THE RELATIONSHIP BETWEEN WATER TEMPERATURE AND BULL TROUT DISTRIBUTION AND ABUNDANCE

by

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ABSTRACT

The Relationship Between Water Temperature and

Bull Trout Distribution and Abundance

by

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While water temperature is known to be an important factor influencing bull trout *Salvelinus confluentus* distribution and abundance, many aspects of the relationship are not well understood. The objectives of this work were to 1) describe the relationship between summer stream temperatures and bull trout distribution and abundance in streams and 2) describe the relationship between groundwater temperature and juvenile bull trout occurrence in small stream basins.

An evaluation of 18 different temperature metrics (maximum, mean, etc.) indicated that overall mean temperature was the most effective metric at describing bull trout abundance. Mean water temperatures in the study ranged between 5.2 and 14.6°C. Bull trout were always present where mean temperature was less than 10.0°C, were present at 40% of the sites where mean temperature was between 10.0 and 12.0°C, but were not present where mean temperature was greater than 12.0°C. Bull trout were the only salmonid present at sites where the mean temperature was less than 7.0°C, whereas the percentage of salmonids that were bull trout was variable at sites where mean temperature was between 7.0 and 12.0°C. Bull trout densities greater than 10.0 fish/100 m^2 occurred at mean temperatures between 5.7 and 8.6°C but bull trout densities were relatively low at mean temperatures greater than about 9°C. Similar patterns were observed in relation to maximum summer temperature although the relationships were generally not as strong. The strong association between bull trout abundance and water temperature suggests that natural and anthropogenic influences on water temperature likely have a significant effect on bull trout abundance.

The relationship between juvenile bull trout distribution and groundwater temperature was evaluated in 30 small stream basins. Minimum, maximum, and mean groundwater temperatures were all effective at describing bull trout distribution, whereas a minimum groundwater temperature was the most effective. Juvenile bull trout were present in all stream basins where the minimum groundwater temperature was less than 4.1°C, were present in only 53% of the stream basins where the minimum groundwater temperature was between 4.1 and 6.1°C, and were not present in any stream basins where the minimum groundwater temperature was greater than 6.1°C.

(94 pages)

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Bart L. Gamett

PREFACE

Chapter 2, The Relationship Between Summer Stream Temperature and Bull Trout Distribution and Abundance in the Little Lost River, Idaho Drainage, will be submitted to The North American Journal of Fisheries Management with my major professor, Jeffrey L. Kershner, as a coauthor.

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CHAPTER 1

INTRODUCTION

The bull trout *Salvelinus confluentus* is a species of char native to western North America (Cavender 1978; Hass and McPhail 1991). Over the last century, anthropogenic influences such as habitat alteration and the introduction of exotic species have resulted in widespread declines in many bull trout populations (Ratliff and Howell 1992; Mackay et al. 1997; Rieman et al. 1997). For example, one assessment found that 66% of the bull trout populations in Oregon were probably extinct or had a moderate to high risk of extinction (Ratliff and Howell 1992). Due to these widespread declines, bull trout have been listed as threatened under the United States Endangered Species Act throughout the continental United States (Federal Register 64 (210):58909-58933) and numerous federal, state, and local efforts are currently under way to protect and recover bull trout populations. A critical element to the success of these efforts is an understanding of the factors constraining bull trout distribution and abundance.

Water temperature is known to be an important factor influencing fish distribution and abundance (MacCrimmon and Campbell 1969; Moyle and Cech 1988; Griffith 1993). For example, in one southeastern Wyoming drainage, brown trout *Salmo trutta* were not found where midday summer water temperatures were less than about 16°C or greater than about 24°C (Taniguchi et al. 1998). Another example is provided by the response of rainbow trout *Oncorhynchus mykiss* to a horizontal thermal gradient in a laboratory (McCauley and Pond 1971). When fish were presented with a temperature gradient ranging between 12 and 28°C, they did not occupy temperatures greater than 21°C or less than 15°C.

Water temperature can influence fish distribution and abundance in several ways. First, water temperature may limit the distribution of a species by exceeding the thermal requirements of the fish. Fish have a species-specific range of temperatures over which they can survive and when water temperatures spatially or temporally exceed those levels, the distribution of the species is limited. The distribution patterns of the Amargosa pupfish *Cyprinodon nevadensis amargosae* in one Mojave Desert stream provide a striking example of this influence (Feldmeth 1981). The Amargosa pupfish can tolerate water temperatures up to 42°C. In one stream, water emerges from the ground at 47.5°C and cools as it moves downstream. Accordingly, the upper distribution limit of the pupfish corresponds precisely to the 42°C isotherm. As this isotherm migrates with seasonal changes in temperatures, so does the distribution limit of the fish.

Water temperature can also affect fish distribution and abundance by limiting a specific life-history stage. For example, the thermal regime in one section of the Laramie River is capable of supporting juvenile and adult channel catfish *Ictalurus punctatus* (Patton and Hubert 1996). While these fish can successfully spawn in this section of the river, low water temperatures prevent fry from attaining a sufficient length to survive their first winter. Subsequently, the population is unable to sustain itself through natural reproduction and stocking is required to maintain the population. Another important consideration is that the temperature requirements for a species can vary between life-history stages (Moyle and Cech 1988). For example, brook trout *S. fontinalis* can survive for an extended period of time at temperatures as high as 24°C (Taniguchi 1998), whereas brook trout eggs incubated at 15°C experience high mortality and eggs incubated at 18°C suffer complete mortality (Hokanson et al. 1973).

Water temperature may also affect fish distribution and abundance by influencing the outcome of interspecific competition. This occurs through a process known as condition-specific competition (Dunson and Travis 1991). In this process, the competitive superiority of a species is dependent on the specific conditions at which the interaction occurs. Specifically, several studies have shown water temperature to influence the outcome of interspecific competition (e.g., Taniguchi and Nakano 2000; Cunjak and Green 1986; Baltz et al. 1982; Reeves et al. 1987; De Staso and Rahel 1994). For example, in one laboratory study Taniguchi et al. (1998) evaluated food consumption of brook trout and creek chub *Semotilus atromaculatus* at different temperatures and found that the brook trout were superior competitors at temperatures less than 22°C but that creek chub were superior at temperatures greater than 22°C. In some circumstances, temperature-mediated competition could result in a species being completely displaced from an area.

Water temperature appears to be an important factor influencing bull trout distribution and abundance. As early as 1875, Stone (1878) observed that in the McCloud River basin in California bull trout were found only in streams with relatively cold water temperatures. More recently, other researchers have also found that bull trout are generally associated with relatively cold water. Although bull trout have been observed at temperatures exceeding 20°C (Adams and Bjornn 1997; Rieman and Chandler 1999; Zurstadt 2000), studies in Idaho and Montana indicate that the abundance of juvenile bull trout is greatest in streams where maximum summer temperatures are less than 15°C (Fraley and Shepard 1989; Saffel and Scarnecchia 1995). Similarly, an analysis of 581 sites across the northwestern U.S. indicated juvenile bull trout were most likely to occur where maximum temperatures were between 11 and 14°C (Rieman and Chandler 1999). In several streams in the Cascade Mountains bull trout were not found where temperatures exceeded 16.5°C (Goetz 1997).

Alterations to water temperature resulting from anthropogenic and natural influences may partially explain the decline of some bull trout populations. Anthropogenic influences such as logging (Lynch et al. 1984; Holtby 1988), livestock grazing (Platts 1991), and flow alteration can alter stream temperatures. Likewise, natural influences such as wildfire (Royer and Minshall 1997) and variations in climate also influence stream temperatures. When such influences result in stream temperatures increasing above optimum levels, the bull trout population may decline.

Because water temperature has an important influence on bull trout distribution and abundance, it is essential that managers clearly understand the relationship. However, several elements of the relationship are not well understood. First, it is unclear which aspect of water temperature (e.g., maximum, minimum, mean, etc.) has the strongest influence on bull trout distribution and abundance. Second, it is not clear what temperatures ultimately limit bull trout distribution or how temperature affects bull trout abundance. Third, it is unclear how temperature influences the relative abundance of bull trout in the salmonid community. This limited understanding creates several challenges for those working to protect and recover the species.

The purpose of this study was to examine the relationship between two aspects of stream temperature and bull trout distribution and abundance. Chapter 2 examines the relationship between summer water temperature and bull trout distribution, density, and the percentage of salmonids that are bull trout. Chapter 3 examines the relationship between juvenile bull trout distribution and groundwater temperature. In Chapter 4, I provide a brief summary of the work and offer some concluding thoughts.

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CHAPTER 2

THE RELATIONSHIP BETWEEN SUMMER STREAM TEMPERATURE AND BULL TROUT DISTRIBUTION AND ABUNDANCE IN THE LITTLE LOST RIVER, IDAHO DRAINAGE[1]

Abstract. – We assessed the relationship between eighteen temperature metrics (max, mean, min, etc.) and bull trout *Salvelinus confluentus* presence, bull trout density, and the percentage of salmonids that were bull trout in 39 stream sections in the Little Lost River, Idaho basin. Although several temperature metrics were effective at describing bull trout abundance, mean temperature (July 1 – September 30) appeared to be the most effective overall. Mean water temperatures in the study sites ranged between 5.2 and 14.6°C. Bull trout were present at all sites where mean temperature was less than 10.0°C, were present at 40% of the sites where mean temperature was between 10.0 and 12.0°C, but were not present at any sites where mean temperature was greater than 12.0°C. Bull trout were the only salmonid present at sites where the mean temperature was less than 7.0°C. The percentage of salmonids that were bull trout was variable at sites where mean temperature was between 7.0 and 12.0°C. Bull trout densities greater than 10.0 fish/100 m^2 occurred at mean temperatures between 5.7 and 8.6°C, but bull trout densities were relatively low at mean temperatures greater than about 9°C. Maximum water temperatures (July 1 – September 30) in the study sites ranged between 8.1 and 25.9°C. Although bull trout were present at all sites where maximum temperature was less than 17.0°C, they were not present at any sites where maximum

[1] Coauthored by Bart L. Gamett and Jeffrey L. Kershner.

temperature was greater than 20.0°C. Bull trout densities greater than 10.0 fish/100m^2 occurred at maximum temperatures between 8.8 and 14.9°C but bull trout densities were relatively low at temperatures greater than about 15°C. The strong association between bull trout and cold water temperatures suggest that natural and anthropogenic influences on water temperature likely have a significant effect on bull trout distribution and abundance.

Introduction

Over the last century, bull trout *Salvelinus confluentus* have experienced widespread declines (Ratliff and Howell 1992; Mackay et al. 1997; Rieman et al. 1997). As a result, bull trout have been listed as threatened under the United States Endangered Species Act throughout the continental United States (Federal Register 64 (210):58909-58933) and numerous federal, state, and local efforts are underway to protect and recover the species. A critical element to the success of these efforts is an understanding of the factors influencing bull trout distribution and abundance.

Water temperature is one of the most important factors influencing bull trout distribution and abundance (Rieman and McIntyre 1993). Evidence suggests that bull trout require relatively cold water. As early as 1875, Stone (1878) recognized the association between bull trout and cold water temperatures when he observed that in the McCloud River basin bull trout were found only in cold streams. Since this early observation, many other researchers have also found that bull trout are generally associated with relatively cold water (e.g., Fraley and Shepard 1989; Ratliff and Howell

1992; Saffel and Scarnecchia 1995; Bonneau and Scarnecchia 1996; Adams and Bjornn 1997).

While it is critical that managers understand the relationship between water temperature and bull trout abundance, many aspects of the relationship are not clearly defined. For example, it is unclear how water temperature influences bull trout distribution, density, or the percentage of salmonids that are bull trout (composition). It is also unclear which temperature metrics (e.g., maximum, minimum, mean, etc.) and temporal scales (summer, winter, etc.) most influence bull trout. This limited understanding creates several challenges for those working to protect and recover the species. For example, it is unclear how changes in water temperature resulting from anthropogenic influences have affected bull trout distribution and abundance.

The purpose of this study was to describe the relationship between summer stream temperatures and bull trout distribution and abundance. Our specific objectives were to 1) evaluate various temperature metrics to determine which are the most closely associated with bull trout occurrence, composition, and density and 2) describe the relationship between selected temperature metrics and bull trout occurrence, composition, and density.

Study Area

The study was conducted in tributaries to the Little Lost River, Idaho (Figure 2-1). The Little Lost River is a hydrologically isolated basin in south-central Idaho that covers approximately 2,500 km^2. The river originates in the Lost River and Lemhi mountain ranges and flows in a southerly direction where, when undiverted for irrigation, it sinks into the basalt flows of the Snake River Plain.

The Little Lost River is located on the southern and eastern periphery of the bull trout's range (Rieman et al. 1997). It is possible that bull trout were established in this drainage by a headwater stream transfer from the Salmon River drainage (Behnke 1992). Recent sampling indicates bull trout in the Little Lost River basin are widely distributed and both resident and migratory life history forms are present (Gamett 1999). However, the distribution of bull trout across the basin is patchy. In several streams bull trout densities (fish >70 mm) exceed 10.0 fish/100 m^2 while the species is completely absent in other streams. Other fish species commonly found in streams in the basin include rainbow trout *Oncorhynchus mykiss,* brook trout *S. fontinalis*, brook trout x bull trout hybrids, and shorthead sculpin *Cottus confusus*. Cutthroat trout *O. clarki*, which are likely not native to the basin, are generally found only in mountain lakes.

The climate of the drainage is variable. Mean annual precipitation in the drainage ranges from less than 25 cm at lower elevations to over 100 cm at the higher elevations. Long-term weather data (1948-2000) are available from the Howe weather station located in the lower end of the drainage. The mean annual air temperature at this station is 6.5°C with recorded temperatures ranging from –39 to 39°C. The mean annual precipitation is 21.5 cm. The mean annual air temperature for 1999 was 2.4°C, whereas annual precipitation was 15.5 cm. Temperature data from four weather stations in the drainage indicated that air temperatures during the study period (July 1 – September 30) ranged from –12°C to 32°C.

Summer stream temperature regimes in the basin are also variable. Some

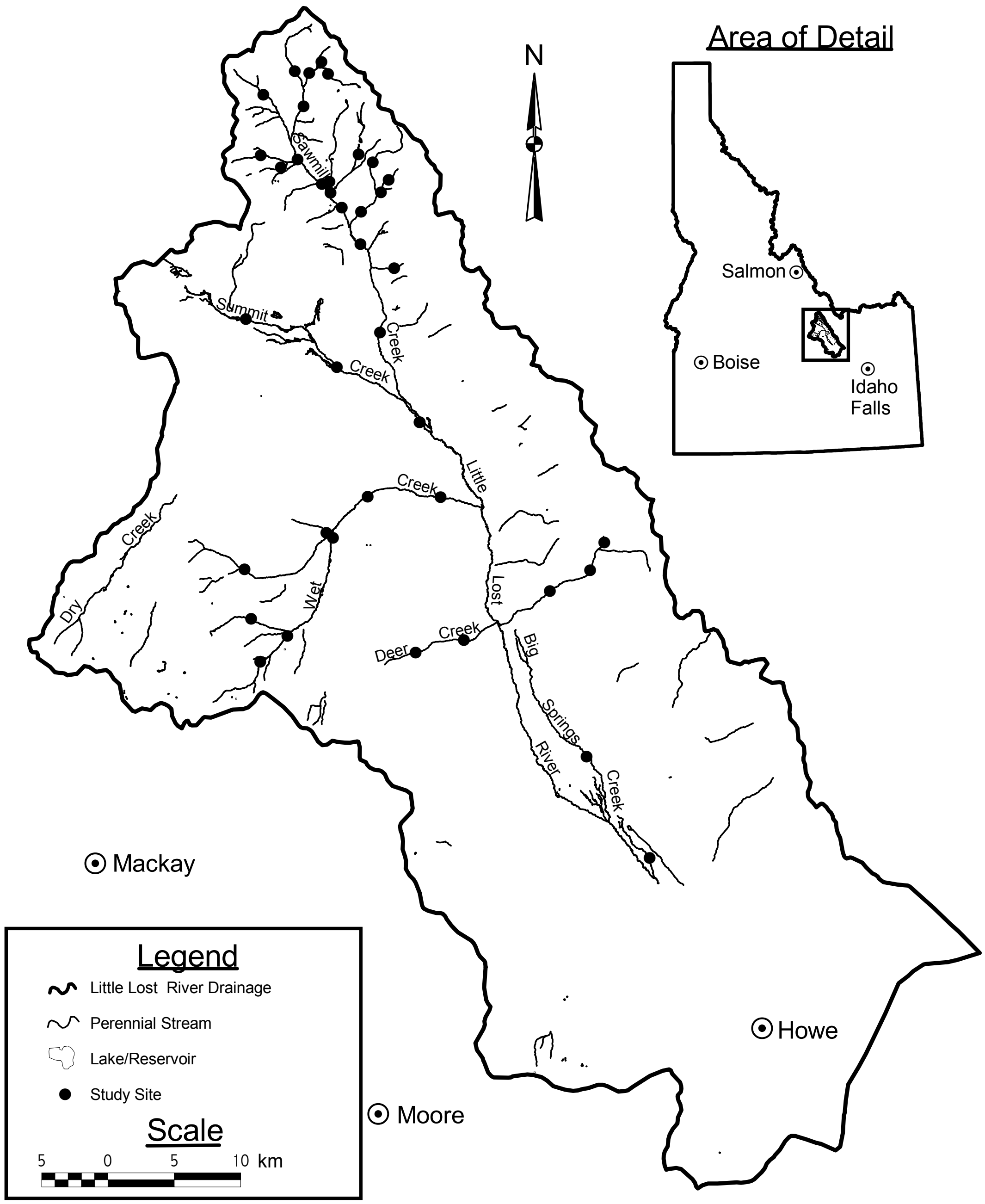

Figure 2-1 – Location of the study sites.

stream reaches have maximum annual temperatures less than 10°C and diel fluctuations of about 2°C, whereas other reaches have maximum annual temperatures greater than 25°C and diel fluctuations exceeding 15°C (Gamett 1999, unpublished data). Some streams also exhibit strong temperature gradients. For example, water in Coal Creek emerges from the ground at 6-7°C but can exceed 22°C less than 2 km downstream (B. Gamett, unpublished data). The diverse water temperature regimes found in this river basin provide an excellent opportunity to assess the relationship between water temperature and bull trout distribution and abundance.

The characteristics of the study sites varied. The study sites were located on U.S. Forest Service, Bureau of Land Management, and private lands. The physical nature of the sites varied widely (Table 2-1, Appendix Table A-1). Some of the sites were located in streams fed primarily by springs, whereas other sites were in streams heavily influenced by snowmelt. The study sites were located in streams associated with a variety of riparian vegetation including communities dominated by meadow, deciduous, and conifer species. In addition, several of the sites were located in conifer forest communities that were burned by wildfire in 1988.

Methods

We assessed the relationship between summer stream temperature and bull trout distribution and abundance by comparing water temperatures with bull trout occurrence and abundance at 39 study sites. The study was conducted between July 1 and September 30, 1999.

Table 2-1 – Summary of the physical characteristics of the study sites at the time fish populations were sampled.

Site	Mean (Range, SD)
Length (m)	100 (34-153, 18)
Air temperature (°C)	19.8 (3.6-28.8, 6.4)
Water temperature (°C)	10.7 (5.0-19.4, 3.7)
Conductivity (µS)	153 (10-360, 107)
pH[1]	8.5 (8.2-9.1, 0.2)
Mean width (m)	3.7 (1.2-10.1, 2.4)
Mean depth (m)	0.2 (0.1-0.3, 0.1)
Max depth (m)	0.6 (0.4-1.3, 0.3)
Surface area (m^2)	377 (112-1153, 270)
Volume (m^3)	72 (10-276, 67)
Elevation (m)	2124 (1554-2522, 230)

[1] Data missing for one site

Study Site Selection

Study sites were randomly selected from a set of potential study sites. Potential study sites were defined as streams that 1) were tributaries to the Little Lost River, 2) maintained perennial water flow, 3) contained salmonids, 4) had at least an intermittent connection to the drainage stream net, and 5) were not blocked by long-term barriers that would prevent salmonids from moving from the drainage stream net to the reach. These criteria ensured that the absence of bull trout and other salmonids in a study site was not due to migration barriers or the inability of a stream to support salmonids. These determinations were based on data from Gamett (1999) and visual observation. No data were available for a few streams located on private land so these streams were not included as potential study sites. Once the potential study sites were delineated, we randomly selected 100-m long stream sections as study sites. One assumption in the selection of study sites for this type of study is that the sites are independent of each other. However, achieving complete independence is often difficult in field studies. We sought to increase the level of independence between sites by allowing only one study site per stream reach, which were delineated by major shifts in stream or riparian habitat type or the confluence of two relatively large tributaries. While this strategy does not result in complete independence among sites, it should minimize correlation.

Although study sites were selected at random, the locations of some of the study sites were modified in the field. Study site locations were modified for three reasons. First, the random locations of some sites were in areas where it was not possible to effectively sample the fish population (e.g., large beaver dams, dense riparian vegetation, etc.) or the location was heavily disturbed (e.g., heavily used camping areas, culverts, etc.). In these situations, the study site was relocated to the nearest suitable location. Second, when permission to access some of the study sites selected on private land was not obtained, the site was relocated to adjacent public land. Third, the random location of some sites was immediately below or included the confluence of two streams. To avoid thermal gradients formed by the confluence of streams, we relocated some sites so that the top end of the study site was at least 40 m below stream confluences.

Stream Temperature Assessment

Water temperature data were collected from each study site using waterproof StowAway TidbiT temperature loggers (Onset Computer Corporation). The manufacturer's specifications indicate these temperature loggers have a total error of ±0.35°C at 21.1°C (accuracy ± 0.2°C; resolution ± 0.15°C). Each temperature logger was tested prior to the study to ensure it was operating within these specifications. Testing was conducted by comparing the readings of the logger to the readings of a thermometer traceable to the National Institute of Standards and Technology (NIST).

Testing was completed in both ice water (approximately 0°C) and room temperature (approximately 22°C) circulating water baths. Temperature loggers were launched, placed in the water bath, and allowed to stabilize for at least 30 minutes. The temperature of the water bath was then assessed every minute for ten minutes using the NIST traceable thermometer. We then compared the temperatures recorded by each temperature logger to that of the NIST traceable thermometer. All temperature loggers were operating under the total error of ± 0.35°C.

Water temperature data were collected from each site between July 1 and September 30. This time frame provided a standardized temporal interval when streams in the study area were generally accessible and experience the warmest temperatures. Temperature loggers were programmed to record water temperature every 8 minutes (180 readings/day; 16,560 readings over the study period). Temperature loggers were then suspended in an open-ended galvanized steel pipe measuring 60 mm in diameter and 78 mm in length. This approach allowed the logger to be protected from sunlight and disturbance while allowing the logger to be in direct contact with the water. Temperature loggers were placed in the stream 1 to 10 m below the study sites to ensure electrical fields generated during electrofishing did not interfere with the operation of the logger. The units were anchored in the stream in a location where water would freely circulate around the logger. Each logger was checked at least once during the study period to ensure it was still located correctly and any sediment or debris accumulation was removed from the unit at that time.

Following the collection of the temperature data, 18 temperature metrics were calculated for each site (Table 2-2). These metrics were selected because they represent the major characteristics of a streams temperature regime. Each metric covered the period from July 1 to September 30.

Fish Population Assessment

Fish population data were collected once from each site between July 30 and September 2 using the multiple pass depletion method. Excluding the upper Mill Creek site, fish population data were collected from stream sections approximately 100 m in length (mean length = 101 m; range = 81-153 m; SD = 14 m). The upper Mill Creek site was only 34 m long due to a fish barrier that was not detected until the reach was sampled. Block nets were placed at the upstream and downstream end of each study site prior to sampling. Fish were captured with backpack electrofishing units with sampling beginning at the downstream end of the site and proceeding upstream. The length and species of all salmonids captured were recorded. Based on our observations, we considered trout less than 70 mm in total length to be young-of-the-year and these fish were not included in the study due to poor sampling efficiency. In order to reduce error associated with the population estimates and increase the probability of detecting bull trout, a minimum of three electrofishing passes was completed in each site. However, when no salmonids greater than 70 mm were captured in the second pass, only two electrofishing passes were completed. More than three passes were completed when three passes provided an irregular pattern of depletion.

Fish population estimates were calculated for each site using MICROFISH 3.0 (Van Deventer and Platts 1985). We calculated a separate population estimate for each species. When a sufficient number of a species was not captured to obtain a population estimate, we used the number of fish captured as the population estimate. Fish that

Table 2-2 – Temperature metrics evaluated in this study[1]. All metrics cover the time period from July 1 through September 30 and are based on temperature data collected at eight minute intervals.

Temperature metric	Definition
MAX	Highest temperature
MIN	Lowest temperature
RNG	Difference between the MAX and the MIN
MEAN	Mean of all temperature readings
MOV	Maximum value of the moving seven-day mean daily maximum. The moving seven-day mean daily maximum for a specific day is the mean of the daily maximums for the day, the three days prior to the day, and the three days following the day.
MMAX	Mean of all daily maximum temperatures
MMIN	Mean of all daily minimum temperatures
MMOV	Mean of all moving seven-day mean daily maximum temperatures
PG5	Percentage of all temperatures that exceed 5°C
PG10	Percentage of all temperatures that exceed 10°C
PG15	Percentage of all temperatures that exceed 15°C
PG20	Percentage of all temperatures that exceed 20°C
DMOV10	Number of days that the moving seven-day mean daily maximum exceeded 10°C
DMOV15	Number of days that the moving seven-day mean daily maximum exceeded 15°C
DMOV20	Number of days that the moving seven-day mean daily maximum exceeded 20°C
DMAX10	Number of days that the daily maximum exceeded 10°C
DMAX15	Number of days that the daily maximum exceeded 15°C
DMAX20	Number of days that the daily maximum exceeded 20°C

[1] Throughout this paper we use an upper case format (e.g., MEAN) when referring to a temperature metric calculated as part of this study. We use a lower case format (e.g., mean) when referring to a temperature metric calculated by other authors.

appeared to be bull trout x brook trout hybrids were captured in nine study sites. These hybrids were sympatric with bull trout at eight of the sites, whereas brook trout were only present in three of the sites. Four of the sites containing hybrids had MEAN temperatures lower than the coldest site where brook trout were found. Based on these patterns we assumed that hybrids had thermal preferences similar to bull trout and we included them with the bull trout.

Fish population estimates were used to calculate three bull trout population metrics for each site. These population metrics were bull trout occurrence, composition, and density. Bull trout occurrence was designated as a "1" if bull trout were present and "0" if bull trout were absent. Bull trout density (fish/100 m^2) was calculated by dividing the bull trout population estimate by the wetted stream surface area and multiplying by 100. The wetted surface area was determined by multiplying the length of the site by the mean wetted stream width. Wetted width was assessed every 10 m through the site. We determined bull trout composition by dividing the bull trout population estimate by the total trout population estimate and multiplying by 100.

Data Analysis

We used regression techniques to evaluate the relationship between the 18 temperature metrics and bull trout occurrence, composition, and density. We evaluated the relationship between bull trout occurrence and each temperature metric using logistic regression. A separate regression was used to evaluate each temperature metric using the temperature metric as the independent variable and bull trout occurrence as the dependent variable. Akaike's Information Criterion (AIC) (Burnham and Anderson 1998) was used as a quantitative index of the strength of the relationship between the temperature metric and bull trout occurrence. Since lower values of this criterion indicate a stronger relationship between the independent and dependant variables, we considered those temperature metrics with lower AIC values to have a stronger relationship to bull trout occurrence relative to metrics with higher AIC values.

Logistic regression was also used to evaluate the relationship between bull trout composition and each temperature metric. However, low p-values for the Hosmer and Lemeshow goodness-of-fit test indicated the composition data violated the assumption of linearity. Despite this violation, we believed that logistic regression was the most useful means of evaluating bull trout composition and assumed the test to be sufficiently robust to effectively analyze the data.

We evaluated the relationship between bull trout density and each temperature metric using polynomial regression. After considering second-, third-, and fourth-order polynomials, we elected to use a fourth-order polynomial since these models visually appeared best fitted to the density data. We also evaluated using untransformed and transformed [ln(density+1)] density data. We elected to use the transformed density data for our analysis since it yielded better fitting models. A separate regression was used to evaluate each temperature metric using the temperature metric as the independent variable and transformed bull trout density as the dependent variable. The adjusted r^2 value was used as a quantitative index of the strength of the relationship between the temperature metric and bull trout density. Those temperature metrics with higher adjusted r^2 values were considered to have a stronger relationship to bull trout density relative to metrics with lower adjusted r^2 values. All regressions were completed using PROC LOGISTIC in SAS/STAT Release 8.0.

We described the relationship between selected temperature metrics and bull trout occurrence, composition, and density using the regression models and frequency table analysis. The frequency table analysis involved sorting the temperature metric values in ascending order and examining the data for patterns in bull trout abundance. Following this review, we divided the temperature metrics into bins that appeared to best describe patterns in abundance. We then calculated the mean, range, and standard error for each population metric within each bin.

Results

Study sites experienced a wide range of temperature regimes. Some sites, such as Badger Creek #3, were relatively cold throughout the study period with small daily and seasonal temperature fluctuations, whereas other sites, such as Summit Creek #1, were relatively warm with large daily and seasonal temperature fluctuations (Figure 2-2). Recorded stream temperatures for all sites ranged from -0.1 to 25.9°C. Stream temperature metrics for each site are summarized in Appendix Table A-2.

Bull trout, rainbow trout, brook trout, and bull trout x brook trout hybrids were the only salmonids captured in the study sites. Salmonid density ranged from 0.2 to 41.1 fish/100 m^2. Bull trout were present in 69% of the 39 study sites. Bull trout composition ranged from 0 to 100% and bull trout densities ranged from 0.0 to 39.3 fish/100 m^2. Fish population metrics for each site are summarized in Appendix Table A-3.

Evaluation of Temperature Metrics

Several temperature metrics were closely correlated with the bull trout population metrics (Table 2-3). Likewise, most of the temperature metrics were closely correlated

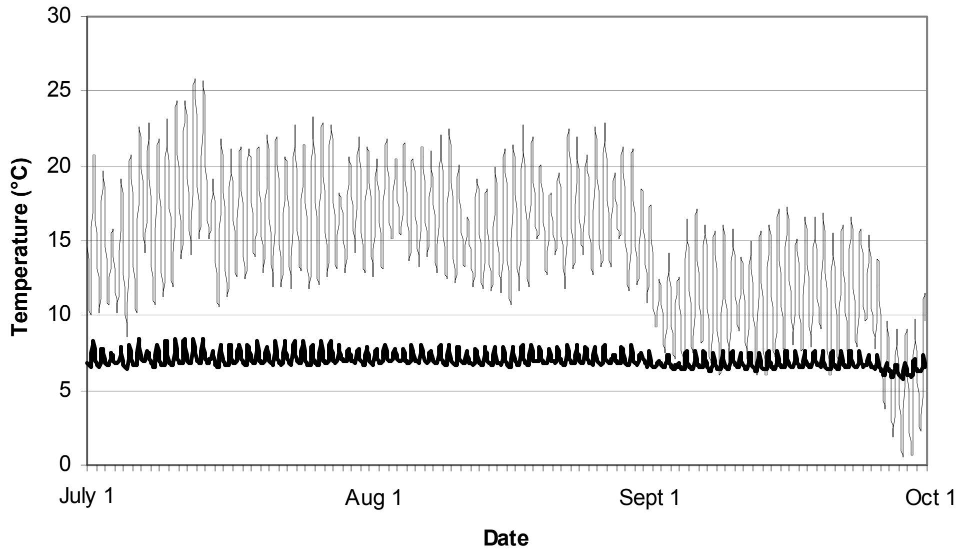

Figure 2-2 – Examples of the varying stream temperature regimes at the study sites. The Summit Creek #1 (thin line) and Badger Creek #3 (thick line) sites are shown.

Table 2-3 – Correlation matrix for bull trout population metrics and temperature metrics.

Temperature	Bull trout population metric		
metric	Occurrence	Composition	Density
MAX	-0.67	-0.71	-0.35
MIN	-0.20	-0.15	-0.21
RNG	-0.49	-0.54	-0.22
MEAN	-0.77	-0.79	-0.45
MOV	-0.70	-0.73	-0.37
MMAX	-0.70	-0.76	-0.38
MMIN	-0.75	-0.73	-0.49
MMOV	-0.70	-0.76	-0.38
PG5	-0.42	-0.71	-0.43
PG10	-0.75	-0.76	-0.43
PG15	-0.78	-0.62	-0.41
PG20	-0.38	-0.23	-0.15
DMOV10	-0.45	-0.60	-0.17
DMOV15	-0.82	-0.75	-0.50
DMOV20	-0.36	-0.22	-0.14
DMAX10	-0.45	-0.61	-0.19
DMAX15	-0.82	-0.75	-0.51
DMAX20	-0.44	-0.27	-0.18

Table 2-4 – Correlation matrix for the temperature metrics.

Tepmerature Metric	Temperature Metric																	
	MAX	MIN	RNG	MEAN	MOV	MMAX	MMIN	MMOV	PG5	PG10	PG15	PG20	DMOV 10	DMOV 15	DMOV 20	DMAX 10	DMAX 15	DMAX 20
MAX	1.00																	
MIN	-0.25	1.00																
RNG	0.93	-0.58	1.00															
MEAN	0.93	0.06	0.75	1.00														
MOV	1.00	-0.21	0.92	0.94	1.00													
MMAX	0.99	-0.14	0.88	0.95	0.99	1.00												
MMIN	0.71	0.39	0.45	0.92	0.74	0.75	1.00											
MMOV	0.99	-0.14	0.88	0.95	0.99	1.00	0.76	1.00										
PG5	0.49	0.44	0.25	0.65	0.52	0.58	0.69	0.58	1.00									
PG10	0.91	0.00	0.77	0.97	0.93	0.94	0.87	0.94	0.55	1.00								
PG15	0.82	0.03	0.68	0.88	0.83	0.81	0.84	0.81	0.43	0.82	1.00							
PG20	0.49	-0.06	0.43	0.47	0.49	0.45	0.44	0.45	0.16	0.36	0.68	1.00						
DMOV10	0.86	-0.31	0.84	0.75	0.86	0.87	0.50	0.87	0.43	0.81	0.48	0.18	1.00					
DMOV15	0.85	0.03	0.71	0.90	0.87	0.87	0.79	0.87	0.50	0.88	0.88	0.43	0.59	1.00				
DMOV20	0.48	-0.05	0.42	0.46	0.48	0.43	0.42	0.43	0.16	0.34	0.66	1.00	0.17	0.43	1.00			
DMAX10	0.86	-0.29	0.83	0.76	0.86	0.88	0.51	0.88	0.45	0.81	0.48	0.17	1.00	0.59	0.17	1.00		
DMAX15	0.87	0.01	0.73	0.92	0.89	0.89	0.81	0.89	0.50	0.90	0.89	0.45	0.61	0.99	0.44	0.61	1.00	
DMAX20	0.55	-0.03	0.47	0.53	0.55	0.51	0.48	0.51	0.19	0.41	0.74	0.98	0.21	0.50	0.98	0.21	0.52	1.00

with each other (Table 2-4). The AIC values from the logistic regressions indicate that the number of days that the moving 7-day mean daily maximum exceeded 15°C (DMOV15) was the temperature metric most closely associated with bull trout occurrence followed by the number of days that the daily maximum exceeded 15°C (DMAX15), the mean of all temperatures (MEAN), the mean of all daily maximum temperatures (MMAX), and the mean of all moving 7-day mean daily maximum temperatures (MMOV) (Table 2-5). The temperature metric most closely associated with bull trout composition was the mean of all daily minimum temperatures (MMIN) followed by DMAX15, the percentage of all temperatures that exceed 15°C (PG15), MEAN, and DMOV15 (Table 2-5). The adjusted r^2 values from the polynomial regressions indicate that the MEAN temperature metric was the most closely associated with bull trout density followed by MMIN, MMOV, MMAX, and the maximum value of the moving 7-day mean daily maximum (MOV) (Table 2-5). The MEAN temperature metric was the only metric that ranked in the top five temperature metrics for each bull trout population metric. The lowest temperature (MIN), the difference between the highest temperature (MAX) and the MIN (RNG), the number of days that the moving 7-day mean daily maximum exceeded 20°C (DMOV20), the number of days that the daily maximum exceeded 20°C (DMAX 20), and the percentage of all temperatures that exceed 20°C (PG20) were poorly associated with all bull trout population metrics. We considered the MEAN temperature metric to be the most effective overall at describing bull trout distribution and abundance since it was the only metric that ranked in the top five temperature metrics for all three bull trout population metrics.

Table 2-5 – Results of logistic and polynomial regressions evaluating the relationship between the bull trout population metrics and the temperature metrics. The five temperature metrics with the strongest relationship to each population metric are shown in bold.

	Bull trout population metric		
Temperature metric	Occurrence AIC value	Composition AIC value	Density adjusted r^2 value
MAX	25.5	488.7	0.4934
MIN	50.6	620.0	-0.0409
RNG	40.5	618.6	0.1921
MEAN	**19.3**	**350.3**	**0.5708**
MOV	21.4	467.8	**0.5406**
MMAX	**20.2**	451.1	**0.5410**
MMIN	22.7	**257.1**	**0.5466**
MMOV	**20.3**	450.7	**0.5414**
PG5	38.9	378.2	0.447
PG10	20.7	425.7	0.5113
PG15	21.3	**346.5**	0.4893
PG20	38.7	n/a[1]	0.0225
DMOV10	22.2	609.1	0.3585
DMOV15	**16.7**	**350.5**	0.5033
DMOV20	41.6	n/a[1]	0.0191
DMAX10	20.7	600.5	0.3954
DMAX15	**18.5**	**329.9**	0.5158
DMAX20	39.1	623.1	0.0318

[1] Data for these metrics were so poorly fitted to the logistic model that the validity of the model was questionable. Therefore, we disregarded these metrics.

Relationship Between Bull Trout Distribution and Abundance and Selected Temperature Metrics

We selected the MEAN and MAX temperature metrics for detailed analysis. We selected MEAN temperature because it effectively described all three bull trout population metrics and was relatively easy to collect and calculate. Although several temperature metrics were more effective than MAX temperature at describing bull trout abundance, we elected to make a detailed analysis of this metric because it is generally associated with bull trout distribution and abundance in the literature.

MEAN temperature metric – The probability of bull trout being present decreased as MEAN temperature increased (Table 2-6, Figure 2-3). The MEAN temperature of the study sites ranged from 5.2 to 14.6°C, whereas the MEAN temperature of sites where bull trout were present ranged between 5.2 and 11.9°C. Bull trout were present at all sites where the MEAN temperature was less than 10.0°C but were present in only 40% of the sites where MEAN temperature was between 10.0 and 12.0°C. Bull trout were not present at any sites where the MEAN temperature exceeded 12.0°C. The MEAN temperature of sites where bull trout were absent ranged from 10.4 to 14.6°C.

The logistic model for MEAN temperature was effective at describing bull trout occurrence (Table 2-7, Figure 2-3). The model predicted a 90, 50, and 10% probability that bull trout would be present at MEAN temperatures of 9.7, 10.9, and 12.1°C, respectively. A MEAN temperature of 10.9°C (probability level = 0.50) accurately predicted 90% of the bull trout presences and absences.

Salmonid species composition was closely associated with MEAN temperature (Table 2-6, Table 2-7, Figure 2-3). Although rainbow trout and brook trout are believed

Table 2-6 – Frequency table describing the relationship between MEAN and MAX temperature and bull trout occurrence, density, and percentage of salmonids that were bull trout. Range and standard error are shown in parentheses.

Temperature metric (°C)	n	Bull trout population metric: Mean number of sites with bull trout (%)	Mean composition (%)	Mean density (fish/100 m²)
<u>MEAN</u>				
<7.0	6	100	100 (100-100,0)	10.2 (0.6-27.5,3.9)
7.0-7.9	7	100	71 (4-100,15)	15.0 (0.7-39.6,5.6)
8.0-8.9	6	100	49(11-100,16)	10.1 (0.4-29.2,5.7)
9.0-9.9	4	100	26 (2-64,13)	1.6 (0.4-3.3,0.7)
10.0-10.9	4	50	4 (0-15,3)	0.4 (0-1.6,0.4)
11.0-12.0	6	33	2 (0-6,1)	0.1 (0-0.6,0.1)
>12.0	6	0	0	0
<u>MAX</u>				
<10.0	5	100	81 (4-100,19)	5.3 (0.6-14.0,2.4)
10.0-14.9	11	100	74 (11-100,11)	17.3 (0.4-39.6,4.2)
15.0-16.9	6	100	40 (2-100,15)	2.2 (0.2-6.4,1.0)
17.0-20.0	12	42	5 (0-19,2)	0.4 (0-2.1,0.2)
>20.0	5	0	0	0

to have had access to all of our sites, bull trout were the only salmonid present at sites where the MEAN temperature was less than 7.0°C. Bull trout composition declined steadily as MEAN temperatures increased from 7.0 to 12.0°C and was 0% at all sites with MEAN temperatures greater than 12.0°C. Sites where bull trout were the only salmonid present had MEAN temperatures between 5.2 and 8.6°C.

Although bull trout density was variable over the range of MEAN temperatures, distinct patterns in density were apparent (Table 2-6, Table 2-8, Figure 2-3). At sites where MEAN temperature was less than 9.0°C the average bull trout density was 11.9 fish/100 m^2. However, at sites where MEAN temperature was between 9.0 and 12.0°C,

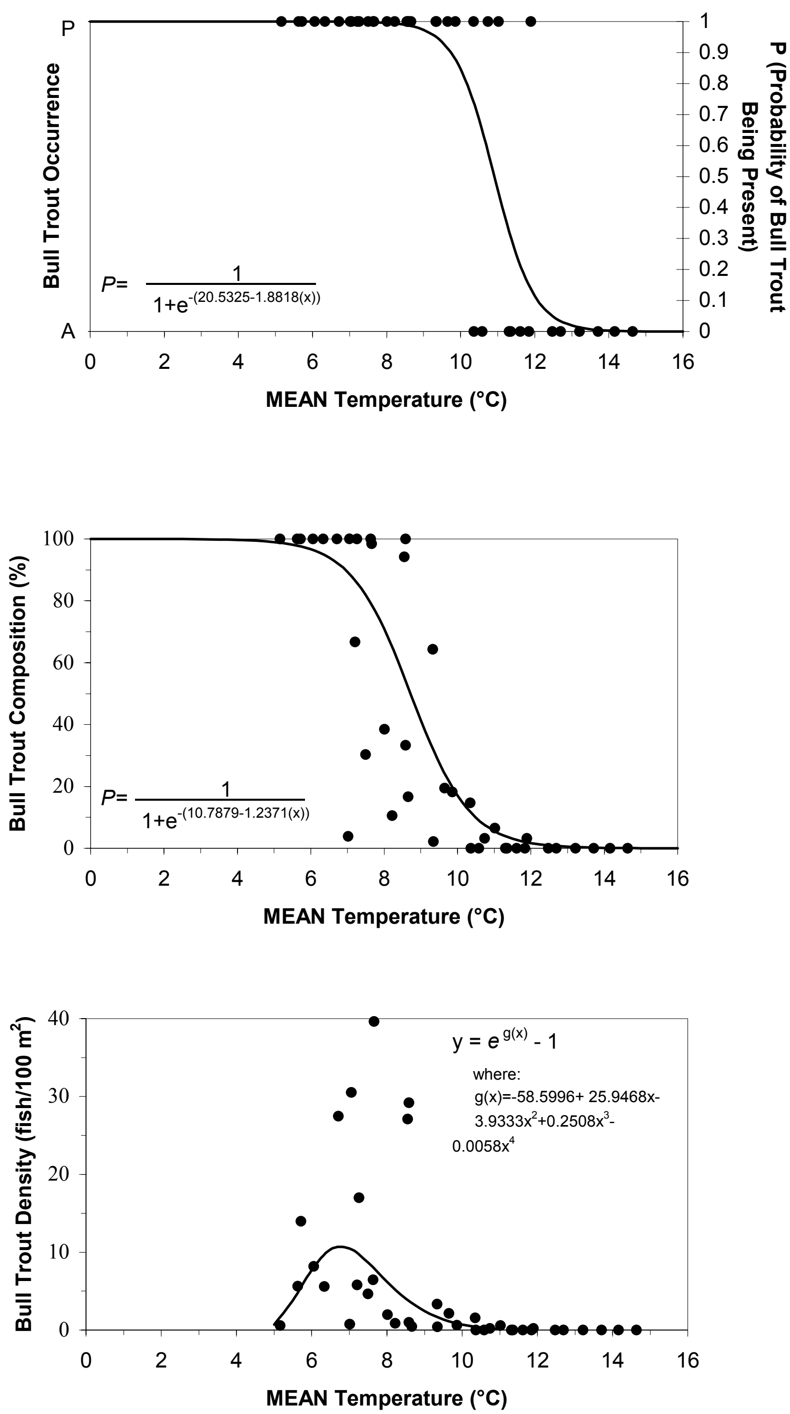

Figure 2-3 – The relationship between MEAN temperature and bull trout occurrence, bull trout density, and the percentage of salmonids that were bull trout. The logistic regression models generated the curves on the occurrence and composition graphs whereas the polynomial regression model generated the curve on the density graph.

Table 2-7 – Results of logistic regression analyses evaluating the relationship between MEAN and MAX temperature and bull trout occurrence and the percentage of salmonids that were bull trout.

Population/ temperature metric	n	AIC	Parameter	DF	Estimate	Standard error	P
Occurrence							
MEAN	39	19.3	Intercept	1	20.5325	8.0287	0.0105
			MEAN	1	-1.8818	0.7370	0.0107
MAX	39	25.5	Intercept	1	17.1584	6.3825	0.0072
			MAX	1	-0.9222	0.3457	0.0076
Composition							
MEAN	39	350.3	Intercept	1	10.7879	0.9332	<0.0001
			MEAN	1	-1.2371	0.1091	<0.0001
MAX	39	488.7	Intercept	1	6.3216	0.6225	<0.0001
			MAX	1	-0.4140	0.0398	<0.0001

Table 2-8 – Results of polynomial regression analyses evaluating the relationship between bull trout density and the MEAN and MAX temperature.

Metric	N	Adjusted r^2	P	Parameter	DF	Estimate	Standard error
MEAN	39	0.5708	<0.0001	Intercept	1	-58.5996	25.3449
				x	1	25.94675	11.3525
				x^2	1	-3.9333	1.8429
				x^3	1	0.2508	0.1287
				x^4	1	-0.0058	0.0033
MAX	39	0.4934	<0.0001	Intercept	1	-30.4644	17.5816
				x	1	7.9240	4.7833
				x^2	1	-0.6611	0.4635
				x^3	1	0.0224	0.0191
				x^4	1	-0.0003	0.0003

the average bull trout density was only 0.6 fish/100 m^2. Bull trout densities were 0.0 fish/100 m^2 for all sites with MEAN temperatures greater than 12.0°C. High bull trout densities (>10.0 fish/100 m^2) occurred at MEAN temperatures between 5.7 and 8.6°C. The polynomial regression model suggests that peak bull trout densities occur at MEAN temperatures of about 6.8°C, whereas the site with the highest observed bull trout density (39.6 fish/100 m^2) had a MEAN temperature of 7.7°C.

The distribution of rainbow trout and brook trout also appeared to be influenced by MEAN temperature. Rainbow trout were not present in the six sites where MEAN temperature was less than 7.0°C, but were present in 57% of the seven sites where MEAN temperature was between 7.0 and 7.9°C and were present in 92% of the 26 sites where MEAN temperature was 8.0°C or greater. Brook trout were not present in the 10 sites where MEAN temperature was less than 7.5°C but were present in 34% of the 29 sites where MEAN temperature was 7.5°C or greater.

MAX temperature metric – As with the MEAN temperature metric, the probability of bull trout being present decreased as MAX temperature increased (Table 2-8, Figure 2-4). The MAX temperature of the study sites ranged from 8.1 to 25.9°C while the MAX temperature of sites where bull trout were present ranged between 8.1 and 20.0°C. Bull trout were present at all sites where the MAX temperature was less than 17.0°C but were present in only 42% of the sites where MAX temperature was between 17.0 and 20.0°C and were not present at any of the five sites where the MAX temperature exceeded 20.0°C. The MAX temperature of sites where bull trout were absent ranged from 17.3 to 25.9°C.

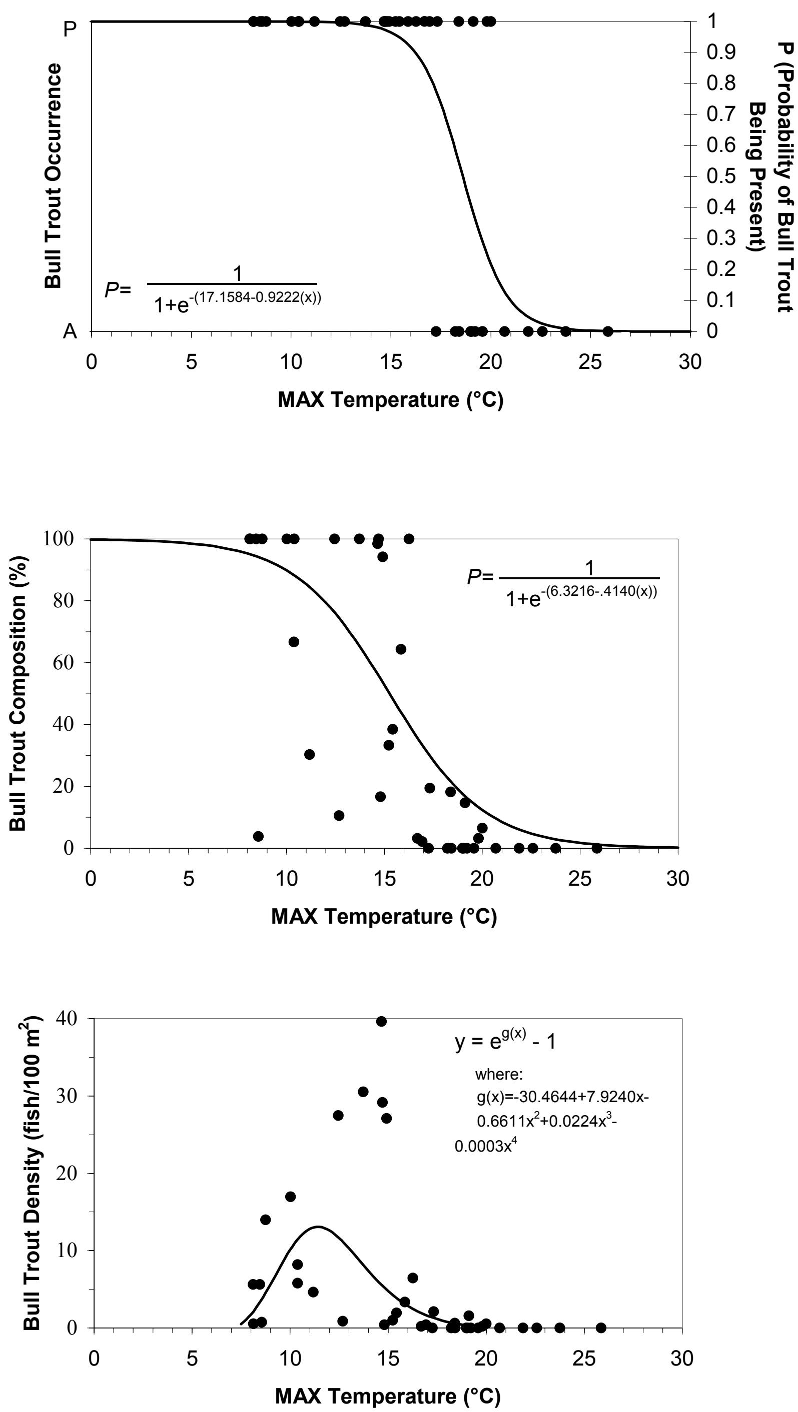

Figure 2-4 – The relationship between MAX temperature and bull trout occurrence, bull trout density, and the percentage of salmonids that were bull trout. The logistic regression models generated the curves on the occurrence and composition graphs whereas the polynomial regression model generated the curve on the density graph.

The logistic model for the MAX temperature metric was effective at describing bull trout occurrence (Table 2-7, Figure 2-4). This model indicated that there was a 90, 50, and 10% probability of bull trout being present at MAX temperatures of 16.2, 18.6, and 21.0°C, respectively. A MAX temperature of 18.6°C (probability level = 0.5) accurately predicted 85% of the bull trout presences and absences.

Salmonid species composition was closely associated with MAX temperature (Table 2-8, Figure 2-4). The percentage of salmonids that were bull trout averaged 81% at sites where MAX temperature was less than 10.0°C, 74% at sites where MAX temperature was between 10.0 and 14.9°C, 40% at sites where MAX temperature was between 15.0 and 16.9°C, 5% at sites where MAX temperature was between 17.0 and 20.0°C, and 0% at sites where MAX temperature was greater than 20.0°C. Sites where bull trout composition was 100% had MAX temperatures between 8.1 and 16.3°C. Although bull trout composition ranged between 2 and 100% at temperatures less than 17.0°C, bull trout composition was always less than 20% at sites where MAX temperature was above 17.0°C.

Bull trout densities were variable over the range of MAX temperatures (Table 2-6, Table 2-8, Figure 2-4). Mean bull trout density was 5.3 fish/100 m^2 at MAX temperatures less than 10.0°C but increased to 17.3 fish/100 m^2 at sites where MAX temperature was between 10.0 and 14.9°C. Bull trout density was relatively low at MAX temperatures above 15.0°C. High bull trout densities (>10.0 fish/100 m^2) occurred at MAX temperatures between 8.8 and 14.9°C. The polynomial regression model estimated peak bull trout densities to occur at about 11.4°C while the site with the highest observed bull trout density (39.6 fish/100 m^2) had a MAX temperature of 14.7°C.

The distribution of rainbow trout and brook trout also appeared to be influenced by MAX temperature. Rainbow trout were present in only one of the five sites where MAX temperature was less than 10.0°C, were present in just 33% of the 12 sites where MAX temperature was less than 14.0°C, but were present in 89% of the 27 sites where MAX temperature was greater than 14.0°C. Brook trout were not present in the eight sites where MAX temperature was less than 11.0°C, were present in only one of the eight sites where MAX temperature was between 11.0 and 15.0°C, but were present in 39% of the 23 sites where MAX temperature was greater than 15.0°C.

Discussion

Evaluation of Temperature Metrics

Although several temperature metrics were effective at describing various aspects of bull trout abundance, the MEAN temperature was considered the most effective overall. Other work assessing the relationship between different temperature metrics and bull trout abundance is limited. Adams and Bjornn (1997) believed that the temperature unit metric, which is a linear transformation of mean temperature, might have been more effective than maximum temperature at describing the downstream distribution limit of bull trout in the Weiser River, Idaho basin. Similarly, recent work in west central Idaho indicates that in stream reaches where bull trout are present, mean summer temperature with a quadratic term is more effective than maximum summer temperature with a quadratic term at describing bull trout density (Caleb Zurstadt, Boise National Forest, personal communication).

Distribution and Abundance

When evaluating the relationship between water temperature and bull trout distribution and abundance, it is important to consider both optimum temperatures and temperatures that limit the species distribution. Bull trout appear capable of occupying a wide range of temperatures, having been observed at water temperatures from 0 to nearly 30°C (Rieman and Chandler 1999). Adams and Bjornn (1997) observed both juvenile and adult bull trout in a stream where the water temperature measured at the focal point of the fish was 20.5°C and Zurstadt (2000) observed bull trout swimming and feeding at water temperatures of 23.5°C. Likewise, bull trout were found in a stream in central Washington where the maximum annual temperature was 20.1°C (Craig 2001). In the current study we found bull trout at sites with MAX temperatures between 8.1 and 20.0°C. Similarly, juvenile bull trout were found in stream reaches in the Lake Pend Oreille drainage at maximum summer temperatures between 7.8 and 20.0°C (Saffel and Scarnechia 1995). In contrast, Goetz (1997) examined several streams in the Cascade Mountains and did not observe juvenile bull trout at temperatures greater than 13°C or adults where temperatures exceeded 16.5°C.

While bull trout have been observed over a wide range of temperatures, temperatures greater than about 20°C may limit their distribution in the Little Lost River basin. Selong et al. (2001) assessed the survival of age 0 bull trout fed to satiation over a 60-d period at temperatures ranging between 8 and 28°C. They found that survival was

98% or greater at temperatures of 18°C or less, 79% at 20°C, but 0% at temperatures of 22°C or greater. No mortality occurred for 31 d at 20°C while time to 100% mortality at temperatures of 22, 24, and 26°C was 38 d, 10 d, and 24 h, respectively. This work suggests that bull trout may not be able to occupy streams while maximum temperatures are in excess of about 20°C. Indeed, we collected 16 bull trout ranging in length from 54 to 290 mm at one site where the MAX temperature was 19.1°C, five bull trout ranging in length between 108 and 298 mm at another site where the MAX temperature was 20.0°C, but did not collect any bull trout at sites where the MAX temperature was greater than 20.0°C. While we acknowledge that bull trout have been found in areas where water temperature exceeds 20°C (e.g., Rieman and Chandler 1999; Zurstadt 2000), we believe that they will likely not persist in such habitats for extended periods.

The lower limit of suitable temperatures for bull trout has not been defined. We found bull trout in the coldest sites in our study, which had MAX temperatures of 8.1°C Likewise, Saffel and Scarnecchia (1995) found juvenile bull trout in the coldest sites in their study, which had maximum summer temperatures of 7.8°C. Additionally, bull trout are often found in streams that have winter temperatures at or near 0°C (Rieman and Chandler 1999, current study). While the minimum temperature at which bull trout can persist is not clear, these data suggest that bull trout may be capable of occupying the coldest waters found in natural environments within their range.

While bull trout are capable of occupying a wide range of temperatures, density data suggest that MEAN temperatures of 7 to 8°C may be optimal for bull trout. In our study, the five sites with the highest bull trout densities had MEAN temperatures between

6.7 to 8.6°C and the site with the highest density (39.6 fish/100m^2) had a MEAN temperature of 7.7°C. Similarly, our regression model indicates that peak densities would occur at about 6.8°C. Other studies have yielded similar results. In an assessment of 33 stream reaches in west central Idaho, the five reaches with the highest densities of bull trout had mean temperatures between 7.4 and 8.3°C (Zurstadt 2000; mean temperatures were based on data collected between July 10 – September 10, 1996 and July 18 – September 25, 1997, Caleb F. Zurstadt, personal communication). Additionally, an analysis of 581 sites across the northwestern U.S. indicated that juvenile bull trout were most likely to occur at summer mean temperatures of 6-9°C (Rieman and Chandler 1999; mean temperatures were based on data collected between July 15 – August 31 over a several year period, Bruce E. Rieman, personal communication).

When considering the MAX temperature metric, temperatures of about 13°C may be optimal for bull trout. In our study, the five sites with the highest bull trout densities had MAX temperatures between 12.5 and 14.9°C and the site with the highest density (39.6 fish/100 m^2) had a MAX temperature of 14.7°C. Our regression model indicates that peak densities would occur at about 11.4°C. Similarly, in 18 stream reaches in northern Idaho, the four highest bull trout densities occurred where maximum summer temperatures were between 11.1 and 13.9°C (Saffel and Scarnecchia 1995). In the Flathead River, Montana, juvenile bull trout abundance was greatest in streams where maximum summer temperatures were less than 15°C (Fraley and Shepard 1989). An analysis of 581 sites across the northwestern U.S. completed by Rieman and Chandler (1999) indicated that juvenile bull trout were most likely to occur where maximum temperatures were between 11 and 14°C. Selong et al. (2001) evaluated the growth of age 0 bull trout in the laboratory and found that fish achieved peak growth at about 13.2°C. Although this temperature is similar to the MAX temperature at which we observed peak densities of bull trout, it is difficult to compare the two studies since the laboratory work involved holding fish at constant temperatures and feeding fish to satiation, whereas fish in our study were exposed to fluctuating temperatures and a limited food supply.

The relative proportion of salmonids that are bull trout appears to be strongly influenced by water temperature. Bull trout were the only salmonid species present at study sites where MEAN temperatures were less than 7.0°C even though rainbow trout and brook trout presumably had access to those areas. The salmonid species composition shifted from 100% bull trout at MEAN temperatures less than 7.0°C to 0% bull trout at MEAN temperatures greater than 12.0°C. Likewise, in several Oregon streams, bull trout comprised 100% of the salmonid composition at colder temperatures but comprised 0% of the salmonid composition at warmer temperatures (Ratliff 1992; Ziller 1992). Recent work in several streams in British Columbia has also shown that the percentage of salmonids that were bull trout decreased with increasing stream temperatures (Haas 2001). Shifts in salmonid species composition associated with changes in water temperature has also been observed in other salmonids. For example, in southwestern Wyoming, Taniguchi et al. (1998) observed that a shift from brook trout to brown trout was associated with an increase in stream temperature.

Although salmonid species composition was closely associated with MEAN temperature in our study, trout densities were highly variable. For example, in those sites where bull trout were the only salmonid species present, trout densities ranged between 0.6 and 27.5 fish/100 m^2. Likewise, in those sites where bull trout were absent, trout densities ranged from 0.2 to 24.5 fish/100 m^2. These data suggest that in streams where temperatures are suitable for salmonids, water temperature has a strong influence on the salmonid species composition but salmonid densities are largely controlled by habitat attributes other than water temperature (e.g., gradient, pool frequency, food availability, etc.).

Competition

Interspecific competition may explain the shifts in salmonid species composition that we observed. The outcome of competition between two species can be dependent on the specific abiotic conditions in which the competition occurs (Dunson and Travis 1991). This process has been termed condition-specific competition. Temperature-mediated competition, a form of condition-specific competition where the competitive superiority of two species is determined by the temperature at which the interaction occurs, has been demonstrated in several studies involving various fish species (e.g., Taniguchi and Nakano 2000; Cunjak and Green 1986; Baltz et al. 1982; Reeves et al. 1987; De Staso and Rahel 1994). For example, in one laboratory study Taniguchi et al. (1998) evaluated food consumption of brook trout and creek chub *Semotilus atromaculatus* at different temperatures and found that the brook trout were superior competitors at temperatures less than 22°C but that creek chub were superior at temperatures greater than 22°C. Such temperature-mediated interactions may influence the percentage of salmonids that are bull trout. Laboratory work indicates that bull trout achieve maximum growth at 13.2°C, whereas rainbow trout achieve maximum growth at 17.2°C (Selong et al. 2001). This suggests that bull trout may be a superior competitor at 13°C, whereas rainbow trout may be a superior competitor at 17°C even though both species are capable of occupying both temperatures. This may explain why we found that bull trout comprised a high proportion of the salmonids at cold temperatures, whereas rainbow trout comprised a high proportion of the salmonids at warmer temperatures.

In some circumstances, temperature-mediated competition may completely eliminate bull trout from areas where temperatures are sub-optimal. This process has been referred to as competitive exclusion (Whooton 1998). Taniguchi and Nakano (2000) believed that competitive exclusion resulting from temperature-mediated competition may shape the lower distribution limits of Dolly Varden *S. malma* in some Japanese streams. Bonneau and Scarnecchia (1996) observed distribution patterns of bull trout and cutthroat trout in a thermal gradient of 8-15°C. They found bull trout generally occupied that portion of the gradient where temperatures were less than 9°C and cutthroat trout occupied that portion of the gradient where temperatures were greater than 10°C. Because bull trout have been found over the entire range of temperatures observed in this thermal gradient, competitive exclusion, rather than temperature, may have been limiting their distribution. At a larger scale, competitive exclusion could result in bull trout being excluded from entire streams or stream basins even though bull trout are capable of surviving in the temperatures found in such streams or stream basins. Furthermore, the extent to which competitive exclusion alters the thermal distribution limits of the bull trout will likely depend on the specific species involved. For example, bull trout may be found at relatively high temperatures when rainbow trout are the only other salmonid present but be confined to colder temperatures when cutthroat trout are also present.

Likewise, intraspecific competition may have an important influence on the temperatures at which bull trout are found. Bull trout will likely seek optimal temperatures, which our analysis suggests may be areas where maximum annual temperatures are about 13°C. Subsequently, at low levels of intraspecific competition, bull trout may not be found at temperatures much above 13°C. However, at higher levels of intraspecific competition, bull trout may expand into habitats with sub-optimal temperatures. Thus the temperatures at which bull trout are observed may vary depending on the levels of intraspecific competition. We suspect that varying levels of interspecific and intraspecific competition over the range of the bull trout may partially explain the differences in the observed thermal distribution limits of this species. However, these mechanisms need further study before definite conclusions can be made.

Temperature-mediated competition may also be an important factor determining whether introduced species replace bull trout. Introduced species are thought to pose a significant risk to bull trout populations (Ratliff and Howell 1992; Rieman et al. 1997). For example, hatchery introductions have established brook trout over much of the bull trout's range (Mackay et al. 1997; Thurow et al. 1997) and the decline of bull trout in some areas has been accompanied by an increase in brook trout numbers (Leary et al. 1993; Mackay et al. 1997; Gamett 1999). Despite widespread introductions, brook trout are not present in many streams containing bull trout (Howell and Buchanan 1992; Mackay et al. 1997; Gamett 1999). While brook trout may not have had the opportunity to colonize some of these streams, their absence in other streams may be related to temperature-mediated competition. This conclusion is supported by a comparison of brook trout distribution patterns in the Big Lost River and Little Lost River basins. The Big Lost River basin does not contain bull trout, but brook trout have been established throughout the drainage (B. Gamett, unpublished data). Distribution patterns in this basin suggest that brook trout can occupy the coldest streams available, including streams where the maximum summer temperatures are likely well below 15°C. However, in the Little Lost River basin, where brook trout were introduced by at least 1915 (Gamett 1999) and are believed to have had access to all of our study sites, we did not find brook trout in any of the eight sites where MAX temperature was less than 11.0°C and they were present in only one of the 16 sites where MAX temperature was less than 15.0°C. However, brook trout were present in 39% of the 23 sites where MAX temperature was greater than 15.0°C. Similarly, Buckman et al. (1992) and Ratliff (1992) believed that cold water temperatures may have precluded brook trout from invading some Oregon streams containing bull trout. Although further study is needed, these patterns suggest that brook trout are capable of occupying very cold streams but may not be able to invade such streams when bull trout are present. If this is the case, increases in stream temperatures could result in brook trout expanding into additional areas, subsequently eliminating the bull trout.

Effects of Changes in Stream Temperature

Our study suggests that relatively minor changes in water temperature could have significant impacts on bull trout distribution and abundance. For example, bull trout were the only salmonid present at sites where MEAN temperature was less than 10°C but were not present at any sites where MEAN temperature was greater than 12°C. Similarly, bull trout densities averaged 15.0 fish/100 m^2 at sites where MEAN temperatures were between 7.0 and 7.9°C but averaged only 1.6 fish/100 m^2 at sites where MEAN temperatures were between 9.0 and 9.9°C. This suggests that changes in stream temperatures could have significant effects on bull trout populations.

Such changes in stream temperature could result from both anthropogenic and natural influences. There are several anthropogenic influences that have the potential to modify stream temperature regimes. Here we consider three factors operating at different temporal and spatial scales that may be important to bull trout. These are alterations to stream flow, changes in stream shading, and shifts in global temperature.

Water withdrawal from a stream can significantly modify water temperatures. Water is withdrawn from streams over a large portion of the bull trout's range for agricultural, domestic, industrial, and hydroelectric purposes. Water withdrawal can increase stream temperatures by decreasing the volume of water in a stream, thus reducing the stream's ability to buffer thermal input. Additionally, water withdrawal can increase stream temperatures by reducing water velocity through the stream channel, thereby increasing the amount of time water is exposed to thermal influences.

Changes in stream temperature associated with alterations to stream flow could have significant effects on bull trout populations. We used the SSTEMP stream temperature model (Bartholow 1999) and the models generated in the current study to evaluate the potential effects of water withdrawal on a bull trout population in a hypothetical stream reach (B. Gamett, unpublished data; Appendix Table B-1). We believe this model is useful in this type of analysis but caution that it should be carefully calibrated when working with actual streams. The hypothetical reach, which was representative of those occupied by bull trout in the Little Lost River drainage, was 10 km long, mean width at a discharge 0.3 m^3/second was 2.5 m, mean depth at a discharge 0.3 m^3/second was 0.15 m, stream gradient was 1%, upstream elevation was 2,400 m, stream shading was 50%, and the mean daily temperature of water entering the reach was 8.0°C. The model was run for August 1 and we assumed the maximum annual stream temperature would occur on this date. At a discharge of 0.3 m^3/s, the predicted maximum temperature at the bottom of the 10 km reach was 15.8°C. However, when flow was reduced by 90%, the predicted maximum temperature at the bottom of the reach increased to 23.0°C. Our models indicate that such a shift would drop the probability of bull trout being present at the bottom of the reach from 93% to 2% and drop the percentage of salmonids that were bull trout from 45% to 4%.

Alterations to stream shading can also alter stream temperatures. The amount of solar radiation entering a stream can have a strong influence on water temperature (Brown 1969; Meehan 1970). Although the magnitude of the effect will vary, reductions in streamside vegetation from activities such as logging and grazing can result in an increase in stream temperature (Lynch et al. 1984; Holtby 1988; Platts 1991). For example, in the Needle Branch drainage in eastern Oregon, maximum annual stream temperatures increased from 13.9 to 29.4°C following a clear-cut and burn that removed most of the streamside vegetation (Brown and Krygier 1970). Similarly, maximum annual stream temperatures increased from 15 to 21.5°C in a stream in northern England after most of the trees along a portion of the stream were cut (Gray and Edington 1969).

Changes in stream temperature associated with modifications to stream shading could have important effects on bull trout populations. We used the SSTEMP stream temperature model (Bartholow 1999) and the models generated in the current study to evaluate the potential effects of changes in stream shading on a bull trout population in a hypothetical stream reach (B. Gamett, unpublished data; Appendix Table B-1). We used the same hypothetical reach described above with the exception that flow was held constant at 0.3 m^3/second. When stream shading was 90%, the predicted maximum temperature at the bottom of the 10 km reach was 10.4°C. Our models indicate that at this temperature the probability of bull trout being present would be 100% and the percentage of salmonids that are bull trout would be 88%. However, when stream shading was reduced to 10%, the predicted maximum temperature at the bottom of the reach increased to 21.6°C. At this temperature the probability of bull trout being present drops to 6% and the percentage of salmonids that are bull trout drops to 7%.

Changes in water temperature resulting from climate change may also significantly alter bull trout populations. Post Pleistocene climate warming is believed to have resulted in a reduction in bull trout distribution (Cavender 1978; Behnke 1981; Bond 1992). Future climate change, accelerated by anthropogenic influences, will likely continue to alter bull trout distributions. Several studies have predicted that continued global warming will result in widespread declines in the distribution of cold water species across North America (e.g., Meisner 1990; Eaton and Scheller 1996; Keleher and Rahel 1996). These scenarios also predict fragmentation of remaining habitat, which will likely lead to further declines. Since bull trout require relatively cold water, the effects of global warming could be particularly significant for this species. Nakano et al. (1996)

evaluated the potential impact of global warming on Dolly Varden a species closely related to bull trout, in the Japanese archipelago. They believed that an increase in mean annual air temperature of 1, 2, 3, and 4°C would reduce the distribution of Dolly Varden by 27.6, 67.2, 79.6, and 89.6%, respectively. The impact of short-term climate change on bull trout abundance may be evident in Timber Creek in the Little Lost River basin. In 1987, sampling in lower Timber Creek indicated that bull trout were the only salmonid present in this reach of stream (Corsi and Elle 1989). The reach was again sampled in 1995 following several years of severe drought (Gamett 1999). This sampling indicated that rainbow trout had invaded the reach and comprised 17% of the salmonid population, whereas bull trout comprised 83%. A similar pattern was also observed in an adjacent stream. This shift in species composition may have been associated with changes in water temperatures associated with the drought. We believe the effects of climate change on bull trout will likely be most pronounced in the southern portion of the species range where suitable thermal habitat is already limited. Furthermore, the negative effects of climate change will likely be further exasperated by additional fragmentation in distribution patterns.

It is also important to consider the role of natural influences on stream temperature and the potential implications for bull trout distribution and abundance. For example, reductions in stream shading resulting from wildfire may lead to an increase in stream temperature (Royer and Minshall 1997). This is demonstrated by a wildfire that burned the Wallace Creek drainage in central Idaho (Bruce Roberts, Salmon-Challis National Forest, unpublished data). On July 14, 2000, an intense wildfire burned much of the riparian area along Wallace Creek while the nearby Perreau Creek watershed was unburned. Prior to the fire, both streams had nearly identical temperature regimes (Figure 2-5) and in the 5 d prior to the fire, Wallace Creek and Perreau Creek had maximum stream temperatures of 12.5 and 12.9°C, respectively. However, in the 5 d following the fire, the maximum temperature in Wallace Creek increased to 16.0°C while

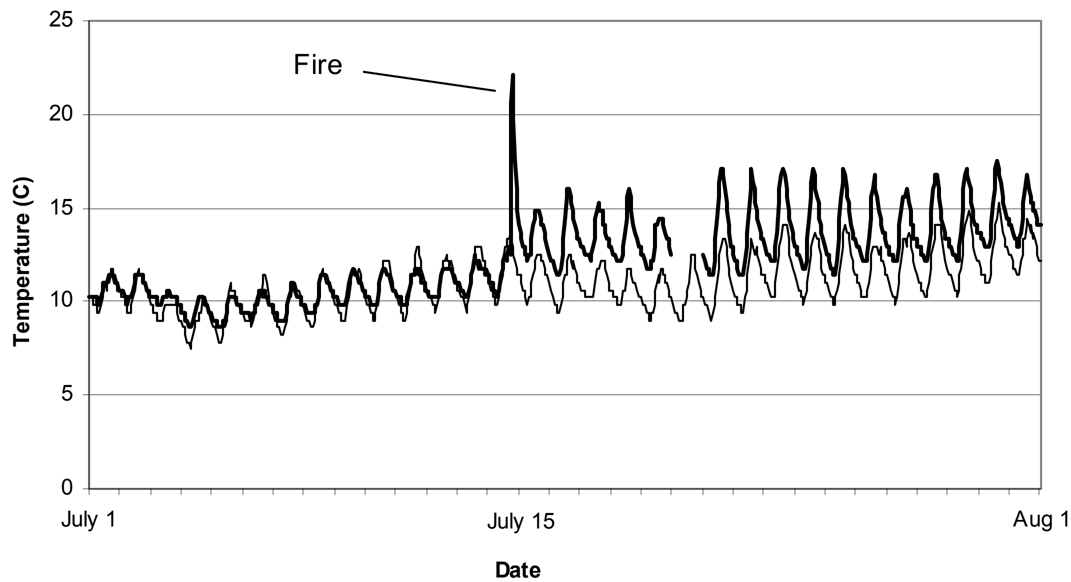

Figure 2-5 – Stream temperatures in Wallace Creek and in Perreau Creek. Wallace Creek (burned) is the thick line and Perreau Creek (unburned) is the thin line (Bruce Roberts, Salmon-Challis National Forest, unpublished data).

the maximum temperature in Perreau Creek was only 12.5°C. Such shifts in temperature could result in shifts in bull trout distribution and abundance.

Naturally high water temperatures may have important implications for bull trout populations. Natural factors such as groundwater temperature, aspect, exposure, and limited flow may result in stream temperatures unsuitable for bull trout. We believe that relatively high water temperatures resulting from such natural factors may explain the absence of bull trout in many streams. This may be the case with Deer Creek, a tributary to the Little Lost River. Deer Creek is a spring fed stream that contains rainbow trout and shorthead sculpin (Gamett 1999, current study). Although bull trout are present in the

Little Lost River below Deer Creek and in several adjacent stream basins, they are not found in Deer Creek. However, water emerges from the ground at the springs feeding Deer Creek at temperatures between 13.3 and 13.5°C and in the current study we did not find bull trout at sites where the MEAN temperature was 12.0°C or greater. Thus, the relatively warm temperature of the groundwater feeding Deer Creek could explain the absence of bull trout in the stream. Since both anthropogenic and natural influencescan have important effects on stream temperature, it is important that both factors be considered when evaluating a stream's ability to support bull trout.

Monitoring

We recommend the development of standard time periods and metrics for use in evaluating the relationship between water temperature and bull trout distribution and abundance. While several studies have discussed the influence of water temperature on bull trout, there are often differences in the reported temperature metrics, population metrics, and time periods covered. For example, one study may describe the relationship between mean July temperature and bull trout occurrence, whereas another study may report the relationship between maximum summer temperature and bull trout density. Such differences make it difficult to compare the various studies. In order to overcome the problems created by these inconsistencies we encourage managers and researchers to develop and use standardized time periods and temperature metrics when evaluating the relationship between water temperature and bull trout. Within and adjacent to our study area, we recommend the use of the MEAN temperature metric covering a time interval from July 1 through September 30. We recommend this approach for three reasons. First, MEAN temperature is very effective at describing bull trout abundance. Second, this metric is straightforward and easy to calculate. Third, many streams within the area may not be accessible outside this period due to snow conditions. The use of this standardized time interval and temperature metric will allow researchers and managers to more easily compare data between various studies, thus advancing our understanding of the relationship between water temperature and bull trout distribution and abundance.

Study Limitations

Our study had several weaknesses. First, our effort was limited to one river basin representing only a small portion of the bull trout's range. Additional work is needed in other areas to assess whether the temperature relationships identified in this study apply across the species range. Second, fish species found elsewhere in the bull trout's range, such as westslope cutthroat trout *O. c. lewisi*, chinook salmon *O. tshawytscha*, and mountain whitefish *Prosopium williamsoni*, were not present in our study area. Interspecific competition with these species could result in bull trout occupying a different thermal niche than that measured in this study. Third, our population and temperature data were limited to the summer season. Therefore, we were not able to evaluate the response of bull trout to seasonal and annual variations in water temperature. Areas that are too warm for bull trout in the summer may provide important migratory or winter habitat for bull trout at other times of the year. Subsequently, a stream should not be considered unimportant to bull trout simply because summer temperatures exceed those required by the fish. Fourth, our study included data from only one year. Annual variability in precipitation and temperature can produce changes in stream temperatures that will likely affect bull trout populations and additional work is needed to assess how bull trout respond to these fluctuations. Finally, fish population data were only collected once during the study period. Therefore, we may not have captured shifts in bull trout distribution and abundance resulting from temperatures changing over the study period.

Conclusions

In conclusion, our work suggests that water temperature is an important factor influencing bull trout distribution and abundance. Therefore, successfully protecting and recovering bull trout populations will require that managers clearly understand how water temperatures influence bull trout populations. This includes not only understanding what temperatures are optimal for bull trout and what temperatures limit their distribution, but also understanding how interspecific and intraspecific competition may alter the manner in which bull trout respond to water temperature. Furthermore, it will be critical that managers protect, and where appropriate, restore stream temperature regimes. This will require a clear understanding of how both natural and anthropogenic factors influence stream temperatures. As managers come to understand and apply these principles, an important step will be made towards protecting and recovering bull trout populations.

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CHAPTER 3

THE RELATIONSHIP BETWEEN GROUNDWATER TEMPERATURE AND JUVENILE BULL TROUT OCCURRENCE IN CENTRAL IDAHO[2]

Abstract. – The relationship between juvenile bull trout *Salvelinus confluentus* distribution and groundwater temperature was evaluated in 30 small stream basins in central Idaho. Minimum, maximum, and mean groundwater temperatures were all effective at describing bull trout distribution with minimum groundwater temperatures being the most effective. Juvenile bull trout were present in all stream basins where the minimum groundwater temperature was less than 4.1°C, were present in only 53% of the stream basins where the minimum groundwater temperature was between 4.1 and 6.1°C, and were not present in any stream basins where the minimum groundwater temperature was greater than 6.1°C.

Introduction

Over the last century, bull trout *Salvelinus confluentus* have experienced widespread declines (Ratliff and Howell 1992; Mackay et al. 1997; Rieman et al. 1997). Subsequently, bull trout have been listed as threatened under the United States Endangered Species Act throughout the continental United States (Federal Register 64 (210):58909-58933) and numerous federal, state, and local efforts are under way to protect and recover the species. A critical element to the success of these efforts is an understanding of the factors influencing bull trout distribution and abundance.

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[2] Coauthored by Bart L. Gamett and Jeffrey L. Kershner.

Bull trout distribution is often patchy. Studies throughout the western United States have found that bull trout are often present in one watershed but not in adjacent watersheds (Ratliff and Howell 1992; Rieman and McIntyre 1995; Rich 1996; Rieman et al. 1997; Watson and Hillman 1997; Gamett 1999). Even within individual streams distribution is often variable. Such fragmented distribution patterns are likely the result of natural environmental conditions that restrict distribution and anthropogenic influences that have led to local extinctions. However, a limited understanding of the environmental factors influencing bull trout distribution and limited historical data often make it unclear whether natural or anthropogenic factors are responsible for the absence of bull trout in a stream basin.

Groundwater temperature may be an important environmental factor influencing the distribution of bull trout. Groundwater temperature is thought to be an important factor influencing the distribution of other charrs, including Dolly Varden *S. malma*, white-spotted charr *S. leucomaenis* (Nakano et al. 1996), and brook trout *S. fontinalis* (Meisner 1990). Since water temperature has a strong influence on bull trout distribution (current study, Fraley and Shepard 1989; Rieman and McIntyre 1993), it is possible that groundwater temperature also affects the distribution of this species. However, with the exception of one study where mean annual air temperature was used to estimate the effects of groundwater temperature on bull trout distribution (Lee et al. 1997), we are unaware of any published work addressing the relationship. The purpose of this study was to evaluate and describe the relationship between the temperature of groundwater entering streams and juvenile bull trout presence/absence to determine if groundwater temperature influences bull trout distribution.

Study Area

This study was conducted in 30 stream basins located in the Little Lost River and Salmon River, Idaho drainages (Appendix Table C-1). The estimated amount of stream in the study basins occupied by salmonids ranged in length from approximately 1 to 10 km. Fish species known to occur in the selected watersheds include bull trout, brook trout, westslope cutthroat trout, rainbow/steelhead trout, chinook salmon, and sculpin (Corsi and Elle 1989, Liter and Lukens 1992; Schrader and Lukens 1992; Gamett 1999; Salmon-Challis National Forest, unpublished data; Salmon District Bureau of Land Management, unpublished data).

Methods

We assessed the relationship between groundwater temperature and juvenile bull trout presence/absence by comparing juvenile bull trout presence/absence with the temperature of groundwater entering streams in selected stream basins.

Stream Basin Selection

Fourteen stream basins were located in the Little Lost River drainage and 16 stream basins were located in the Salmon River drainage. Half of the stream basins in each river basin contained juvenile bull trout, which were defined as bull trout less than or equal to 150 mm in length. Stream basins were classified as juvenile bull trout present if juvenile bull trout had been documented in the stream basin within the last 15 years. Stream basins were classified as juvenile bull trout absent if at least two sections of stream totaling 100 m in length had been sampled in the basin in the last 15 years and no juvenile bull trout were found. Furthermore, these stream basins were required to 1) support salmonids, 2) be connected to a stream containing bull trout, and 3) not be blocked by long-term barriers that would prevent fish passage. These criteria ensured that the absence of bull trout in a stream basin was not due to migration barriers or the inability of the watershed to support salmonids. One exception to these criteria was allowed for Bog Creek where only one site totaling 100 m in length was sampled. This was allowed since salmonids are believed to occupy only about 1 km of Bog Creek. Juvenile bull trout presence or absence within stream basins was determined from data collected by personnel from the Salmon-Challis National Forest, the Salmon River Region of the Idaho Department of Fish and Game, the Salmon District of the Bureau of Land Management, and the Idaho Department of Environmental Quality (Appendix Tables D-1, D-2, D-3, and D-4). Data used to evaluate bull trout occurrence were collected using either electrofishing or snorkeling except for Flume Creek where data from one of the sites were collected using angling. We believe that this approach provides a reasonable amount of assurance that juvenile bull trout were indeed absent from the streams designated as juvenile bull trout absent. However, it is important to acknowledge that it is possible that this level of sampling failed to detect their presence. Limited data and logistical constraints did not allow us to randomly select stream basins. However, we did attempt to select stream basins representing the range of conditions found in the study area. Some stream basins contained isolated streams that were not connected to the main stream in the drainage. In such cases, we did not consider fish population data from the isolated streams nor did we collect groundwater data from the isolated streams.

Water Temperature Assessment

We used instantaneous measurements to assess groundwater temperature in each stream basin. Since groundwater discharge within a streambed can be difficult to identify, we measured groundwater temperature at springs feeding streams. Field evaluations and reviews of aerial photographs were used to identify springs feeding streams within selected stream basins. We then selected two to nine springs in each stream basin for assessment. We selected springs that were located as close to the fish bearing portion of the stream as possible. A single instantaneous temperature was measured at each spring at the point where the water emerged from the ground. Temperatures were assessed using digital thermometers (Reo Temp Model TM99A) and were recorded to one decimal place. Thermometers were calibrated by equipment traceable to the National Institute of Standards and Technology and were accurate to ± 0.4°C. All temperature assessments were completed between October 4 and November 10, 1999.

Once data were collected, we calculated three temperature metrics for each stream basin. These were the minimum stream basin groundwater temperature (MINGWT), mean stream basin groundwater temperature (MEANGWT), and maximum stream basin groundwater temperature (MAXGWT). The MEANGWT was the average of all the instantaneous temperatures for the stream basin.

Data Analysis

We evaluated the relationship between the three temperature metrics and juvenile bull trout presence/absence using logistic regression. A separate logistic regression was used to evaluate each of the three temperature metrics using the temperature metric as the independent variable and juvenile bull trout presence/absence as the dependent variable. Akaike's Information Criterion (AIC) (Burnham and Anderson 1998) was used as a quantitative index of the strength of the relationship between the temperature metric and juvenile bull trout presence/absence. Lower AIC values indicate a better goodness of fit. All regressions were completed using PROC LOGISTIC in SAS/STAT Release 7.0.

We described the relationship between the temperature metrics and juvenile bull trout distribution using the logistic regression models and frequency table analysis. The frequency table analysis involved sorting the temperature metric values in ascending order and examining the data for patterns in juvenile bull trout presence/absence. Following this review, we divided the temperature metric into three bins. The first bin covered the range of temperatures over which bull trout were generally present. The second bin covered the range of temperatures where bull trout presence was variable. The third bin covered the range of temperatures where bull trout were generally not present. Since patterns in distribution were driving the delineation of these bins, the range of temperatures in each bin was variable. We then determined the mean number of stream basins with juvenile bull trout present in each bin.

Results

Groundwater temperatures were assessed at a total of 101 springs (Appendix Table E-1 and E-2). These springs had elevations ranging between 1,579 and 2,625 m and latitudes ranging between 43.92 and 45.01 ^{o}N. There was considerable variability in groundwater temperatures with temperatures of the springs ranging between 2.7 and

13.5°C. MEANGWT ranged from 3.7 to 13.4°C. MINGWT values ranged from 2.7 to 13.3°C whereas MAXGWT values ranged from 4.3 to 13.5°C.

The presence/absence of juvenile bull trout in stream basins was strongly correlated to groundwater temperature. Although MINGWT, MEANGWT, and MAXGWT were all significantly related to juvenile bull trout presence/absence (Table 3-1), the AIC values indicate that the MINGWT was the most effective metric for describing bull trout distribution. Therefore, we provide detailed results only for the MINGWT metric. The MINGWT metric was very effective at describing juvenile bull trout presence/absence in stream basins. Stream basins where juvenile bull trout were present had MINGWT values ranging between 2.7 and 6.1°C, whereas stream basins where juvenile bull trout were absent had MINGWT values ranging between 4.1 and 13.3°C (Figure 3-1). The logistic model predicted that juvenile bull trout were more than 50% likely to occur in stream basins where the MINGWT was less than 5.2°C and less than 50% likely to occur in stream basins where the MINGWT was greater than 5.2°C (Figure 3-1). A MINGWT value of 5.2°C (probability= 0.50) accurately predicted 73% of the bull trout occurrences. Specifically, this value accurately predicted 80% of the juvenile bull trout presences and 67% of the juvenile bull trout absences.

The results from the frequency table analysis were similar to those of the logistic regression. Frequency table analysis indicated that juvenile bull trout were present in all seven stream basins where the MINGWT was less than 4.1°C (Table 3-2). However, juvenile bull trout were present in only 53% of the 15 stream basins where the MINGWT was between 4.1 and 6.1°C and were not present in any of the eight stream basins where

Table 3-1 – Results of logistic regression analyses to evaluate the relationship between MINGWT, MEANGWT, and MAXGWT and juvenile bull trout presence/absence in stream basins.

Temperature metric	N	AIC	Parameter	DF	Estimate	Standard error	Chi-square
MINGWT	30	30.64	Intercept	1	6.0765	2.3664	6.5935*
			MINGWT	1	-1.1625	0.4597	6.3947*
MEANGWT	30	31.33	Intercept	1	7.0903	2.7578	6.6100*
			MEANGWT	1	-1.2045	0.4829	6.2201*
MAXGWT	30	36.078	Intercept	1	5.0342	2.0788	5.8646*
			MAXGWT	1	-0.7392	0.3080	5.7611*

* $p<0.05$

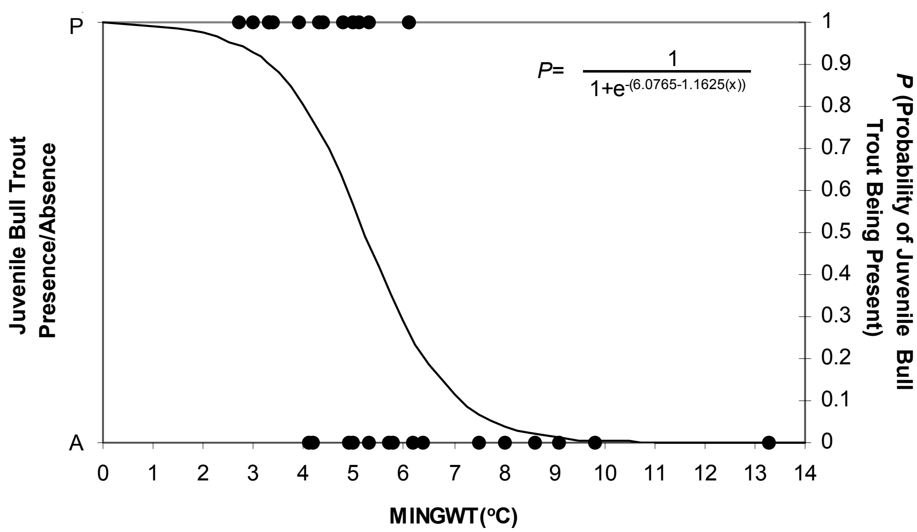

Figure 3-1 – Relationship between juvenile bull trout occurrence and MINGWT. Observed presences (P) and absences (A) are depicted by a ●. The probability of presence/absence as determined by the logistic models are represented by the curve.

Table 3-2 – Frequency table showing the relationship between MINGWT and juvenile bull trout occurrence.

Temperature (°C)	N	Stream basins with juvenile bull trout present (%)
<4.1	7	100
4.1-6.1	15	53
>6.1	8	0

the MINGWT was greater than 6.1°C.

Discussion

The distribution of juvenile bull trout appears to be strongly influenced by groundwater temperature. This study suggests that the distribution of juvenile bull trout is limited by MINGWT values greater than about 6°C. This is very similar to the findings of Lee et al. (1997), who used mean annual air temperature to estimate that the lower limit of bull trout distribution in the northwestern United States corresponded to groundwater temperatures of about 5 to 7°C. Similarly, in Japan the distribution of Dolly Varden, a species closely related to bull trout, is limited to areas where groundwater temperatures are less than about 8°C (Nakano et al. 1996).

Anthropogenic influences and natural processes may increase groundwater temperatures leading to a reduction in bull trout distribution. Groundwater temperature is controlled by air temperature, land surface and groundcover characteristics, the thermal conductivity of the zone of aeration, groundwater recharge temperature, and heat from the earth's interior (Heath 1964). Anthropogenic activities and natural processes that modify these factors could modify groundwater temperatures and subsequently alter bull trout distribution patterns. For example, Pluhowski and Kantrowitz (1963) found that mean annual groundwater temperatures were about 1°C higher in a cleared area compared to a wooded area. This suggests that anthropogenic activities such as logging or natural processes such as wildfire could result in an increase in groundwater temperature and a reduction in bull trout distribution.

Global warming is another factor that has the potential to alter groundwater temperatures. Air temperature has a strong influence on groundwater temperature (Heath 1964) and groundwater temperature is approximately the same as local mean annual air temperature (Collins 1925; Meisner 1990). This relationship suggests that if global warming were to produce an increase in mean annual air temperature, a similar increase could occur in groundwater temperature. Meisner (1990) believed increases in groundwater temperature associated with global warming could result in a substantial decline in brook trout distribution in the eastern United States. Nakano et al. (1996) evaluated the potential impact of global warming on Dolly Varden in the Japanese archipelago. They predicted that an increase in mean annual air temperature of 1, 2, 3, and 4°C would reduce the distribution of Dolly Varden by 27.6, 67.2, 79.6, and 89.6%, respectively.

Likewise, increases in groundwater temperature could result in a reduction in bull trout distribution. In a separate assessment, we evaluated the potential for changes in groundwater temperature to alter bull trout presence/absence in our study basins (B. Gamett, unpublished data). As indicated in the current study, we assumed juvenile bull trout would be present in all stream basins where MINGWT was less than 4.1°C, in 50% of the stream basins where MINGWT was between 4.1 and 6.1°C, and none of the stream basins where MINGWT was greater than 6.1°C. We also assumed that a change in mean annual air temperature would produce a corresponding change in MINGWT. We found that an increase in mean annual air temperature of 0.5, 1.0, 2.0, and 3.0°C would result in juvenile bull trout disappearing from 33, 53, 73, and 93% of the stream basins that were occupied in our study, respectively. Conversely, a decline in mean annual air temperature of 0.5, 1, 2, and 3°C would result in juvenile bull trout colonizing 40, 47, 60, and 73% of the unoccupied stream basins, respectively. This analysis suggests that climate change may have profound effects on bull trout distribution and also supports the conclusions of Cavender (1978), Behnke (1981), and Bond (1992) who believed that post Pleistocene climate warming has resulted in a reduction in bull trout distribution.

Two mechanisms may partly explain why groundwater temperature influences bull trout distribution. First, groundwater temperature may limit bull trout distribution through an effect on the summer thermal regime of a stream. Meisner (1990) believed that streams receiving relatively warm groundwater might not provide sufficient summer thermal habitat for brook trout. Likewise, it is possible that streams that receive groundwater with temperatures greater than about 6°C cannot remain cool enough during the summer to sustain juvenile bull trout. Groundwater temperature may also limit bull trout distribution by affecting egg incubation. Bull trout spawn in the fall and eggs incubate over the winter (Fraley and Shepard 1989). During this time, harsh winter conditions may prevent egg incubation in many stream reaches. This may explain why fall-spawning salmonids such as bull trout (Baxter and Hauer 2000), arctic char (Craig 1978), brook trout (Witzel and MacCrimmon 1983; Curry et al. 1995), brown trout (Witzel and MacCrimmon 1983) and kokanee (Garret et al. 1998) often spawn in areas of groundwater influence. If bull trout spawn in areas of groundwater influence, then the groundwater must also meet the thermal requirements of egg incubation. It is possible that bull trout eggs cannot successfully incubate at temperatures greater than about 6°C. However, further study into both of these mechanisms is needed before any conclusions can be drawn.

While groundwater temperatures are closely associated with mean annual air temperatures, we advise caution when using mean annual air temperature to estimate the temperature of groundwater entering streams. Mean annual air temperature, or elevation and latitude, which are correlated to mean annual air temperature, can be used to estimate the temperature of groundwater entering streams (e.g., Meisner 1990). However, groundwater temperature at a depth of 3 m can vary from mean annual air temperature by as much as 6°C (Collins 1925). This amount of variation limits the degree with which mean annual air temperature, elevation, or latitude can be used to predict local groundwater temperatures.

The temperature of groundwater entering streams can vary considerably even when the springs are in close proximity to one another. The temperature of springs assessed in our study varied between 2.7 and 13.5°C. Even springs with similar elevations varied considerably (Figure 3-2). Since our study covered only 1.09° (121 km) of latitude, it is unlikely that latitude accounts for much of this variation. The variation that can occur in groundwater temperature at similar elevations and latitudes is demonstrated by a comparison of Deer Creek spring #3 and unnamed tributary spring #2. These two springs were located about 10 km apart and had differences in elevation of only 188 m and differences in latitude of only 0.5 km. Despite these springs having nearly identical elevations and latitudes, they differed in temperature by 8.3°C.

In conclusion, the temperature of groundwater entering streams appears to be an important factor influencing the distribution of juvenile bull trout. This relationship may be useful in assessing historical bull trout distribution patterns and may aid in identifying the potential effects of anthropogenic and natural processes on bull trout. The use of

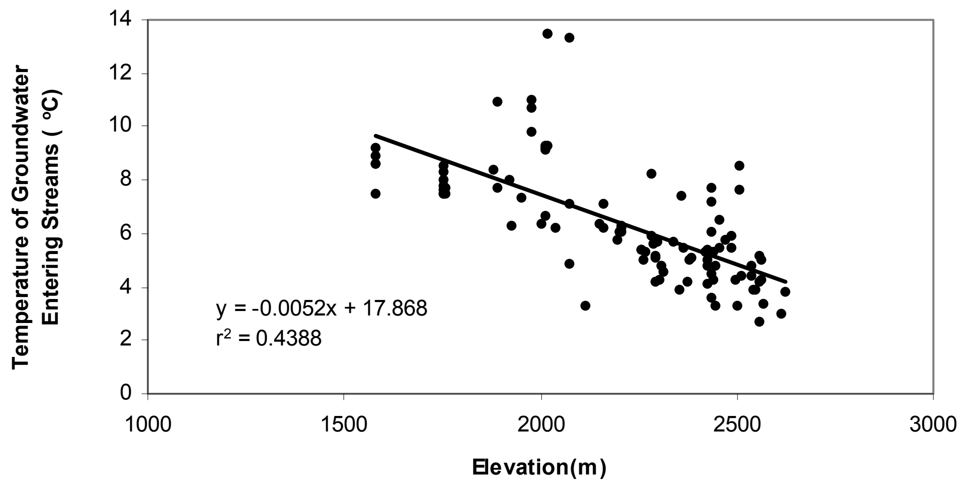

Figure 3-2 – Relationship between water temperature at the springs and elevation.

groundwater temperatures in assessing bull trout distribution may be particularly useful since these data are easy to collect and in many cases can be collected from a stream basin in just a few hours.

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CHAPTER 4

CONCLUSION

This study supports the work of others in suggesting that bull trout *Salvelinus confluentus* distribution and abundance is influenced by water temperature. Our work involving stream temperature has shown a strong relationship between summer stream temperatures and bull trout occurrence, bull trout density, and the percentage of salmonids that are bull trout. Likewise, our work involving groundwater temperature has shown a strong relationship between groundwater temperature and the occurrence of juvenile bull trout in small stream basins.

The strong relationship between water temperature and bull trout distribution and abundance suggests that successfully protecting and recovering bull trout populations will require protecting and, where appropriate, restoring water temperature regimes. Successfully managing water temperatures for bull trout will require that managers 1) thoroughly understand the relationship between water temperature and bull trout distribution and abundance, 2) understand how natural and anthropogenic factors influence water temperature, 3) understand how these factors operate across a range of spatial and temporal scales, and 4) understand how the response of bull trout to water temperature may be influenced by interspecific and intraspecific interactions.

This study should assist in that process in several ways. First, we have identified a temperature metric that effectively describes bull trout occurrence, bull trout density, and the percentage of salmonids that are bull trout. This will allow managers to more effectively monitor and manage stream temperatures for bull trout. Second, we have described how water temperature affects bull trout distribution and abundance. This understanding should help managers better protect and recover bull trout populations. Furthermore, this knowledge should help managers understand how natural and anthropogenic factors that alter water temperature regimes may affect bull trout. Subsequently, they will be able to better understand the role of past, current, and future anthropogenic and natural influences on bull trout populations. Finally, we have begun exploring how various factors such as competition and naturally warm stream temperatures may influence bull trout populations. These mechanisms may have an important influence on many bull trout populations and should prove to be fruitful avenues for future research.

APPENDICES

Appendix A

Summary of Habitat, Water Temperature, and

Fish Population Characteristics at the Study Sites

Table A-1. Habitat characteristics observed at study sites. Habitat characteristics were collected on the sampling date.

Site Name	Length (m)	Mean Width (m)	Mean Depth (m)	Max. Depth (m)	Surface Area (m^2)	Volume (m^3)	Air Temp. (°C)	Water Temp. (°C)	Cond. (μS)	pH	Elev. (m)
Badger Creek #1	101	2.3	0.2	0.5	231	36	22.6	8.5	220	8.8	1936
Badger Creek #2	100	2.4	0.2	0.5	242	45	14.8	6.8	240	8.7	2077
Badger Creek #3	104	1.3	0.2	0.6	136	27	28.5	7.7	180	8.4	2195
Bear Creek	112	2.3	0.1	0.4	251	19	27.4	17.5	60	8.2	2121
Big Creek	92	2.5	0.2	0.4	230	42	23.6	12.3	190	8.5	2249
Big Springs Creek	90	4.2	0.2	0.8	381	89	24.6	12.3	260	8.7	1635
Deer Creek #1	108	1.2	0.2	0.5	128	19	23.7	13.7	310	8.5	1808
Deer Creek #2	104	1.5	0.1	0.4	151	18	24.1	15.7	270	8.5	1951
Fallert Springs Creek	81	5.8	0.2	0.6	463	97	16.5	11.6	320	8.3	1554
Firebox Creek	102	2.6	0.1	0.4	262	29	23.4	11.3	10	8.2	2499
Iron Creek, Left Fork	109	2.4	0.1	0.5	256	25	24.3	7.7	30	8.3	2323
Jackson Creek	89	2.0	0.1	0.5	180	17	22	6.1	20	8.6	2256
Little Lost River #1	104	6.5	0.2	1.2	674	159	11	7.1	110	8.7	1946
Little Lost River #2	92	9.8	0.2	1.3	900	195	13.6	10.8	70	8.2	2026
Little Lost River #3	153	7.5	0.2	1.3	1153	276	28.8	6.6	60	8.4	2090
Little Lost River #4	132	7.8	0.2	0.7	1034	242	10.6	7.9	60	8.9	2124
Little Lost River #5	88	9.2	0.2	0.5	809	157	15.3	11	40	8.2	2170
Little Lost River #6	102	10.1	0.2	0.7	1029	206	10.8	11.3	30	8.4	2316
Little Lost River #7	96	3.4	0.2	0.6	323	64	22.2	10.5	10	8.5	2439
Little Lost River, Right Fork	101	1.4	0.1	0.4	140	10	11	7.3	10	8.9	2522
Mill Creek #1	96	5.0	0.1	0.4	475	46	16.1	9	30	8.6	2107
Mill Creek #2	34	3.3	0.2	0.9	112	17	9.7	7.6	10	8.7	2427
Smithie Fork	95	2.9	0.2	0.6	341	52	24.9	14.1	20	8.3	2438
Squaw Creek #1[1]	103	3.0	0.1	0.4	306	39	25.7	9.7	130	8.4	2130
Squaw Creek #2[1]	102	2.1	0.1	0.6	215	32	12.7	7.5	160	n/a	2376
Squaw Creek #3[1]	98	1.3	0.1	0.4	129	13	7.5	5	220	8.7	2223
Squaw Creek #1[2]	100	1.7	0.2	0.5	173	35	16.7	9.7	280	8.2	1986
Squaw Creek #2[2]	96	2.8	0.2	0.7	268	56	20.6	13.3	360	8.2	2195
Squaw Creek, North Fork	114	3.0	0.1	0.5	339	37	22.5	7.1	90	8.5	2408
Summit Creek #1	83	2.0	0.2	0.7	167	36	23.8	19.4	290	9.1	1851
Summit Creek #2	102	3.7	0.2	0.5	407	113	22.2	14.5	270	8.5	1919
Summit Creek #3	130	3.9	0.2	0.5	507	83	23.3	19.3	230	9.0	1951
Timber Creek	84	2.6	0.1	0.4	215	24	3.6	5.1	140	8.5	2387
Warm Creek	85	2.7	0.2	0.5	232	40	25.8	7.5	110	8.4	2115
Wet Creek #1	106	4.7	0.3	1.2	500	155	20.9	12.4	220	9.0	1843
Wet Creek #2	99	4.7	0.2	0.6	463	91	26.1	10.6	240	9.0	1934
Wet Creek #3	93	3.2	0.3	1.0	298	75	24.8	13.1	230	8.5	1983
Wet Creek #4	120	2.7	0.2	0.8	325	60	22.1	15.2	240	8.4	2137
Wet Creek #5	100	2.6	0.2	0.5	256	47	23.1	13.1	200	8.5	2190

[1] Located in the Sawmill Canyon drainage.
[2] Located in the Wet Creek drainage.

Table A-2. Stream temperature metrics observed at study sites. See text for definitions of each metric.

Site Name	Temperature Metric MAX	MIN	RNG	MEAN	MOV	MMAX	MMIN	MMOV
Badger Creek #1	12.7	3.1	9.6	8.2	12.1	10.7	6.5	10.7
Badger Creek #2	10.4	4.0	6.4	7.2	10.0	9.1	6.1	9.1
Badger Creek #3	8.6	5.8	2.8	7.0	8.3	7.9	6.6	7.9
Bear Creek	19.6	-0.1	19.7	10.4	18.2	15.2	6.8	15.2
Big Creek	14.8	3.3	11.5	8.7	14.1	12.3	6.2	12.3
Big Springs Creek	19.1	2.5	16.5	11.6	17.9	15.0	8.2	15.0
Deer Creek #1	18.4	4.1	14.4	12.7	17.4	14.9	10.4	14.9
Deer Creek #2	17.3	8.2	9.0	13.2	16.8	15.2	11.7	15.2
Fallert Springs Creek	21.9	3.0	18.9	14.2	20.5	17.0	11.4	17.0
Firebox Creek	13.7	-0.1	13.9	7.1	12.9	10.9	4.4	10.9
Iron Creek, Left Fork	10.4	-0.1	10.5	6.1	9.6	7.6	4.7	7.6
Jackson Creek	8.1	0.0	8.2	5.2	7.8	6.2	4.2	6.2
Little Lost River #1	20.7	-0.1	20.8	11.8	19.2	16.4	7.8	16.4
Little Lost River #2	20.0	-0.1	20.1	11.0	18.0	15.4	7.2	15.4
Little Lost River #3	19.1	0.0	19.1	10.3	17.5	14.6	7.0	14.6
Little Lost River #4	17.3	0.0	17.3	9.7	16.2	13.4	6.6	13.4
Little Lost River #5	15.9	-0.1	15.9	9.3	14.7	12.4	6.6	12.4
Little Lost River #6	14.9	-0.1	15.0	8.6	13.8	11.9	5.7	11.9
Little Lost River #7	14.7	0.2	14.5	7.7	13.5	11.6	4.9	11.6
Little Lost River, Right Fork	16.3	0.1	16.2	7.6	14.6	12.4	4.8	12.3
Mill Creek #1	16.9	0.0	17.0	9.3	15.8	13.1	6.6	13.1
Mill Creek #2	10.0	4.9	5.1	7.3	9.8	8.5	6.7	8.5
Smithie Fork	14.7	0.7	14.0	8.6	13.6	11.8	6.0	11.8
Squaw Creek #1[1]	15.2	0.8	14.5	8.6	14.1	11.8	6.2	11.8
Squaw Creek #2[1]	11.2	3.0	8.2	7.5	10.5	9.4	6.2	9.4
Squaw Creek #3[1]	8.8	2.2	6.6	5.7	8.3	7.3	4.7	7.3
Squaw Creek #1[2]	18.2	2.7	15.5	10.6	17.5	14.9	7.5	14.8
Squaw Creek #2[2]	19.2	1.2	18.0	11.3	18.3	14.9	8.0	14.9
Squaw Creek, North Fork	8.5	3.1	5.3	5.6	8.1	7.0	5.0	7.0
Summit Creek #1	25.9	0.4	25.5	14.6	24.1	19.1	10.5	19.1
Summit Creek #2	23.8	1.6	22.2	13.7	21.7	17.0	10.4	17.0
Summit Creek #3	22.6	4.0	18.6	12.5	21.3	17.8	8.4	17.8
Timber Creek	12.5	0.0	12.5	6.7	11.3	9.2	4.7	9.2
Warm Creek	8.1	4.2	3.9	6.3	8.0	7.4	5.7	7.4
Wet Creek #1	16.7	1.9	14.8	10.7	15.9	13.4	8.0	13.4
Wet Creek #2	19.8	0.2	19.6	11.9	18.4	15.7	8.4	15.7
Wet Creek #3	19.0	0.1	18.9	11.4	17.8	15.0	7.7	15.0
Wet Creek #4	18.4	0.1	18.3	9.9	17.2	14.2	6.1	14.2
Wet Creek #5	15.4	0.8	14.6	8.0	14.4	12.7	5.2	12.7

[1] Located in the Sawmill Canyon drainage.
[2] Located in the Wet Creek drainage.

Table A-2 (continued). Stream temperature metrics observed at study sites. See text for definitions of each metric.

Site Name	Temperature Metric									
	PG5	PG10	PG15	PG20	DMOV 10	DMOV 15	DMOV 20	DMAX 10	DMAX 15	DMAX 20
Badger Creek #1	97	18	0	0	61	0	0	66	0	0
Badger Creek #2	98	1	0	0	0	0	0	11	0	0
Badger Creek #3	100	0	0	0	0	0	0	0	0	0
Bear Creek	93	53	11	0	87	54	0	88	48	0
Big Creek	98	29	0	0	85	0	0	85	0	0
Big Springs Creek	98	67	18	0	87	58	0	88	58	0
Deer Creek #1	99	85	21	0	88	57	0	88	55	0
Deer Creek #2	100	98	16	0	92	59	0	92	58	0
Fallert Springs Creek	99	87	41	2	89	61	5	88	61	10
Firebox Creek	77	17	0	0	59	0	0	65	0	0
Iron Creek, Left Fork	70	0	0	0	0	0	0	1	0	0
Jackson Creek	63	0	0	0	0	0	0	0	0	0
Little Lost River #1	96	68	23	1	89	66	0	88	70	6
Little Lost River #2	95	60	16	0	88	54	0	88	54	1
Little Lost River #3	94	54	10	0	87	50	0	86	41	0
Little Lost River #4	93	46	4	0	85	26	0	84	29	0
Little Lost River #5	93	43	1	0	84	0	0	82	10	0
Little Lost River #6	89	32	0	0	83	0	0	79	0	0
Little Lost River #7	84	23	0	0	83	0	0	82	0	0
Little Lost River, Right Fork	81	24	0	0	86	0	0	85	5	0
Mill Creek #1	94	41	2	0	86	7	0	84	15	0
Mill Creek #2	100	0	0	0	0	0	0	2	0	0
Smithie Fork	93	31	0	0	84	0	0	82	0	0
Squaw Creek #1[1]	94	28	0	0	81	0	0	78	1	0
Squaw Creek #2[1]	96	4	0	0	25	0	0	33	0	0
Squaw Creek #3[1]	75	0	0	0	0	0	0	0	0	0
Squaw Creek #1[2]	98	52	10	0	92	55	0	90	49	0
Squaw Creek #2[2]	97	65	15	0	86	56	0	86	52	0
Squaw Creek, North Fork	78	0	0	0	0	0	0	0	0	0
Summit Creek #1	97	84	49	13	91	83	53	88	82	49
Summit Creek #2	98	83	39	3	88	61	12	87	61	16
Summit Creek #3	99	70	27	2	92	85	12	92	81	18
Timber Creek	77	8	0	0	49	0	0	39	0	0
Warm Creek	98	0	0	0	0	0	0	0	0	0
Wet Creek #1	98	59	4	0	85	26	0	85	27	0
Wet Creek #2	97	71	21	0	88	61	0	85	62	0
Wet Creek #3	97	65	17	0	87	58	0	85	56	0
Wet Creek #4	93	45	9	0	86	50	0	86	42	0
Wet Creek #5	87	27	0	0	85	0	0	86	2	0

[1] Located in the Sawmill Canyon drainage.
[2] Located in the Wet Creek drainage.

Table A-3. Fish population metrics observed at study sites. RB=rainbow trout, BK=brook trout, BL=bull trout.

Site Name	Date Sampled	Occurrence			Composition (%)			Density (fish/100 m^2)		
		RB	BK	BL	RB	BK	BL	RB	BK	BL
Badger Creek #1	08/19/99	yes	no	yes	89	0	11	7.4	0.0	0.9
Badger Creek #2	08/26/99	yes	no	yes	33	0	67	2.9	0.0	5.8
Badger Creek #3	08/26/99	yes	no	yes	96	0	4	18.4	0.0	0.7
Bear Creek	08/17/99	yes	no	no	100	0	0	16.7	0.0	0.0
Big Creek	08/10/99	yes	no	yes	83	0	17	2.2	0.0	0.4
Big Springs Creek	08/12/99	yes	yes	no	68	32	0	4.5	2.1	0.0
Deer Creek #1	08/07/99	yes	no	no	100	0	0	3.1	0.0	0.0
Deer Creek #2	08/07/99	yes	no	no	100	0	0	24.5	0.0	0.0
Fallert Springs Creek	08/12/99	no	yes	no	0	100	0	0.0	0.2	0.0
Firebox Creek	08/24/99	no	no	yes	0	0	100	0.0	0.0	30.5
Iron Creek, Left Fork	08/18/99	no	no	yes	0	0	100	0.0	0.0	8.2
Jackson Creek	08/23/99	no	no	yes	0	0	100	0.0	0.0	0.6
Little Lost River #1	09/01/99	yes	yes	no	96	4	0	3.7	0.1	0.0
Little Lost River #2	09/01/99	yes	no	yes	94	0	6	8.0	0.0	0.6
Little Lost River #3	08/23/99	yes	yes	yes	76	10	15	8.1	1.0	1.6
Little Lost River #4	08/31/99	yes	yes	yes	70	11	19	7.6	1.2	2.1
Little Lost River #5	08/11/99	yes	no	yes	36	0	64	1.9	0.0	3.3
Little Lost River #6	08/31/99	yes	no	yes	6	0	94	1.7	0.0	27.1
Little Lost River #7	08/05/99	yes	no	yes	2	0	98	0.6	0.0	39.6
Little Lost River, Right Fork	08/24/99	no	no	yes	0	0	100	0.0	0.0	6.4
Mill Creek #1	09/02/99	yes	yes	yes	37	60	2	7.2	11.6	0.4
Mill Creek #2	08/25/99	no	no	yes	0	0	100	0.0	0.0	17.0
Smithie Fork	07/30/99	no	no	yes	0	0	100	0.0	0.0	29.2
Squaw Creek #1[1]	07/30/99	yes	yes	yes	44	22	33	1.3	0.7	1.0
Squaw Creek #2[1]	08/11/99	yes	yes	yes	30	39	30	4.6	6.0	4.6
Squaw Creek #3[1]	08/18/99	no	no	yes	0	0	100	0.0	0.0	14.0
Squaw Creek #1[2]	08/06/99	yes	no	no	100	0	0	9.3	0.0	0.0
Squaw Creek #2[2]	08/14/99	yes	no	no	100	0	0	41.1	0.0	0.0
Squaw Creek, North Fork	08/27/99	no	no	yes	0	0	100	0.0	0.0	5.6
Summit Creek #1	08/19/99	yes	yes	no	75	25	0	1.8	0.6	0.0
Summit Creek #2	07/31/99	yes	no	no	100	0	0	4.8	0.0	0.0
Summit Creek #3	07/31/99	yes	yes	no	67	33	0	7.5	3.7	0.0
Timber Creek	08/17/99	no	no	yes	0	0	100	0.0	0.0	27.5
Warm Creek	08/18/99	no	no	yes	0	0	100	0.0	0.0	5.6
Wet Creek #1	08/30/99	yes	no	yes	97	0	3	6.0	0.0	0.2
Wet Creek #2	08/30/99	yes	no	yes	97	0	3	6.5	0.0	0.2
Wet Creek #3	08/06/99	yes	no	no	100	0	0	5.7	0.0	0.0
Wet Creek #4	08/06/99	yes	no	yes	82	0	18	2.8	0.0	0.6
Wet Creek #5	08/06/99	yes	no	yes	62	0	38	3.1	0.0	2.0

[1] Located in the Sawmill Canyon drainage.
[2] Located in the Wet Creek drainage.

Appendix B

Variables Used with the SSTEMP Model

Table B-1. Variables used with the SSTEMP stream temperature model.

	Assessment	
Input Variable	Stream Shading	Water Withdrawal
Segment Inflow (m^3/s)	0.3	0.3 and 0.03
Inflow Temperature (°C)	8.0	8.0
Segment Outflow (m^3/s)	0.3	0.3 and 0.03
Accretion Temperature (°C)	5.0	5.0
Latitude (°)	44.0	44.0
Segment Length (km)	10.0	10.0
Upstream Elevation (m)	2,400	2,400
Downstream Elevation (m)	2,300	2,300
Stream Gradient (%)	1	1
Width's A Term (s/m^2)	3.181	3.181
B Term	0.2	0.2
Mean Width (m)	2.5	2.5 and 1.6[1]
Mean Depth (m)	0.15	0.15 and 0.05[1]
Manning's n	0.035	0.035
Air Temperature (°C)	15.0	15.0
Relative Humidity (%)	45	45
Wind Speed (m/s)	0	0
Ground Temperature (°C)	5.0	5.0
Thermal Gradient (j/m^2/s/C)	1.650	1.650
Possible Sun (%)	90	90
Dust Coefficient	7.0	7.0
Ground Reflectivity (%)	15	15
Total Shade (%)	10 and 90	50
Date	August 1	August 1

[1] The model automatically adjusts this variable when discharge is modified.

Appendix C

Description of Stream Basins

Table C-1. Description of stream basins used in the study.

River Basin	Stream Name	Description	Juvenile Bull Trout Occurrence	Approximate Length of Stream Occupied by Salmonids (km)
Little Lost	Fallert Springs Creek	upstream of the Little Lost River	Absent	6
	Big Springs Creek	source springs downstream 10 km	Absent	7
	Coal Creek	upstream of Wet Creek	Absent	1
	Deer Creek	upstream of the National Forest boundary	Absent	4
	Wet Creek (unnamed tributary)	upstream of Wet Creek	Absent	2
	Summit Creek	upstream of Summit Creek Campground	Absent	3
	North Fork Squaw Springs	upstream of Squaw Creek	Absent	1
	Squaw Creek	upstream of North Fork Squaw Creek	Present	3
	Right Fork Little Lost River	upstream of Little Lost River	Present	1
	Warm Creek	upstream of Little Lost River	Present	3
	Timber Creek	upstream of Slide Creek	Present	1
	Wet Creek	upstream of Hilts Creek	Present	2
	Williams Creek	upstream of National Forest boundary	Present	2
	Hawley Creek	upstream of Iron Creek	Present	2
Salmon	Wildcat Creek	upstream of Cruikshank Creek	Absent	3
	Bog Creek	upstream of Big Bear Creek	Absent	1
	Ford Creek	upstream of Bear Valley Creel	Absent	2
	Flume Creek	upstream of Agency Creek	Absent	2
	Trealor Creek	upstream of Squaw Creek	Absent	4
	Peach Creek	upstream of private land	Absent	10
	Short Creek	upstream of Basin Creek	Absent	2
	Muley Creek	upstream of Salmon River	Absent	6
	Big Bear Creek	upstream of Wheetip Creek	Present	5
	Kadletz Creek	upstream of Bear Valley Creek	Present	6
	Twelvemile Creek	upstream of National Forest boundary	Present	8
	Big Gulch Creek	upstream of National Forest boundary	Present	3
	Burnt Creek	source springs downstream 2 km	Present	2
	Mahogany Creek	upstream of Pahsimeroi River	Present	5
	McKay Creek	upstream of Forest Service Trail #151	Present	2
	North Fork Iron Creek	upstream of Iron Creek	Present	8

Appendix D

Summary of Sampling Data Used to

Assess Juvenile Bull Trout Occurrence

Table D-1. Summary of sampling data used to classify stream basins in the Little Lost River basin as juvenile bull trout absent.

Stream	Site Location	Date Sampled	Sampling Method[1]	Length Sampled (m)	Data Source[2]
Fallert Springs Creek	4 km above Little Lost River	Sep-93	e-fish 1	139	Gamett (1999)
	4 km above Little Lost River	Aug-87	e-fish 2[3]	139	Corsi and Elle (1989)
	1.5 km above Little Lost River	Aug-99	e-fish 2	81	SCNF
Big Springs Creek	800 m above Road #582	Sep-93	e-fish 2	117	Gamett (1999)
	800 m above Road #582	Aug-87	e-fish 2[3]	44	Corsi and Elle (1989)
	Upstream of site located 800 m above Road #582	Aug-87	e-fish 2[3]	118	Corsi and Elle (1989)
Coal Creek	near source springs	Jul-95	e-fish 2	52	Gamett (1999)
	30 m above Wet Creek	Sep-99	e-fish 1	140	SCNF
Deer Creek	at National Forest boundary	Jun-95	e-fish 3	55	Gamett (1999)
	240 m above National Forest boundary	Aug-99	e-fish 3	104	SCNF
	North Fork, 200 m above South Fork	Jun-95	e-fish 4	30	Gamett (1999)
	South Fork, 500 m abve North Fork	Jun-95	e-fish 2	56	Gamett (1999)
Wet Creek (unnamed tributary)	100 m above Wet Creek	Sep-95	e-fish 1	34	Gamett (1999)
	600 m above Wet Creek	Jul-97	e-fish-1	91	Gamett (1999)
	1 km above Wet Creek	Oct-99	e-fish 1	75	SCNF
Summit Creek	100 m below Iron Springs	Jun-97	e-fish 1	59	Gamett (1999)
	Iron Springs	Jun-97	e-fish 1	170	Gamett (1999)
	immediately above Summit Creek Campground	Jul-99	e-fish 5	130	SCNF
North Fork Squaw Springs	500 m above Squaw Creek	Oct-99	e-fish 1	53	SCNF
	300 m above Squaw Creek	Oct-99	e-fish 1	87	SCNF

[1] E-fish indicates electrofishing where the number indicates the number of passes completed.
[2] SCNF: Salmon-Challis National Forest, unpublished data.
[3] The number of passes was not provided for these sites but at least two passes were completed.

Table D-2. Summary of sampling data used to classify stream basins in the Salmon River basin as juvenile bull trout absent.

Stream	Site Location	Date Sampled	Sampling Method[1]	Length Sampled (m)	Data Source[2]
Wildcat Creek	1.5 km above Cruikshank Creek	Jun-99	e-fish 2	58	SRIDFG
	2.5 km above Cruikshank Creek	Jun-99	e-fish 2	51	SRIDFG
Bog Creek	immediately above Big Bear Creek	Aug-99	e-fish 1	100	SRIDFG
Ford Creek	near mouth	Aug-98	e-fish 1	100	SRIDFG
	below Payne Creek Road	Aug-98	e-fish 1	100	SRIDFG
Flume Creek	above private fence	Jul-97	e-fish 2	36	SRIDFG
	National Forest boundary	Jul-98	angling	500	SDBLM
Trealor Creek	above Squaw Creek	Jul-98	e-fish 1	80	SCNF
	1.5 km above Squaw Creek	Jul-98	e-fish 2	70	SCNF
	3.5 km above Squaw Creek	Jul-98	e-fish 1	70	SCNF
Peach Creek	200 m above private land	Sep-98	e-fish 1	100	IDEQ
	1.5 km above Salmon River	Jul-98	e-fish 2	90	SCNF
	3 km above Salmon River	Jul-98	e-fish 2	120	SCNF
	6 km above Salmon River	Jul-98	e-fish 2	98	SCNF
Short Creek	lower section	Aug-98	e-fish 2	60	SRIDFG
	upper section	Aug-98	e-fish 2	60	SRIDFG
Muley Creek	1 km above Salmon River	Jul-98	e-fish 2	70	SCNF
	2 km above Salmon River	Jul-98	e-fish 2	70	SCNF
	upper reach of stream	Jul-98	e-fish 1	70	SCNF

[1] E-fish indicates electrofishing where the number indicates the number of passes completed.
[2] SRIDFG: Salmon Region Idaho Department of Fish and Game, unpublished data,, SDBLM: Salmon District Bureau of Land Management, unpublished data, SCNF: Salmon-Challis National Forest, unpublished data, IDEQ: Idaho Department of Environmental Quality, unpublished data.

Table D-3. Summary of sampling data used to classify stream basins in the Little Lost River basin as juvenile bull trout present.

Stream	Site Location	Date Sampled	Sampling Method[1]	Length Sampled (m)	Data Source[2]
Squaw Creek	900 m above North Fork Squaw Creek	Aug-96	e-fish 1	50	Gamett (1999)
Right Fork Little Lost River	500 m above Little Lost River	Aug-99	e-fish 2	101	SCNF
Warm Creek	mouth of canyon	Aug-99	e-fish 3	85	SCNF
Timber Creek	above Slide Creek	Aug-99	e-fish 3	97	SCNF
Wet Creek	800 m above Hilts Creek	Jun-96	e-fish 3	138	Gamett (1999)
Williams Creek	1.6 km above Forest Service boundary	Jun-95	e-fish 3	49	Gamett (1999)
Hawley Creek	above Iron Creek Road	Sep-95	e-fish 1	47	Gamett (1999)

[1] E-fish indicates electrofishing where the number indicates the number of passes completed.
[2] SCNF: Salmon-Challis National Forest, unpublished data.

Table D-4. Summary of sampling data used to classify stream basins in the Salmon River basin as juvenile bull trout present.

Stream	Site Location	Date Sampled	Sampling Method[1]	Length Sampled (m)	Data Source[2]
Big Bear Creek	above Wheetip Creek	Aug-99	e-fish 1	100	SRIDFG
Kadletz Creek	at Bear Valley Creek Road	Aug-98	e-fish 1	n/a	SRIDFG
Twelvemile Creek	multiple sites	Aug-92	snorkel	392	SCNF
Big Gulch Creek	above Forest Service boundary	Jun-94	e-fish 1	400	CDBLM
Burnt Creek	1 km below source springs	Jun-94	e-fish 1	n/a	CDBLM
Mahogany Creek	2 km above Pahsimeroi River	Jun-90	e-fish 2	90	Schrader and Lukens (1992)
McKay Creek	above Forest Service Trail #151	Jul-99	e-fish 1	100	IDEQ
North Fork Iron Creek	multiple sites	Jul-92	snorkel	433	SCNF

[1] E-fish indicates electrofishing where the number indicates the number of passes completed.
[2] SRIDFG: Salmon Region Idaho Department of Fish and Game, unpublished data, SDBLM: Salmon District Bureau of Land Management, unpublished data, CDBLM: Challis District Bureau of Land Management, unpublished data, SCNF: Salmon-Challis National Forest, unpublished data, IDEQ: Idaho Department of Environmental Quality, unpublished data.

Appendix E

Summary of Groundwater Temperature Data

Table E-1. Summary of groundwater temperature data collected in the Little Lost River basin.

Stream	Juvenile Bull Trout Occurrence	Spring Number	Latitude	Longitude	Elevation (m)	Temperature (˚C)
Squaw Creek	Present	1	44.3592	-113.3150	2313	4.6
		2	44.3592	-113.3190	2280	5.9
		3	44.3715	-113.3088	2438	4.3
Right Fork Little Lost River	Present	1	44.4471	-113.3717	2557	5.2
		2	44.4476	-113.3714	2558	4.2
		3	44.4485	-113.3704	2561	5
		4	44.4485	-113.3704	2562	4.3
		5	44.4497	-113.3684	2615	3
		6	44.4497	-113.3684	2625	3.8
Warm Creek	Present	1	44.3127	-113.2908	2377	5
		2	44.313	-113.2903	2384	5.1
Timber Creek	Present	1	44.4378	-113.4358	2457	5.5
		2	44.4442	-113.4434	2566	3.4
Wet Creek	Present	1	44.0248	-113.4863	2365	5.5
		2	44.0267	-113.4750	2292	5.1
		3	44.027	-113.4757	2292	5.2
Williams Creek	Present	1	44.1302	-113.1735	2207	6.1
		2	44.1302	-113.1735	2207	6.3
		3	44.1302	-113.1735	2207	6.2
Hawley Creek	Present	1	44.3677	-113.4272	2423	5.4
		2	44.3678	-113.4268	2419	5.3
Fallert Creek	Absent	1	43.9248	-113.1298	1579	9.2
		2	43.9248	-113.1298	1579	8.9
		3	43.929	-113.1316	1581	8.6
		4	43.929	-113.1316	1581	8.6
Big Springs Creek	Absent	1	44.054	-113.2181	1757	7.7
		2	44.054	-113.2181	1757	7.5
		3	44.0529	-113.2184	1754	7.5
		4	44.0525	-113.2184	1752	8
		5	44.0525	-113.2184	1752	7.8
		6	44.0525	-113.2184	1752	7.6
		7	44.0532	-113.2177	1756	7.5
		8	44.0515	-113.2156	1754	8.3
		9	44.0515	-113.2156	1754	8.5
Coal Creek	Absent	1	44.0473	-113.4593	2337	5.7
		2	44.0462	-113.4618	2360	7.4
Deer Creek	Absent	1	44.0437	-113.3385	2017	13.5
		2	44.0437	-113.3385	2017	13.5
		3	44.039	-113.3427	2074	13.3
Wet Creek (unnamed tributary)	Absent	1	44.0345	-113.4380	2259	5.4
		2	44.0342	-113.4381	2262	5
		3	44.0338	-113.4465	2268	5.3
		4	44.0327	-113.4437	2297	5.7
Summit Creek	Absent	1	44.2807	-113.4847	1975	9.8
		2	44.2807	-113.4847	1975	10.7
		3	44.28	-113.4843	1975	11
North Fork Squaw Springs	Absent	1	44.1254	-113.3965	2014	9.3
		2	44.1241	-113.3968	2012	9.2
		3	44.1242	-113.3968	2017	9.3
		4	44.1245	-113.3974	2013	9.1

Table E-2. Summary of groundwater temperature data collected in the Salmon River basin.

Stream	Juvenile Bull Trout Occurrence	Spring Number	Latitude	Longitude	Elevation (m)	Temperature (˚C)
Big Bear Creek	Present	1	44.6373	-113.0739	2437	4.5
		2	44.6387	-113.0622	2536	4.4
Kadletz Creek	Present	1	44.773	-113.7433	1951	7.3
		2	44.7503	-113.7948	2446	4.8
		3	44.7472	-113.8039	2559	2.7
		4	44.7438	-113.8064	2549	3.9
Twelvemile Creek	Present	1	45.0065	-113.8800	1579	7.5
		2	44.9437	-113.8476	2036	6.2
		3	44.9407	-113.8571	2115	3.3
Big Gulch Creek	Present	1	44.3505	-113.4757	2435	7.2
		2	44.3505	-113.4770	2426	4.8
		3	44.3533	-113.4767	2426	5
		4	44.358	-113.4790	2484	5.9
		5	44.3582	-113.4797	2484	5.5
Burnt Creek	Present	1	44.15	-113.6330	2437	6.1
		2	44.1517	-113.6260	2507	7.6
		3	44.1517	-113.6260	2507	8.5
		4	44.1512	-113.6316	2434	7.7
Mahogany Creek	Present	1	44.1828	-113.7542	2502	3.3
		2	44.1817	-113.7563	2512	4.4
		3	44.1785	-113.7642	2542	3.9
		4	44.1618	-113.7627	2536	4.8
McKay Creek	Present	1	44.4842	-114.5223	2437	3.6
		2	44.4871	-114.5212	2444	3.3
		3	44.4894	-114.5211	2495	4.3
North Fork Iron Creek	Present	1	44.9775	-114.0980	2292	4.2
		2	44.9772	-114.0947	2353	3.9
		3	44.935	-114.1077	1926	6.3
Wildcat Creek	Absent	1	44.7372	-113.2040	2310	4.8
		2	44.7368	-113.1972	2304	4.3
		3	44.7377	-113.1909	2376	4.2
Bog Creek	Absent	1	44.6725	-113.1068	2258	5.4
		2	44.6787	-113.1047	2287	5.6
		3	44.6876	-113.0949	2439	5.3
Ford Creek	Absent	1	44.76	-113.7426	2073	4.9
		2	44.7645	-113.7384	2014	6.7
		3	44.7657	-113.7367	2004	6.4
		4	44.7708	-113.7289	1890	7.7
Flume Creek	Absent	1	44.9848	-113.4864	1919	8
		4	44.9839	-113.5025	1878	8.4
		5	44.9865	-113.5040	1889	10.9
Trealor Creek	Absent	1	44.3868	-114.4695	2158	6.2
		2	44.3856	-114.4818	2073	7.1
Peach Creek	Absent	1	44.2876	-114.6466	2149	6.4
		2	44.2975	-114.6526	2161	7.1
		3	44.2773	-114.6439	2283	8.2
Short Creek	Absent	1	44.3062	-114.8607	2197	5.8
		2	44.3062	-114.8607	2202	6.1
Muley Creek	Absent	1	44.2845	-114.6769	2423	4.1
		2	44.2924	-114.6774	2456	6.5
		3	44.293	-114.6780	2472	5.8