)	0.54 (0.13)	0.19 (0.06)
Canyon Creek	1	887.8	22.76 (29.50)	7.64 (1.89)	0.33 (0.15)	0.82 (0.21)	0.30 (0.09)
Scott Creek	1	1404.8	13.13 (15.51)	3.27 (0.75)	0.17 (0.07)	0.55 (0.19)	0.22 (0.13)
	2	257.0	7.34 (9.67)	2.58 (1.09)	0.10 (0.02)	0.43 (0.10)	0.12 (0.03)
	3	280.7	7.20 (6.63)	2.54 (0.86)	0.08 (0.04)	0.35 (0.13)	0.10 (0.03)
Middle Fork Warmspring Creek	1	1190.6	7.99 (9.17)	2.73 (0.67)	0.15 (0.05)	0.41 (0.07)	0.17 (0.07)
	2	697.1	7.11 (5.58)	3.52 (0.78)	0.21 (0.11)	0.49 (0.08)	0.26 (0.09)
	3	1120.8	8.36 (8.93)	2.82 (0.73)	0.15 (0.05)	0.41 (0.07)	0.26 (0.06)
	4	559.4	6.15 (6.26)	2.83 (1.03)	0.19 (0.05)	0.43 (0.11)	0.23 (0.05)
South Fork Deer Creek	1	764.9	9.56	3.49	0.24	0.53	0.33
	2	678.7	9.98 (6.56)	3.53 (1.28)	0.30 (0.06)	0.57 (0.12)	0.29 (0.09)
	3	1564.2	6.95 (4.69)	2.22 (0.56)	0.17 (0.07)	0.53 (0.07)	0.21 (0.06)
	4	539.7	5.40 (2.35)	1.55 (0.36)	0.19 (0.08)	0.38 (0.08)	0.16 (0.05)
Bearskin Creek	1	1113.6	18.26 (22.10)	3.31 (0.76)	0.23 (0.10)	0.50 (0.12)	0.23 (0.06)
	2	1298.0	10.64 (16.01)	2.85 (0.94)	0.27 (0.13)	0.48 (0.12)	0.16 (0.06)
	3	1066.1	10.35 (4.63)	2.45 (0.76)	0.26 (0.12)	0.61 (0.13)	0.17 (0.07)
	4	413.6	15.91 (13.81)	2.12 (0.48)	0.15 (0.09)	0.41 (0.07)	0.15 (0.04)
	5	872.6	8.55 (10.50)	2.29 (0.61)	0.19 (0.06)	0.36 (0.08)	0.13 (0.04)
Cache Creek	1	964.0	7.65 (6.25)	3.68 (0.89)	0.15 (0.05)	0.54 (0.12)	0.14 (0.06)
	2	542.9	7.14 (10.63)	4.29 (1.68)	0.17 (0.04)	0.45 (0.10)	0.13 (0.05)
East Fork Cache Creek	1	420.8	12.02 (13.56)	1.38 (0.71)	0.18 (0.09)	0.53 (0.14)	0.14 (0.07)
	2	309.5	5.95 (3.42)	1.55 (0.56)	0.35 (0.18)	0.70 (0.22)	0.18 (0.11)
	3	246.4	6.66 (6.24)	3.26 (0.97)	0.18 (0.06)	0.52 (0.17)	0.11 (0.04)
Dagger Creek	1	699.2	10.93 (7.71)	2.20 (0.77)	0.17 (0.04)	0.50 (0.10)	0.13 (0.03)
	2	378.8	9.71 (6.88)	2.47 (0.83)	0.16 (0.05)	0.44 (0.09)	0.12 (0.03)
	3	983.4	7.93 (6.49)	2.53 (0.59)	0.19 (0.06)	0.50 (0.14)	0.22 (0.07)
	4	554.5	5.33 (3.59)	2.45 (0.72)	0.16 (0.05)	0.38 (0.11)	0.19 (0.05)
	5	505.2	5.68 (5.27)	2.48 (0.84)	0.19 (0.06)	0.41 (0.13)	0.18 (0.05)
Cold Creek	1	376.5	9.65 (7.31)	1.66 (0.63)	0.33 (0.09)	0.43 (0.09)	0.18 (0.03)
	2	702.9	7.90 (6.67)	2.53 (0.78)	0.15 (0.05)	0.41 (0.10)	0.15 (0.07)
	3	519.7	6.42 (7.04)	2.27 (0.50)	0.14 (0.05)	0.38 (0.08)	0.14 (0.05)

The standard deviation is given in parentheses after the mean value.

Table A.6, Continued.

Stream	Reach	Width: Depth Ratio	Width: Max. Depth Ratio	Residual Pool Depth (m)	Pocket Pools per 100 m	Mean Depth of Pocket Pools (m)	Mean Dominate Substrate (Mode)*	Mean Subdominant Substrate (Mode)*
North Fork Canyon Creek	1	25.18	7.94	0.42	26.8	0.29	4.8 (4)	3.6 (3)
	2	16.09	6.14	0.32	20.7	0.27	3.7 (4)	4.0 (5)
	3	17.28	6.51	0.32	34.2	0.28	4.1 (4)	4.5 (5)
	4	19.55	6.63	0.35	36.8	0.27	4.9 (5)	4.5 (5)
Canyon Creek	1	23.20	9.36	0.52	44.9	0.29	4.6 (4)	3.8 (4)
Scott Creek	1	19.29	5.95	0.33	11.5	0.31	4.8 (6)	3.8 (5)
	2	26.36	5.99	0.31	11.3	0.21	3.6 (4)	1.9 (1)
	3	33.06	7.27	0.25	9.6	0.19	3.9 (5)	3.4 (4)
Middle Fork Warmspring Creek	1	18.77	6.63	0.24	9.0	0.29	4.3 (5)	3.7 (5)
	2	16.79	7.23	0.22	8.8	0.30	3.7 (1)	4.4 (6)
	3	18.29	6.85	0.15	12.3	0.27	3.8 (1)	3.6 (4)
	4	14.90	6.56	0.20	16.8	0.25	4.3 (5)	3.9 (4)
South Fork Deer Creek	1	14.64	6.56	0.20	1.3	0.28	2.4 (3)	2.2 (1)
	2	11.81	6.24	0.28	0.7	0.33	2.4 (3)	2.3 (3)
	3	12.88	4.22	0.32	1.3	0.24	2.3 (3)	2.2 (1)
	4	8.19	4.11	0.22	0.7	0.19	2.7 (2)	2.1 (1)
Bearskin Creek	1	14.17	6.67	0.27	15.2	0.25	4.5 (5)	3.2 (4)
	2	10.38	5.93	0.33	14.8	0.20	2.7 (1)	2.7 (2)
	3	9.37	4.03	0.44	2.1	0.29	2.8 (3)	2.2 (2)
	4	14.06	5.15	0.26	1.8	0.19	4.6 (5)	3.7 (4)
	5	12.09	6.39	0.23	31.4	0.17	4.4 (5)	3.3 (4)
Cache Creek	1	24.16	6.87	0.40	4.6	0.29	3.5 (4)	2.9 (3)
	2	25.67	9.44	0.33	27.6	0.29	4.6 (6)	4.3 (5)
East Fork Cache Creek	1	7.46	2.58	0.39	0.7	0.34	1.8 (2)	2.1 (3)
	2	4.43	2.22	0.52	2.9	0.25	1.8 (2)	2.0 (1)
	3	18.39	6.23	0.42	6.4	0.25	2.0 (2)	2.2 (2)
Dagger Creek	1	13.20	4.38	0.37	3.1	0.25	2.2 (3)	2.4 (2)
	2	15.33	5.58	0.32	5.5	0.25	2.5 (3)	2.4 (2)
	3	13.26	5.09	0.28	8.2	0.26	4.3 (5)	4.0 (4)
	4	15.07	6.42	0.20	9.7	0.25	4.0 (5)	3.1 (1)
	5	13.15	6.00	0.23	14.6	0.26	4.2 (6)	4.0 (5)
Cold Creek	1	5.00	3.90	0.25	0.0	0.00	1.5 (1)	2.5 (3)
	2	17.09	6.18	0.26	6.5	0.32	1.8 (2)	2.2 (3)
	3	16.08	5.97	0.24	6.9	0.29	1.3 (1)	2.5 (3)

The standard deviation is given in parentheses after the mean value except when otherwise noted.
*Substrate classes were put into numeric classes for analysis: Sand/silt = 1, peagravel = 2, gravel = 3, rubble = 4, cobble = 5, small boulder = 6, boulder = 7, bedrock = 8. The mode is given in parentheses.

Table A.6, Continued.

Stream	Reach	%Surface fines	%Stable bank	Large Woody Debris (Singles) per 100 m^2	Total Large Woody Debris Aggregates per 100 m	Total Large Woody Debris per 100 m^2	Total Large Woody Debris (pieces) per 100 m^2	Lateral Habitat Areas per 100 m
North Fork Canyon Creek	1	8 (4.8)	97 (8.3)	8.6	6.3	15.2	40.8	11.4
	2	9 (4.7)	98 (6.3)	12.7	10.3	23.4	72.8	18.7
	3	7 (11.7)	97 (9.1)	5.8	3.5	9.5	21.8	22.1
	4	6 (3.0)	96 (11.5)	11.5	4.4	15.8	26.8	13.1
Canyon Creek	1	11 (8.1)	94 (11.8)	4.1	3.3	7.5	23.9	14.4
Scott Creek	1	23 (14.1)	90 (14.6)	6.1	2.5	9.0	NA	0.6
	2	23 (12.1)	76 (25.3)	6.2	5.1	11.3	NA	1.6
	3	20 (15.4)	86 (19.6)	7.5	4.6	13.2	NA	1.8
Middle Fork Warmspring Creek	1	25 (15.9)	95 (10.1)	10.6	12.7	23.4	NA	1.8
	2	33 (25.0)	99 (1.9)	18.4	16.1	41.2	NA	0.0
	3	24 (14.7)	100 (1.3)	14.9	12.6	31.7	NA	0.6
	4	20 (13.2)	95 (14.7)	12.0	11.6	25.6	NA	1.3
South Fork Deer Creek	1	27	92	1.2	0.4	2.0	NA	1.6
	2	31 (16.6)	96 (5.9)	5.7	6.5	12.4	NA	1.6
	3	33 (25.3)	97 (5.7)	10.2	6.0	16.8	NA	1.0
	4	57 (29.7)	91 (10.6)	18.9	7.4	26.5	NA	2.4
Bearskin Creek	1	15 (13.1)	97 (3.1)	6.7	4.7	11.4	27.2	4.5
	2	15 (8.1)	98 (4.5)	5.2	4.5	9.9	20.0	10.8
	3	13 (5.7)	94 (6.6)	4.0	0.7	4.7	5.6	13.0
	4	5 (4.8)	97 (3.2)	3.4	1.7	5.1	7.5	9.7
	5	8 (9.1)	96 (5.2)	11.1	7.1	18.3	36.2	14.6
Cache Creek	1	19 (20.0)	97 (8.9)	9.6	7.4	17.2	50.1	3.1
	2	22 (22.2)	98 (11.3)	12.5	10.3	22.8	81.4	4.8
East Fork Cache Creek	1	28 (15.0)	88 (9.5)	1.9	0.0	1.9	1.9	1.2
	2	12 (9.0)	92 (7.3)	10.0	1.9	12.0	16.2	3.2
	3	35 (19.5)	85 (17.9)	13.8	4.1	17.9	23.1	19.9
Dagger Creek	1	23 (13.2)	73 (27.8)	2.3	0.6	2.9	4.3	13.7
	2	26 (21.8)	52 (29.0)	9.2	3.7	13.5	23.0	23.0
	3	25 (14.2)	88 (16.1)	13.9	7.7	22.0	NA	1.9
	4	32 (20.2)	93 (8.2)	14.8	12.6	28.9	NA	0.7
	5	35 (19.3)	84 (11.9)	11.7	16.8	28.7	NA	0.8
Cold Creek	1	65 (21.0)	82 (20.4)	5.0	0.5	5.6	6.4	3.7
	2	57 (30.9)	82 (21.8)	11.4	12.4	24.8	76.7	6.4
	3	54 (25.1)	93 (15.3)	14.6	20.6	35.6	113.9	3.1

*Large woody debris (singles) gives the number of single pieces of large wood in the stream. Total large woody debris equals the sum of aggregates, root wads, and single pieces. Total large woody debris (pieces) equals the sum of the total number of pieces in each aggregate, root wads, and single pieces of large wood. In 1996 the total number of large woody debris pieces in each aggregate was not counted.

Table A.6, Continued.

Stream	Reach	% Undercut bank	% Overhead Cover	% Submerged Cover	% Submerged Vegetation	% Large Substrate
North Fork	1	3.1 (3.6)	26.4 (23.6)	6.7 (8.6)	0.3 (1.3)	28.3 (20.5)
Canyon	2	1.3 (2.3)	15.0 (8.9)	7.5 (6.0)	0.0 (0)	7.5 (8.9)
Creek	3	0.9 (2.0)	32.3 (25.6)	2.7 (3.4)	0.0 (0)	15.5 (15.2)
	4	0.0 (0)	56.8 (31.4)	2.3 (3.4)	0.0 (0)	36.4 (19.1)
Canyon Creek	1	1.9 (3.3)	37.3 (29.0)	8.8 (10.4)	0.0 (0)	15.4 (15.1)
Scott Creek	1	0.9 (2.0)	49.1 (23.4)	4.7 (4.8)	0.0 (0)	25.6 (26.3)
	2	3.0 (3.5)	39.5 (20.2)	19.0 (17.1)	0.0 (0)	31.5 (13.3)
	3	2.7 (2.6)	38.1 (25.7)	13.1 (12.2)	0.0 (0)	30.4 (15.1)
Middle Fork	1	14.2 (15.1)	53.0 (30.2)	12.6 (12.4)	6.4 (9.9)	17.7 (18.0)
Warmspring	2	1.2 (3.0)	48.2 (23.9)	8.6 (7.3)	1.0 (4.1)	33.6 (25.0)
Creek	3	3.0 (5.8)	50.4 (26.8)	8.2 (11.8)	0.2 (0.9)	26.3 (21.4)
	4	4.7 (8.3)	47.7 (25.8)	9.7 (10.3)	0.0 (0)	51.3 (26.9)
South Fork	1	6.1	13.9	5.6	22.2	1.4
Deer Creek	2	5.9 (6.1)	9.4 (7.3)	5.9 (5.2)	15.3 (14.8)	7.2 (16.0)
	3	10.4 (9.9)	25.2 (22.5)	9.4 (15.1)	25.2 (18.2)	5.4 (11.4)
	4	16.5 (11.6)	31.3 (23.4)	7.9 (9.8)	15.2 (15.2)	8.8 (18.6)
Bearskin	1	2.2 (4.4)	10.0 (10.5)	0.6 (2.5)	0.6 (1.7)	13.8 (9.2)
Creek	2	3.9 (6.6)	8.8 (11.7)	3.0 (4.8)	7.3 (14.0)	9.8 (9.7)
	3	6.7 (7.2)	0.9 (2.5)	0.9 (1.9)	12.0 (10.5)	0.2 (1.0)
	4	8.3 (5.0)	1.7 (2.5)	1.7 (2.5)	10.6 (9.5)	10.6 (6.4)
	5	3.5 (3.5)	10.6 (10.8)	3.8 (7.1)	0.2 (1.0)	15.4 (8.8)
Cache	1	3.8 (4.4)	25.2 (15.7)	7.2 (8.2)	8.4 (16.1)	21.7 (13.0)
Creek	2	2.3 (3.7)	24.7 (16.0)	9.3 (10.0)	0.7 (1.8)	30.0 (18.5)
East Fork	1	17.0 (25.4)	9.0 (9.1)	0.0 (0)	26.0 (32.0)	0.0 (0)
Cache	2	7.9 (8.7)	9.6 (11.2)	3.2 (3.7)	27.1 (12.7)	0.0 (0)
Creek	3	4.4 (3.2)	0.0 (0)	5.0 (6.6)	52.5 (23.5)	0.0 (0)
Dagger	1	5.9 (5.2)	0.0 (0)	0.9 (2.7)	3.8 (3.9)	0.6 (1.7)
Creek	2	2.5 (2.7)	3.3 (6.1)	1.7 (2.6)	0.0 (0)	0.0 (0)
	3	8.6 (17.4)	24.8 (28.5)	7.2 (8.1)	0.0 (0)	21.2 (27.2)
	4	6.6 (8.4)	22.6 (13.2)	7.2 (8.7)	0.0 (0)	33.2 (22.3)
	5	5.8 (6.1)	32.9 (21.2)	8.7 (9.8)	0.0 (0)	33.7 (21.7)
Cold Creek	1	19.0 (16.5)	19.0 (12.4)	2.0 (2.6)	4.5 (6.4)	0.5 (1.6)
	2	7.2 (8.0)	15.0 (14.1)	10.8 (8.3)	8.8 (6.5)	3.3 (5.3)
	3	10.0 (6.1)	14.3 (13.1)	21.5 (14.3)	0.0 (0)	8.8 (11.2)

The standard deviation is given in parentheses after the mean value except when otherwise noted. Shade classified as high, medium, or low. For analysis high = 3, medium = 2, and low = 1. The mode is given in parentheses.

Table A.6, Continued.

Stream	Reach	% Bubble Cover	Mean Shade (Mode)*	% Overstory
North Fork Canyon Creek	1	9.3 (9.5)	2.2 (2)	72.7 (17.9)
	2	5.0 (5.4)	2.4 (3)	63.1 (25.5)
	3	10.0 (8.1)	2.7 (3)	83.5 (30.3)
	4	30.0 (23.2)	2.5 (2)	23.3 (31.3)
Canyon Creek	1	10.0 (15.4)	1.5 (1)	90.8 (6.4)
Scott Creek	1	NA	2.0 (2)	28.5 (32.1)
	2	NA	1.3 (1)	81.5 (22.4)
	3	NA	2.1 (2)	43.2 (37.8)
Middle Fork Warmspring Creek	1	NA	2.7 (3)	69.7 (28.4)
	2	NA	2.0 (2)	37.3 (27.0)
	3	NA	1.8 (2)	40.1 (37.7)
	4	NA	2.7 (3)	31.0 (32.7)
South Fork Deer Creek	1	NA	1.1 (1)	21.2
	2	NA	1.9 (2)	64.4 (33.3)
	3	NA	1.4 (1)	28.6 (27.0)
	4	NA	1.7 (1)	19.8 (26.0)
Bearskin Creek	1	1.6 (3.0)	2.2 (2)	76.4 (14.3)
	2	0.9 (2.4)	2.1 (2)	66.5 (13.0)
	3	0.0 (0)	1.3 (1)	38.7 (27.5)
	4	0.6 (1.7)	2.1 (2)	90.0 (8.5)
	5	4.4 (6.1)	2.3 (2)	92.1 (8.1)
Cache Creek	1	3.6 (6.8)	2.3 (3)	61.3 (38.1)
	2	12.3 (13.9)	2.6 (3)	70.3 (31.6)
East Fork Cache Creek	1	0.5 (1.6)	1.1 (1)	27.5 (20.5)
	2	2.5 (8.0)	1.0 (1)	92.5 (3.4)
	3	0.0 (0)	1.1 (1)	57.5 (42.7)
Dagger Creek	1	0.0 (0)	1.3 (1)	25.0 (44.7)
	2	0.8 (2.0)	1.2 (1)	41.7 (49.2)
	3	NA	2.4 (2)	59.8 (31.9)
	4	NA	1.7 (2)	75.5 (34.7)
	5	NA	2.7 (3)	81.7 (25.8)
Cold Creek	1	0.0 (0)	1.5 (1)	10.0 (29.9)
	2	2.5 (8.3)	2.7 (3)	84.3 (25.5)
	3	6.8 (13.6)	2.6 (3)	99.2 (2.5)

Table A.7. Summary of fish densities in reaches.

Stream	Reach	Total Bull Trout	Total Bull Trout per 100 m^2	Total Bull Trout ≤ 140 mm	Total Bull Trout ≤ 140 mm per 100 m^2	Total Bull Trout > 140 mm	Total Bull Trout > 140mm per 100 m^2
North Fork Canyon Creek	1	238	2.40	165	1.67	73	0.74
	2	45	4.48	43	4.28	2	0.20
	3	106	4.33	43	1.76	63	2.57
	4	58	2.82	18	0.88	40	1.95
Canyon Creek	1	120	1.77	53	0.78	67	0.99
Scott Cr.	1	65	1.41	23	0.50	42	0.91
	2	4	0.60	0	0.00	4	0.60
	3	6	0.84	4	0.56	2	0.28
Middle Fork Warmspring Creek	1	32	0.98	27	0.83	5	0.15
	2	49	2.00	47	1.92	2	0.08
	3	86	2.72	84	2.66	2	0.06
	4	39	2.46	36	2.27	3	0.19
South Fork Deer Creek	1	0	0.00	0	0.00	0	0.00
	2	1	0.04	1	0.04	0	0.00
	3	63	1.81	62	1.78	1	0.03
	4	5	0.60	5	0.60	0	0.00
Bearskin Creek	1	42	1.14	40	1.08	2	0.05
	2	66	1.78	62	1.67	4	0.11
	3	31	1.19	29	1.11	2	0.08
	4	41	4.68	36	4.11	5	0.57
	5	50	2.50	42	2.10	8	0.40
Cache Creek	1	3	0.08	3	0.08	0	0.00
	2	3	0.13	3	0.13	0	0.00
East Fork Cache Creek	1	15	2.59	11	1.90	4	0.69
	2	19	3.97	13	2.72	6	1.25
	3	1	0.12	1	0.12	0	0.00
Dagger Creek	1	18	1.17	14	0.91	4	0.26
	2	22	2.35	14	1.50	8	0.86
	3	22	0.88	22	0.88	0	0.00
	4	43	3.16	40	2.94	3	0.22
	5	32	2.55	29	2.31	3	0.24
Cold Creek	1	13	2.08	13	2.08	0	0.00
	2	21	1.18	18	1.01	3	0.17
	3	20	1.70	17	1.44	3	0.25

Table A.7, Continued.

Stream	Reach	Total Rainbow Trout	Total Rainbow Trout per 100 m^2	Total Brook Trout	Total Brook Trout per 100 m^2
North Fork Canyon Creek	1	6	0.06	1	0.01
	2	0	0.00	0	0.00
	3	19	0.78	0	0.00
	4	31	1.51	0	0.00
Canyon Creek	1	15	0.22	0	0.00
Scott Cr.	1	0	0.00	0	0.00
	2	0	0.00	0	0.00
	3	0	0.00	0	0.00
Middle Fork Warmspring Creek	1	28	0.86	0	0.00
	2	5	0.20	0	0.00
	3	0	0.00	0	0.00
	4	0	0.00	0	0.00
South Fork Deer Creek	1	78	2.92	0	0.00
	2	58	2.42	0	0.00
	3	38	1.09	0	0.00
	4	3	0.36	0	0.00
Bearskin Creek	1	1	0.03	19	0.51
	2	0	0.00	24	0.65
	3	0	0.00	5	0.19
	4	0	0.00	2	0.23
	5	0	0.00	0	0.00
Cache Creek	1	150	4.23	18	0.51
	2	193	8.29	3	0.13
East Fork Cache Creek	1	0	0.00	5	0.86
	2	0	0.00	2	0.42
	3	0	0.00	2	0.25
Dagger Creek	1	23	1.49	0	0.00
	2	23	2.46	0	0.00
	3	62	2.49	0	0.00
	4	49	3.60	0	0.00
	5	14	1.12	0	0.00
Cold Creek	1	0	0.00	0	0.00
	2	1	0.06	0	0.00
	3	1	0.08	1	0.08

Table A.8. Summary of habitat characteristics in patches.

Stream	Gradient	Mean Elevation (m)	Daily Mean Temp. (°C)	Mean Daily Maximum Temp. (°C)	Total Habitat Units	Total # Pools	% Pools	Pools per 100 m
North Fork Canyon Creek	8.4	1947	7.5	9.1	303	156	51.5	4.3
Scott Creek	4.4	1917	6.3	8.2	191	86	45.0	4.4
Middle Fork Warmspring Creek	6.8	1878	7.5	9.0	462	251	54.3	7.0
South Fork Deer Creek*	1.4	2046	8.2	11.2	473	312	66.0	8.8
Bearskin Creek	4.6	2062	7.7	9.8	413	256	62.0	5.4
Cache Creek	4.1	2109	9.2	10.9	202	111	55.0	7.4
Dagger Creek	4.4	2023	8.1	10.3	317	206	65.0	10.1
East Fork Cache Creek	1.0	2165	7.7	10.7	114	66	57.9	6.8
Cold Creek	0.5	1968	7.5	9.6	209	119	56.9	7.4

*Values do not include reach 1 of South Fork Deer Creek.

Table A.8, Continued.

Stream	Total Length (m)	Mean Unit Length (m)	Mean Unit Width (m)	Mean Unit Depth (m)
North Fork Canyon Creek	4481.1	13.18 (18.03)	4.44 (1.97)	0.21 (0.09)
Scott Creek	1942.5	10.73 (13.3)	2.94 (0.91)	0.13 (0.07)
Middle Fork Warmspring Creek	3564.4	7.61 (7.97)	2.96 (0.84)	0.17 (0.07)
South Fork Deer Creek*	2782.6	7.13 (4.85)	2.26 (0.95)	0.18 (0.06)
Bearskin Creek	4763.9	11.53 (14.12)	2.63 (0.85)	0.23 (0.11)
Cache Creek	1506.9	7.46 (8.16)	3.92 (1.28)	0.16 (0.05)
Dagger Creek	2031.6	7.48 (6.22)	2.38 (0.77)	0.17 (0.05)
East Fork Cache Creek	976.7	8.57 (8.75)	1.90 (1.05)	0.26 (0.16)
Cold Creek	1599.1	7.65 (7.00)	2.26 (0.72)	0.16 (0.06)

The standard deviation is given in parentheses after the mean value.
*Values do not include reach 1 of South Fork Deer Creek.

Table A.8, Continued

Stream	Mean Pool Max. Depth (m)	Mean Pool Crest Depth (m)	Width: Depth Ratio	Width: Max. Depth Ratio
North Fork Canyon Creek	0.60 (0.17)	0.22 (0.08)	21.14	7.4
Scott Creek	0.46 (0.18)	0.17 (0.11)	24.40	6.32
Middle Fork Warmspring Creek	0.43 (0.09)	0.21 (0.08)	17.44	6.84
South Fork Deer Creek*	0.42 (0.11)	0.20 (0.08)	11.97	5.72
Bearskin Creek	0.49 (0.14)	0.16 (0.06)	11.19	5.43
Cache Creek	0.48 (0.12)	0.14 (0.06)	24.79	7.68
Dagger Creek	0.46 (0.12)	0.16 (0.06)	13.76	5.77
East Fork Cache Creek	0.61 (0.20)	0.15 (0.09)	7.39	3.11
Cold Creek	0.40 (0.09)	0.14 (0.06)	12.60	5.66

Table A.8, Continued.

Stream	Residual Pool Depth (m)	Pocket Pools per 100 m	Mean Depth of Pocket Pools (m)	Mean Dominate Substrate (Mode)*	Mean Subdominant Substrate (Mode)*	% Surface fines	% Stable bank
North Fork Canyon Creek	0.38	39.9	0.28	4.4 (4)	4.1 (4)	8 (7.2)	97 (9.4)
Scott Creek	0.30	11.2	0.24	4.1 (5)	3.0 (1)	22 (13.9)	86 (18.8)
Middle Fork Warmspring Creek	0.20	11.2	0.28	4.0 (2)	3.9 (3)	26 (17.9)	97 (8.9)
South Fork Deer Creek*	0.20	1.2	0.27	2.7 (5)	2.1 (1)	39 (27.4)	95 (7.6)
Bearskin Creek	0.32	5.37	0.49	3.5 (3)	2.9 (2)	12 (9.2)	97 (5.3)
Cache Creek	0.37	14.7	0.29	3.9 (4)	3.4 (3)	21 (20.8)	97 (9.9)
Dagger Creek	0.24	10.3	0.25	4.1 (5)	3.7 (4)	23 (18.1)	83 (21.3)
East Fork Cache Creek	0.46	3.4	0.27	1.9 (2)	2.1 (3)	22 (17.1)	89 (11.6)
Cold Creek	0.25	5.1	0.30	1.6 (1)	2.4 (3)	58 (27.2)	86 (19.8)

The standard deviation is given in parentheses after the mean value except when otherwise noted.
*Values do not include reach 1 of South Fork Deer Creek.

Table A.8 Continued.

Stream	Large Woody Debris (Singles) per 100 m^2	Total Large Woody Debris Aggregates per 100 m	Total Large Woody Debris per 100 m^2	Total Large Woody Debris (pieces) per 100 m^2	Lateral Habitat Areas per 100 m	Mean Shade (Mode)*	% Overstory
North Fork Canyon Creek	7.9	5.3	13.4	34.8	14.4	2.2 (2)	68 (30.6)
Scott Creek	6.3	3.1	9.9	NA	0.9	1.8 (3)	43 (37.6)
Middle Fork Warmspring Creek	13.7	13.2	29.9	NA	1.0	2.3 (2)	47 (34.9)
South Fork Deer Creek*	8.8	5.1	14.3	NA	1.5	1.5 (1)	33 (31.7)
Bearskin Creek	6.2	3.90	10.20	20.36	10.41	2.0 (2)	70 (25.5)
Cache Creek	10.7	8.4	19.2	61.4	3.7	2.4 (3)	65 (35.7)
Dagger Creek	18.1	11.4	30.1	NA	1.3	2.3 (2)	61 (39.6)
East Fork Cache Creek	7.5	1.6	9.1	11.8	6.6	1.1 (1)	62 (37.1)
Cold Creek	10.9	12.3	23.8	72.2	4.7	2.4 (3)	75 (39.3)

The standard deviation is given in parentheses after the mean value except when otherwise noted.
*Values do not include reach 1 of South Fork Deer Creek.

Table A.8, Continued.

Stream	% Undercut bank	% Overhead Cover	% Submerged Cover	% Submerged Vegetation	% Large Substrate	% Bubble Cover
North Fork Canyon Creek	1.9 (3.1)	32.6 (27.3)	5.9 (7.8)	0.1 (0.8)	22.9 (19.5)	12.2 (15.0)
Scott Creek	2.0 (2.7)	43.1 (23.4)	11.0 (12.6)	0.0 (0)	28.6 (2)	NA
Middle Fork Warmspring Creek	6.5 (11.2)	50.3 (26.9)	10.0 (10.9)	2.4 (6.6)	29.0 (24.6)	NA
South Fork Deer Creek*	11.2 (10.5)	24.1 (22.0)	8.5 (12.5)	20.5 (17.2)	6.7 (14.5)	NA
Bearskin Creek	4.6 (5.9)	7.0 (10.0)	2.2 (4.7)	5.9 (10.5)	9.7 (9.6)	1.6 (3.8)
Cache Creek	3.3 (4.2)	25.0 (15.6)	8.0 (8.8)	5.8 (13.6)	24.5 (15.4)	6.6 (10.6)
Dagger Creek	6.6 (10.7)	20.1 (22.1)	6.0 (8.1)	0.7 (2.1)	22.1 (24.5)	NA
East Fork Cache Creek	9.8 (15.7)	7.0 (9.7)	2.7 (4.4)	33.1 (24.8)	0.0 (0)	1.3 (5.4)
Cold Creek	10.5 (10.3)	15.5 (13.3)	13.1 (12.5)	4.7 (6.4)	4.8 (8.2)	3.6 (10.2)

The standard deviation is given in parentheses after the mean value.
*Values do not include reach 1 of South Fork Deer Creek.

Table A.9. Summary of fish densities in patches.

Stream	Total Bull Trout	Total Bull Trout per 100 m^2	Total Bull Trout ≤ 140 mm	Total Bull Trout ≤ 140 mm per 100 m^2	Total Bull Trout > 140 mm	Total Bull Trout > 140 mm per 100 m^2
North Fork Canyon Creek	449.00	3.22	271.00	1.94	178.00	1.27
Scott Creek	75.00	1.38	27.00	0.50	48.00	0.88
Middle Fork Warmpring Creek	206.00	1.95	194.00	1.84	12.00	0.11
South Fork Deer Creek	69.00	0.72	68.00	0.71	1.00	0.01
Bearskin Creek	230.00	1.83	209.00	1.67	22.00	0.18
Cache Creek	6.00	0.10	6.00	0.10	0.00	0.00
East Fork Cache Creek	35.00	1.88	25.00	1.34	10.00	0.54
Dagger Creek	97.00	1.92	91.00	1.80	6.00	0.12
Cold Creek	54.00	1.49	48.00	1.33	6.00	0.17

Table A.9, Continued.

Stream	Total Rainbow Trout	Total Rainbow Trout per 100 m^2	Total Brook Trout	Total Brook Trout per 100 m^2
North Fork Canyon Creek	56.00	0.40	1.00	0.01
Scott Creek	0.00	0.00	0.00	0.00
Middle Fork Warmpring Creek	33.00	0.31	0.00	0.00
South Fork Deer Creek	177.00	1.86	0.00	0.00
Bearskin Creek	1.00	0.01	50.00	0.40
Cache Creek	343.00	5.81	21.00	0.36
East Fork Cache Creek	0.00	0.00	9.00	0.48
Dagger Creek	124.00	2.45	0.00	0.00
Cold Creek	2.00	0.06	1.00	0.03