Models to Predict Suitable Habitat for Juvenile Bull Trout in Washington State - Final Report

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WASHINGTON STATE DEPARTMENT OF
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Doug Sutherland - Commissioner of Public Lands

Cooperative Monitoring
Evaluation & Research
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Forest Practices Adaptive Management Program

The Washington Forest Practices Board (FPB) has adopted an adaptive management program in concurrence with the Forests and Fish Report (FFR) and subsequent legislation. The purpose of this program is to:

> Provide science-based recommendations and technical information to assist the board in determining if and when it is necessary or advisable to adjust rules and guidance for aquatic resources to achieve resource goals and objectives. (Forest Practices Rules, WAC 222-12-045)

To provide the science needed to support adaptive management, the FPB made the Cooperative Monitoring, Evaluation and Research Committee (CMER) a participant in the program. The FPB empowered CMER to conduct research, effectiveness monitoring, and validation monitoring in accordance with guidelines recommended in the FFR.

Disclaimer

This report was prepared for the Cooperative Monitoring, Evaluation and Research Committee (CMER) as part of the Bull Trout Habitat Identification Program (see CMER FY07 Work Plan at http://www.dnr.wa.gov/forestpractices/adaptivemanagement/) and was conducted with the oversight of the Bull Trout Scientific Advisory Group (BTSAG). This report provided valuable information toward understanding how to determine suitable or unsuitable habitat for bull trout. This report was not assessed through the Adaptive Management Program's independent scientific peer review process. Conclusions, interpretations, or recommendations contained within this document are those of the authors and may not reflect the views of CMER and members of the Washington Adaptive Management Program.

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Final Report

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Introduction

This report describes results of research conducted in 2000 to develop models of suitable habitat for juvenile bull trout (*Salvelinus confluentus*) in Washington State. The research is associated with a cooperative agreement (Agreement #134100H001) between U.S. Fish and Wildlife Service (USFWS) and the U.S. Forest Service, Rocky Mountain Research Station (RMRS). The basic objective for the project is to define characteristics of suitable habitat supporting young juvenile and resident bull trout. This information will be used for the purpose of improving management and recovery of this threatened species.

Scope of the study.

Focus on young juveniles and resident bull trout. Bull trout exhibit a broad array of life history strategies (Rieman and McIntyre 1993), including resident, fluvial, adfluvial, and anadromous migratory life histories. Our focus is on young juvenile and resident bull trout. Presumably, the distribution of these life stages or forms represents the distribution of key habitats used for spawning and early rearing (Dunham et al., in press). These habitats are absolutely essential for population persistence. They are also used on a year-round basis by bull trout, so habitat conditions must be suitable at all times. Other life history strategies may be tied to habitats that are not necessarily suitable in all seasons or years, but they are likely important for population dynamics and persistence (Rieman and Dunham 2000).

Focus on contemporary habitat. Another limitation in the scope of our study is a focus on currently suitable habitat. We do not address the issue of historical or potential future habitat conditions (e.g., Bisson et al. 1997). These issues will have to be addressed to fully implement recovery of bull trout.

Focus on downstream distribution limits. Our experience in working with habitat relationships based on density or biomass of salmonids indicates predictive models of fish densities are difficult to develop (e.g., Fausch et al. 1988). In addition to important biological considerations (van Horne 1983), fish densities are difficult to estimate because sampling efficiency can be low and variable, especially for bull trout (Peterson et al. 2001). In contrast, occurrence is easier (though still challenging) to determine, and often produces very useful indications of habitat relationships, especially at larger scales (e.g., Rieman and McIntyre 1995; Dunham et al. 1997; Kruse et al. 1997; Dunham and Rieman 1999; Dunham et al. 1999). For this study, we are interested in patterns of occurrence within streams known to be occupied by bull trout. In particular, we focus on developing models to predict the downstream limits to occurrence of bull trout. Models of distribution limits are the foundation for defining habitat structure and landscape models of species occurrence (Dunham et al., in press).

Study objectives

Habitat models. Our primary objective is to develop a predictive model of suitable habitat used by young juvenile and resident bull trout. There are a variety of habitat characteristics believed to be important for bull trout. Within streams, it is often believed that bull trout select larger habitats (e.g., > 2 m in width) with low levels of fine sediment, cooler temperatures, and higher levels of shade, large wood, and undercut banks, and deeper water (Pratt 1992; Rieman and McIntyre 1993; Rieman and McIntyre 1995; Rich 1996; Dambacher and Jones 1997; Watson and Hillman 1997; Dunham and Rieman 1999; Zurstadt 2000). Other nonnative (e.g., brook trout *Salvelinus fontinalis*) and native salmonids (e.g., rainbow *Oncorhynchus mykiss* and cutthroat *Oncorhychus clarki* trout) may also affect use of habitats by bull trout (Rieman and McIntyre 1993; Rich 1996; Haas, in press).

In this study, we modeled the distribution of young juvenile and resident bull trout in relation to maximum summer water temperatures, occurrence of native and nonnative salmonids, large wood, undercut banks, levels of fine sediment, and stream width (an index of stream size). This collection of variables reflects a broad spectrum of potential habitat-related influences on bull trout that have been referred in the literature. To represent a broad range of environmental variation across the state of Washington, we sampled habitat characteristics and occurrence of bull trout in six streams, ranging from the Blue Mountains in southeast Washington to the Olympic Mountains in the west (Figure 1). To further examine the generality of model predictions, we compared our results to distribution models based on records of summer maximum summer water temperature and bull trout occurrence throughout the Pacific Northwest (Rieman and Chandler 1999), and to results of laboratory experiments of thermal tolerance (T. McMahon, Montana State University, personal communication).

Preliminary temperature models. Because water temperature was a key variable related to bull trout occurrence, we developed a preliminary model of water temperatures to see if they were potentially predictable. We limited our preliminary analysis to basins with records of bull trout occurrence to examine the influences of elevation and spatial location.

Methods

Selection of study streams

Bull trout are known to occur in a wide variety of habitats in Washington State. During the winter and spring of 2000, we consulted with over 70 local biologists to develop a list of candidate study streams. Random selection of streams would have been most ideal, but a number of constraints prevented this. Many streams posed problems with access, safety, and sampling conditions (e.g., glacial streams). To ensure broad coverage of stream habitat conditions experienced by bull trout, we sampled streams over a broad geographic area within the state. We divided the state into three broad regions, west of the Cascade mountain crest, east of the Cascades, and Blue Mountains (southeast Washington). Final selection of study streams was based on consultation with local biologists familiar with each region (Figure 1).

Selection and location of sampling sites within streams

Whenever possible, sites (100 meter reaches of stream) were spaced 2 km apart in an up-downstream array. Site spacing varied occasionally, due to logistical difficulties encountered in the field. The purpose for 2km spacing of sites was to provide enough distance between sites to sample changing habitat conditions as a function of downstream changes in stream characteristics. Because "distance" in terms of linear distance between sites is not necessarily equivalent with "distance" as indicated by changes in habitat, spacing of sites was largely subjective. We had little a-priori knowledge of habitat conditions in streams. More effective stratified sampling designs were therefore not warranted. Most importantly, the location of sampling sites was designed to bracket the downstream distribution limits of young juvenile and resident bull trout in each stream (Figure 2). This was an obvious necessity to model occurrence (presence-absence) of bull trout.

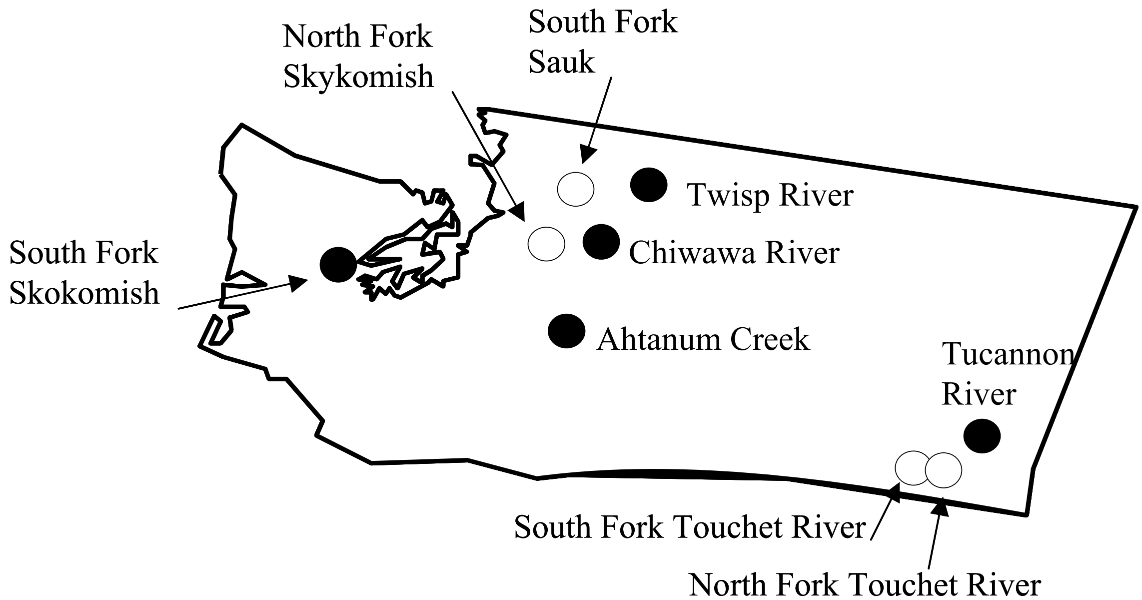

Figure 1. Map showing locations of major study streams. Streams with filled circle symbols are those with both fish and habitat data. Streams with unfilled circle symbols are those without fish data (only temperature was recorded).

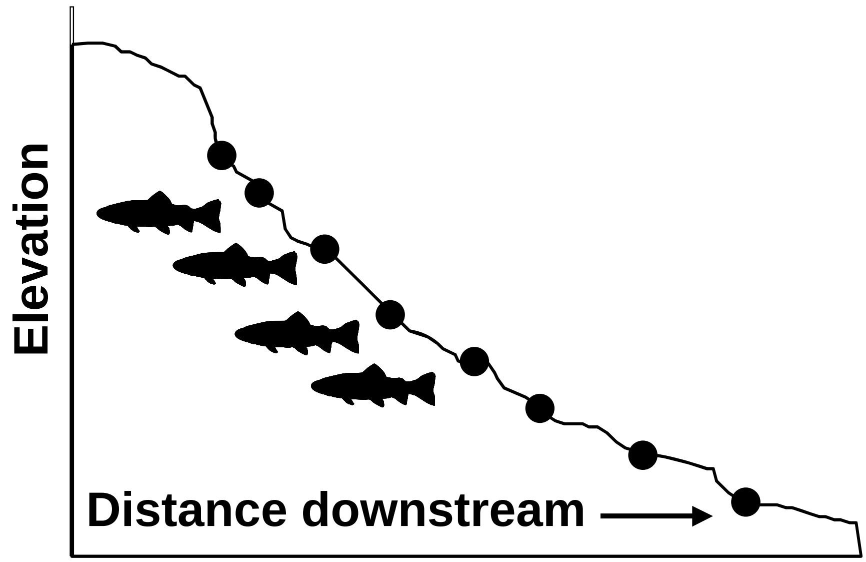

Figure 2. Schematic of the sampling design used in this study. Circles represent locations of 100 meter sample sites. Sites were generally spaced 2 km apart, but spacing varied due to loss of temperature dataloggers and lack of access to some sites. The primary objective was to array sites up- and downstream of the distribution limits for juvenile bull trout in a given stream system.

Fish sampling

All fish sampling was conducted using single-pass night snorkeling (see Thurow 1994), which is among the most efficient methods for sampling bull trout (Peterson et al. 2001). Prior to snorkeling, observers were asked to inspect the sample unit and select the number of snorkelers necessary to survey the unit in a single pass. Snorkel counts of all salmonid species were conducted at night (generally 2230 and 0430, depending on photoperiod) by moving slowly in an upstream direction.

All salmonid fish were identified to species. Due to concerns over the difficulty of correctly distinguishing cutthroat and rainbow trout in the field (Hawkins 1997), these species were lumped into a single category in subsequent data analyses.

Bull trout less than 150mm in total length were considered to be young juveniles or small resident adults. Fish sizes were estimated relative to distances between known objects underwater, or visually, if snorkelers had participated recently in visual calibration (Thurow 1994).

Underwater visibility was determined with a salmonid silhouette. The silhouette was cut out of a blue plastic sheet and spots and other features added with an indelible black marker. Visibility of the silhouette was estimated at three locations using a secchi disk-like approach. One crew member suspended the silhouette in the water column and the snorkeler moved away until marks on the object could not be distinguished. The snorkeler moved back toward the object until it reappeared clearly. This distance was recorded as the maximum visibility. Visibility was estimated in the longest and deepest habitats (i.e. pools or runs) where snorkelers had the longest unobstructed underwater view. Observers also recorded whether a snorkeler could see from bank to bank underwater. Whenever possible, block nets were installed at the upper and lower unit boundaries to prevent fish escape during sampling. In some cases, it was not be possible to hold block nets. This was common in larger (>5 m wetted width) streams, and streams with strong discharge. In such cases, sampling proceeded without block nets.

Habitat data collection

Habitat information was recorded for an entire site (e.g., temperature, undercut banks, large wood, gradient), or at stream transects within sites (Platts et al. 1993). Transect-based measurements were summarized (maximum or mean values), depending on the habitat characteristic under consideration.

Temperature. Temperature thermographs or dataloggers were programmed and calibrated following manufacturer's instructions. We used "Tidbit" temperature dataloggers manufactured by Onset Computer Corporation, Inc. (www.onset.com). These dataloggers are water-tight, but were placed in protective PVC casings to protect from potential damage (e.g. impact from hooves, or scour). Placement of dataloggers within sites followed methods outlined by Dunham (1999) and Zaroban (1999).

Large wood. Large wood was defined as a piece of wood, lying above or within the active channel, at least 3 m long by 10 cm in diameter. Large wood was quantified in terms of total number of pieces, and in terms of a wood classification modified from Moore et al. (1998; Table 1). Live pieces of wood (e.g. live trees) counted as large wood if they were within the active (wetted) channel (for wood counts) or bankfull channel (wood class rating), and leaning at an angle of 45 degrees or less over or in the channel.

Table 1a. Narrative Description of Large Wood Classification Ratings (applies to entire site; see Moore et al. 1998).

Rating	***Description***
1	Wood contributes little to stream habitat complexity, mostly small (10-30 cm, median diameter) single pieces.
2	Wood has combinations of single pieces and small accumulations, providing cover and some complex habitat.
3	Wood present with medium (30-50 cm, median diameter) and large (>50 cm, median diameter) pieces providing accumulations and debris jams, with good cover and complex habitat within the low flow channel (during reduced stream discharge in mid-late summer and early fall, the low flow channel is generally equivalent to the active channel).
4	Wood present as large single pieces, accumulations, and jams that provide good cover and complex habitat at all discharge levels.

Table 1b. Dichotomous key to wood classification ratings (see Moore et al. 1998).

1a) Wood mostly small pieces, contributing little to habitat complexity (RATING = 1)
1b) Small accumulations or large pieces of wood present (GO to 2)

2a) Wood providing some cover and complex habitat, no large pieces (RATING = 2)
2b) As above, but larger pieces present, and good cover (not just "some") (GO to 3)

3a) Wood providing complex habitat only within low-flow channel (RATING = 3)
3b) Wood providing complex habitat in both low-flow and bankfull channel (RATING = 4)

Site Gradient. We estimated channel slopes (gradient) in the field with a hand level (Isaak et al. 1999).

Bankfull width. Bankfull width was estimated following Harrelson et al. (1994).

Habitat measurements recorded at transects. A transect is an imaginary line perpendicular (at a right angle) to the active (wetted) stream channel (Platts et al. 1983). Transects were established at 10m intervals in 100m sites. Habitat measurements were recorded in an upstream direction, starting on the left, and proceeding to the right stream bank. This provided a consistent frame of reference. Each habitat characteristic measured at transects is described below.

> *Wetted or active channel width*- The width of the wetted channel. The margins of the wetted channel can be found by looking for areas were water no longer completely surrounds rocks (Platts et al. 1983).
>
> *Mean depth*-Mean depth was estimated from depth measurements at taken at approximately 1/4, 1/2, and 3/4 the channel width at each transect, and dividing the sum by four to account for zero depth at each bank (Platts et al. 1983).
>
> *Maximum depth*- Maximum depth was also recorded at each transect. The maximum of this value was recorded for each site.
>
> *Visual substrate estimation* - The percent of substrate in four size classes in a one-meter band parallel to each transect was recorded. The four categories were defined as: fines (< 6 mm), gravel (6-75 mm), cobble (75-150 mm), and rubble (> 150 mm). Particle size was estimated as the width: not length or longest axis.

Side channels. Side channels large enough to harbor fish (> 1m wetted width) were surveyed.

Data analysis: fish-habitat models

Summary and preliminary screening of variables. All fish and habitat data were summarized at sites. We began data analysis by looking at intercorrelations among potential predictors (habitat variables) of occurrence of juvenile bull trout. For temperature, our analysis of a regional bull trout – temperature database (Rieman and Chandler 1999; Appendix 1) indicated that maximum daily temperature (warmest temperature of the year), and mean summer temperature were excellent indicators of juvenile bull trout occurrence. These two measures of temperature were strongly correlated in the data collected in Washington state. For data analysis, we used maximum summer temperature.

Several measures of stream size (wetted width, mean depth, maximum depth, bankfull width) were also found to be stronghly correlated ($r > 0.50$). We used wetted width as an index of stream size to be consistent with other studies (e.g., Rieman and McIntyre 1995; Rich 1996; Watson and Hillman 1997; Dunham and Rieman 1999; Zurstadt 2000). Seven additional habitat variables commonly used in analysis of habitat relationships for bull trout were also used: mean percentage of surface fines, channel slope (gradient), undercut bank area, wood (wood counts and wood classification ratings), and occurrence of other salmonids, including rainbow/cutthroat trout, and brook trout.

Data analysis. Data analyses used multiple logistic regression (Littell et al. 1996; Allison 1999) to relate occurrence of juvenile bull trout to habitat variables and occurrence of other fishes. Prior to inspecting the data, we developed an a-priori series of candidate models, and used formal model selection (Burnham and Anderson 1998) to evaluate the relative likelihood of each model, given the data. Candidate models included temperature (summer maximum temperature), wood (wood count and wood classification rating), occurrence of other salmonids (rainbow/cutthroat trout, brook trout), gradient, undercut bank area, surface fines, and stream size (wetted width, maximum depth). In addition to each model that included a single variable or group of related variables, we included a global model with all predictors.

Following model selection, we further analyzed a subset of the data to test for spatial variation in the results. Spatial variation includes variation among sites within streams and variation among streams. Sites within streams are not truly independent, and each observation does not contribute a single degree of freedom to the analysis. The most common effect of such "spatial autocorrelation" is an underestimation of the precision of model parameter estimates and predictions (Littell et al. 1996). Variability among streams (Dunham and Vinyard 1997) may also affect model parameter (slopes, intercepts, and interaction terms) estimates.

To look at both "site" and "stream" influences on the results, we analyzed a subset of data collected at sites along continuous lengths of major streams sampled in each study basin (Appendix 2). The subset of site data consisted only of sites from "mainstem" sampling sites, and excluded side tributaries. We ordered sites in an upstream-downstream array to test for the effects of autocorrelation among sites within streams. Variability among streams was treated by coding "stream" as a categorical or "group" variable in the analysis (see Dunham and Vinyard 1997; Allison 1999).

Finally, to examine the generality of results obtained in this work, we compared our model results to those obtained through a similar analysis of a regional bull trout – temperature database (Rieman and Chandler 1999). Concordance between the regional and Washington State datasets would suggest a similar response of bull trout to stream temperature, whereas discordance could indicate differences in the response of bull trout to temperature, or differential sampling bias (Rieman and Chandler 1999).

Data analysis: stream temperature models

Fish-habitat models indicated that stream temperature was by far the most important variable associated with occurrence of juvenile bull trout (see Results). We were therefore interested in the predictability of stream temperature. We tested the ability of a simple linear model, incorporating elevation and “stream” effects to predict summer maximum stream temperatures observed in each basin. Because we consider this analysis to be preliminary, we did not attempt to correct for spatial autocorrelation. Our objective was simply to determine if stream temperatures were potentially predictable.

Results

Results reported herein must be considered *preliminary*. As noted in the introduction, a final report will be issued by 15 July 2001. A total of 109 sites were sampled for fish occurrence and habitat characteristics in six stream basins in Washington State (Table 2) Correlation analysis using Spearman rank correlation indicated significant correlations between different measures of stream size (Table 3), and between other measures of habitat characteristics used in this analysis. Moderate to strong ($r_s > 0.50$) correlations were generally observed only among different measures of stream size. Maximum depth and wetted width were only weakly correlated and both considered the analysis. Correlations among other variables used in this analysis were statistically significant in some cases, but weak overall ($r_s < 0.50$).

Model selection analysis using logistic regression indicated that summer maximum temperature was the most likely factor to explain patterns of occurrence for juvenile bull trout (Table 4). The global model was also plausible as well, but just half as likely in relation to the model with summer maximum temperature only. None of the models including the effects of individual habitat features other than temperature were likely candidates.

Model parameter estimates for the Washington State data set (modeling summer maximum temperature only) were similar to parameter estimates from a similar analysis of a larger database linking bull trout occurrence to water temperature (Rieman and Chandler 1999; Table 5). Analysis of a spatially ordered subset of data from Washington State indicated significant autocorrelation among sites within streams, but "stream" effects were not significant, indicating that among-stream differences in the relationship between temperature and bull trout occurrence were not detectable. The main effect of accounting for autocorrelation was wider confidence bounds for parameter estimates.

Summer maximum stream temperatures were highly predictable, with a simple model incorporating site elevations, "stream" effects, and stream*elevation interactions explaining 94% of the variance in the response ($F_{9,60} = 97.21$, $p < 0.0001$; Figure 3). This model was fit only for streams with both fish and temperature data collected in 2000. All sites will be analyzed when a complete elevation dataset is available, and results of more extensive analyses will be presented in more detail (including parameter estimates and variances) in future work.

Table 2. Statistical summary of habitat variables measured at sites.

Variable	N	Mean	SD	Maximum	Minimum
Bankfull width (m)	106	23.14	17.36	101.0	4.4
Brook trout density (fish/m^2)	107	0.0007	0.003	0.02	0
Rainbow/cutthroat trout density (fish/m^2)	107	0.03	0.03	0.16	0
Large wood pieces per meter	108	0.11	0.21	2.13	0
Undercut bank area (m^2)	109	4.69	6.94	32.59	0
Maximum depth (m)	109	1.02	0.71	6.00	0.31
Mean width (m)	109	12.35	7.24	37.65	3.61
Maximum water temperature (C)	109	15.80	3.34	25.80	9.41
Stream gradient (%)	109	1.37	1.77	10.02	0
Mean surface fines (%)	109	12.21	12.47	74.00	0

Table 3. Spearman rank correlations between four measures of stream size.

	Maximum depth	Mean depth	Mean width
Bankfull width	0.47 (<0.001)	0.51 (<0.001)	0.29 (0.003)
Maximum depth	1.000	0.61 (<0.001)	0.26 (0.007)
Mean depth	0.61 (<0.001)	1.000	0.54 (<0.001)
Mean width	0.26 (0.007)	0.54 (<0.001)	1.000

Table 4. Candidate models and relative likelihoods, as indicated by Akaike's information criterion (AIC). Larger $\Delta QAIC_c$ weights indicate likely models. See Burnham and Anderson (1998).

Candidate model	Number of parameters	$QAIC_c$	$\Delta QAIC_c$	$\Delta QAIC_c$ weight	% of maximum $\Delta QAIC_c$ weight
Temperature	2	86.05	0.00	0.66	100
Global model	11	87.39	1.35	0.33	33
Salmonids	3	96.37	10.33	0.00	0
Wood	3	96.73	10.69	0.00	0
Surface fines	2	97.10	11.06	0.00	0
Maximum depth	2	100.21	14.16	0.00	0
Gradient	2	100.64	14.60	0.00	0
Wetted width	2	100.20	15.15	0.00	0
Undercut banks	2	101.80	15.75	0.00	0

Table 5. Logistic regression parameter estimates and confidence intervals for three models of bull trout occurrence in relation to summer maximum temperature. The "Washington-All" dataset includes all fish-habitat data collected in 2000. The "Regional" dataset is an extended version of the dataset described by Rieman and Chandler (1999). The "Washington-Spatial" dataset (Appendix 2) includes data from a spatially ordered sample of sites sampled in 2000. Parameter estimates for all datasets are similar.

Dataset	Parameter	Estimated Coefficient	95% Confidence interval
Washington-All	Intercept	5.47	2.87, 8.58
	Temperature	-0.38	-0.58, -0.21
Regional	Intercept	4.64	3.81, 5.83
	Temperature	-0.28	-0.34, -0.23
Washington-Spatial	Intercept	7.91	0.52, 15.31
	Temperature	-0.52	-0.98, -0.07

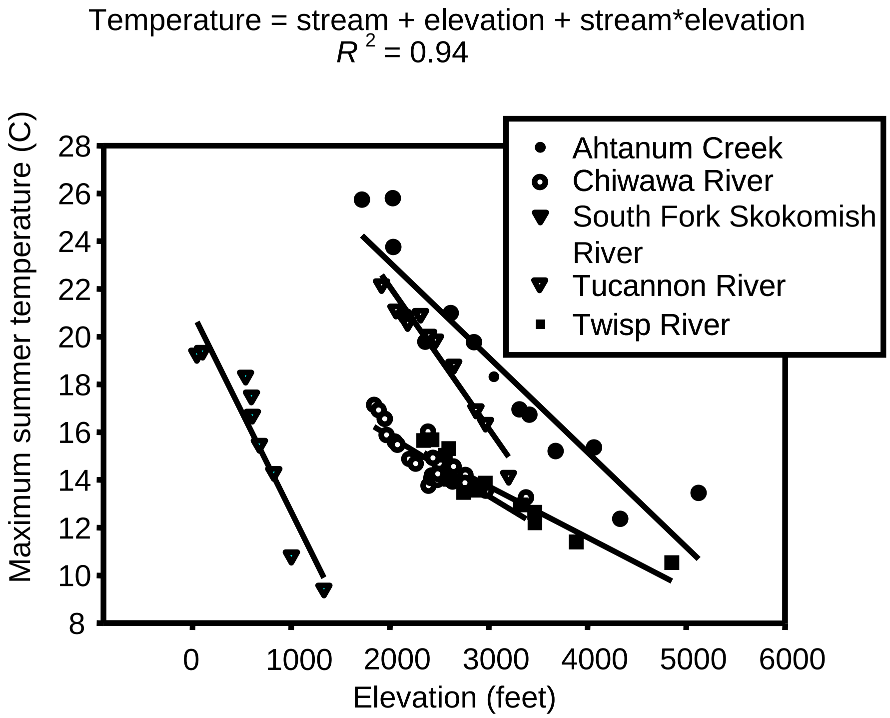

Figure 3. Plot of maximum summer water temperature versus elevation for five stream systems studied in 2000. Each stream is coded by a different symbol, and regression lines are fitted to each stream, since both slopes and intercepts of the stream*elevation relationship varies among streams.

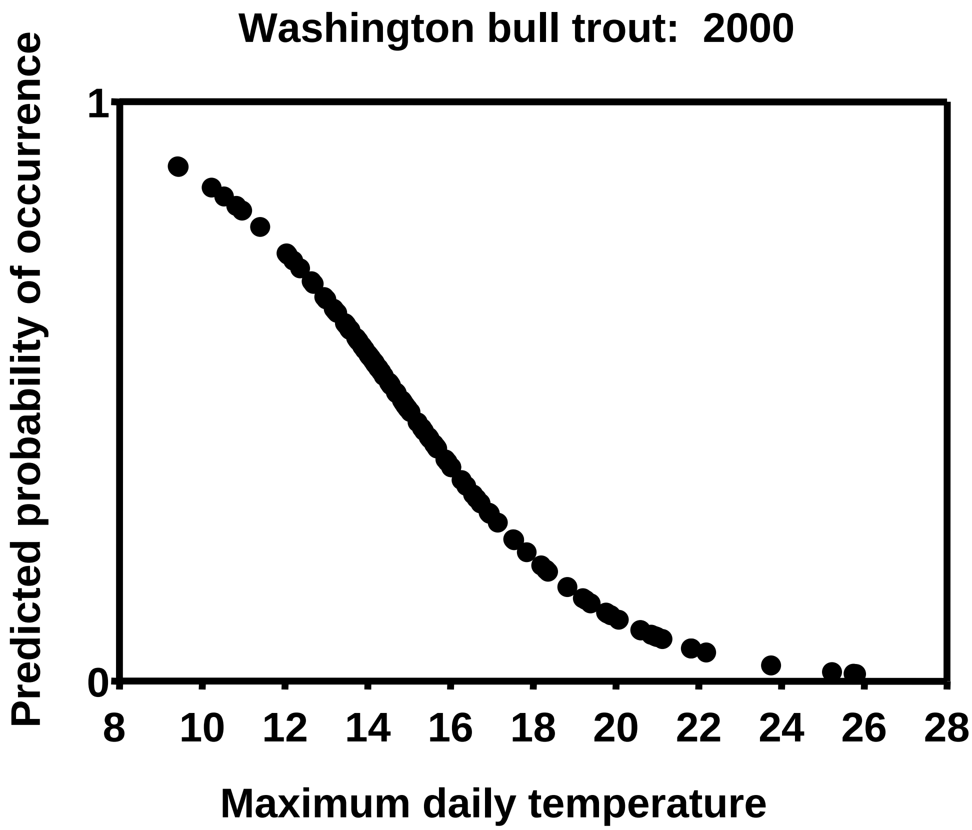

Figure 4. Predicted probability of presence (occurrence) for juvenile bull trout in relation to maximum daily temperature.

Discussion

Occurrence of juvenile bull trout

Occurrence of juvenile bull trout was most strongly related to summer maximum water temperature. This pattern parallels the results of previous studies (e.g., Rieman and McIntyre 1999; Haas, in press) examining correspondence between bull trout occurrence and temperature. The association we observed between bull trout occurrence and temperature was very similar to analyses of a similar data set summarized by Rieman and Chandler (1999), and consistent with laboratory studies on thermal tolerance. For example, In Figure 4, it is clear that probability of occurrence of juvenile bull trout is predicted to be very low as temperatures exceed 20C. The upper incipient lethal temperature for juvenile bull trout under 60 days of exposure to constant temperatures is 20.9C (T. McMahon, Montana State University, personal communication).

Other habitat variables measured at sites (Table 2) did not appear to be strongly related to occurrence, a pattern also found by Haas (in press). The lack of influence of other habitat variables may be due to a number of factors, including:

1) juvenile bull trout do not respond to the variables,
2) variables were not measured at appropriate scales,
3) the range of variation in variables was not sufficient to detect effects,
4) variables were not measured with enough precision to detect effects.

All outcomes are viable possibilities. Some variables, especially undercut banks, wood, and surface fines, are difficult to measure with a reasonable degree of repeatability or precision (Thurow et al. 2001). Lack of precision in measures of these variables could have created "noise" in the data that obscured detection of habitat associations. Evidence for other possibilities (e.g., alternatives 1-3) is discussed below in relation to previous research on bull trout occurrence.

Previous research on bull trout occurrence can be divided into studies addressing occurrence of fish at sites within streams (e.g., Dambacher and Jones 1997; Watson and Hillman 1997; Dunham and Rieman 1999; Zurstadt 2000; Haas, in press), and studies addressing occurrence of bull trout across streams (Rich 1996) or “patches” (Rieman and McIntyre 1995; Dunham and Rieman 1999) of suitable habitat. Here, we focus on smaller-scale studies with designs similar to the one used in this study.

Dambacher and Jones (1997) used an analysis of fish and habitat survey information to define benchmarks for habitat quality for juvenile (defined as fish <170 mm in their study) bull trout in Oregon. They used seven variables, including percent shade, percent riffle gravel, percent bank erosion, percent undercut bank, percent riffle fines, and two measures of large wood (Table 6). Water temperature was not a variable that was directly modeled in their study, though percent shade and bank erosion were considered in part for their potential influences on water temperature (e.g., Poole and Berman 2001). We considered several variables in common with Dambacher and Jones (1997), including undercut banks, fine sediment, and large wood. The range of conditions with respect to these variables in this study (Table 2) should have indicated an influence on juvenile bull trout occurrence if the models developed by Dambacher and Jones applied to our sample of sites. In other words, sites in this study spanned the range between low to high quality, according to Dambacher and Jones’ benchmarks for juvenile bull trout habitats (Table 6). Lack of influence of these variables in this study could be due to minor differences in the methods used to measure the variables, different methods of analysis (e.g., model selection may more precisely identify variables explaining patterns in the data), different habitat relationships in the sample of streams in each study, or the overriding influence of temperature, a primary focus of this study.

Table 6. Habitat quality benchmarks for bull trout from Dambacher and Jones (1997).

	Quality		
Variable	Low	Moderate	High
Percent shade	<66	66-87	>87
Percent riffle gravel	<48	48-60	>60
Percent bank erosion	>4	0-4	0
Percent undercut bank	<3	3-11	>11
Percent riffle fines	>21	8-21	<8
Large wood pieces per 100m	<10	10-25	>25
Large wood (m^3) per 100m	<9	9-28	>28

Watson and Hillman (1997) also analyzed occurrence of bull trout at sites in relation to a variety of habitat characteristics. Several major differences between that study and design of the present study complicate comparisons, however. First, the Watson and Hillman study did not distinguish between different life stages of bull trout (e.g., small juvenile, resident, or migratory fish) in habitat associations. Second, study sites were focused within areas already known or suspected to be occupied by bull trout, so they were likely within the zone of suitable thermal habitat. Third, water temperature itself was measured at a single point in time during the survey. In reference to common variables between the study by Watson and Hillman (1997) and this study, results of the analysis by Watson and Hillman indicated that occurrence of (any) bull trout was more likely with increasing undercut bank area, and decreasing densities of brook and rainbow trout.

Interestingly, occurrence of bull trout was lower with increasing canopy cover, in contrast to the results from the study by Dambacher and Jones (1997), and Zurstadt (2000). Our study did not reveal associations between occurrence of juvenile bull trout and other salmonids (brook or rainbow/cutthroat trout density). Lack of association with brook trout may likely be due to very low densities of brook trout in the sites we sampled. Rainbow/cutthroat trout were common, and sometimes abundant, yet no association was apparent. Haas (in press) found an inverse relationship between rainbow and bull trout densities in British Columbia streams.

Dunham and Rieman (1999) focused primarily on larger-scale patterns of occurrence of bull trout in the Boise basin, Idaho, but also analyzed occurrence of bull trout within patches of cold water. Occurrence of bull trout in stream reaches was positively associated with stream width, with occurrence very unlikely in streams less than 2 m wetted width. Occurrence of brook trout was not related to occurrence of bull trout.

Zurstadt (2000) investigated occurrence of juvenile bull trout in patches of cold water in the upper Payette River, Idaho. Location of sites for sampling was similar to Watson and Hillman (1997) in that sampling was restricted to areas known or suspected to be occupied by bull trout. Zurstadt (2000) analyzed occurrence within channel units (classified as "slow" and "fast" water units). The study revealed positive associations between occurrence of bull trout and depth of slow-water (e.g., pool) habitat units, large wood, canopy density, and pocket pools (see also Saffel and Scarnecchia 1995). Occurrence of juvenile bull trout was negatively related to increased submerged vegetation and occurrence of rainbow (but not brook) trout. Temperature was not measured directly within each unit, and some associations (e.g., canopy density, submerged vegetation, rainbow trout) may have been surrogates for the direct effect of temperature on bull trout occurrence.

Haas (in press) analyzed patterns of occurrence of bull and rainbow trout in sympatry and allopatry at sites in 26 streams in the upper Columbia River basin in British Columbia, Canada. Habitat variables considered included temperature (measured with digital dataloggers as in this study), substrate composition (including percentage of surface fines), large wood, boulders, instream and overhead vegetation, undercut banks, maximum depth, residual pool depth, stream width. The design was similar to this study, and results were similar as well. Only temperature effectively discriminated habitats dominated by rainbow or bull trout.

Empirical stream temperature models

Results of this study indicate stream temperature is an important factor associated with the distribution of juvenile bull trout. Therefore, predictive models of stream temperatures can be used to delineate habitats that may be potentially used by juvenile bull trout. Our simple models indicate summer maximum stream temperatures may be highly predictable, if we can understand the factors associated with spatial or "stream" variability in the effect of elevation on stream temperature. Important large-scale drivers of stream temperature could include climate gradients, watershed geomorphology, and large-scale patterns of land use.

Previous modeling to predict stream temperatures in Washington (Sullivan et al. 1990) using similar methods of analysis (multiple linear regression) was able to explain 69% of the variability in maximum stream temperatures using a combination of variables, including stream size (bankfull width), discharge, mean air temperature, sky view (an index of incident radiation), and elevation. These factors, among many others (see Poole and Berman 2001) may directly or indirectly influence thermal regimes in streams. Furthermore, the influence of individual factors should be expected to vary across streams (Poole and Berman 2001). An indication of this possibility is the significant "stream" effect we observed. Future empirical modeling of stream temperature should explicitly incorporate effects of factors that may account for the spatial variability in stream temperature regimes that we observed in this study. Furthermore, the possibility of temporal variability in temperatures remains to be investigated.

Management and research implications

Predicting bull trout occurrence. Studies of the association between fish occurrence and temperature rely on the assumption that fish observed at a site were actually experiencing temperatures recorded at the site. For example, the current model is based on observations of juvenile bull trout collected at a point in time. We assumed bull trout used those sites throughout the summer and experienced the warmest temperatures (e.g., summer maximum temperature), even though they may not have occurred during the time of observation. Matching fish with temperature records can be difficult, unless fish are continuously monitored in space and time. The fact we observed strong concordance among two very different field datasets and laboratory studies provides a good measure of confidence in the results, but more precise and direct observations of thermal habitat use in the field by bull trout would be useful. To this end, we are pursing collaborative studies to employ miniaturized archival temperature tags attached directly to individual bull trout. As tags are recovered over the next few years, detailed thermal histories of individual fish should provide an excellent frame of reference for interpreting results of distribution-based, and laboratory studies of thermal habitat selection and tolerance.

The fact that we found temperature to be the only "significant" variable indicating occurrence of juvenile bull trout does not mean that other variables, including those analyzed in this study, are not important. Habitat relationships must be considered at multiple spatial scales, and multiple responses (e.g., survival, behavior, growth, abundance) in addition to simple patterns of occurrence, must be considered as well. Studies considering different responses at different scales may reveal new and important habitat requirements for bull trout.

For the purposes of gaining new information for use in land-management decisions, including classifications of suitable habitat for bull trout, we recommend a continued focus at larger scales. Smaller-scale studies are also very important, and necessary, but for species like bull trout with widespread, but locally restricted populations (see Rabinowitz et al. 1986), a large-scale or "coarse-filter" (Hansen et al. 1999) approach is more efficient with limited resources. With the models reported herein, we can now predict the distribution of potentially suitable habitats for juvenile bull trout. With these distribution models, it should be possible to develop maps of suitable habitats, and "patch-based" models of occurrence (Dunham et al., in press) to predict patterns of occurrence at larger scales (e.g., among basins, as opposed to within streams). One premise behind this kind of modeling is that some, but not all, potentially suitable habitat is occupied by bull trout (e.g., Rieman and McIntyre 1995; Dunham and Rieman 1999; Rieman and Dunham 2000).

Distribution models reported herein do not recognize larger-scale constraints on habitat use by bull trout. In the absence of such information, managers must conservatively bull trout occur in any water cold enough to potentially support them. Application of larger-scale models, in conjunction with new sampling protocols (Peterson et al. 2001), would be needed to provide increased resolution for land management classifications to protect bull trout populations and key habitats.

An important facet of bull trout recovery will presumably be to restore populations beyond the boundaries of currently occupied habitat, were possible. In this sense, distribution models may not adequately represent the extent of potentially suitable habitat. Because bull trout are so strongly tied to cold water, we divert this discussion to development of models to predict stream temperatures.

Predicting stream temperatures. Our models suggest summer maximum temperatures can be predicted and possibly mapped with a reasonable measure of precision. Statisical prediction alone is useful, but not sufficient for supporting management decisions. An understanding of the processes affecting stream temperatures will be necessary to guide appropriate management actions. Numerous statistical and process-based models of stream temperature have been applied in the Pacific Northwest (e.g., Lewis et al. 1999; Bartholow 2000), but a combination of both approaches at a landscape scale is needed to provide models and maps of suitable habitat for juvenile bull trout.

Summary

Results of this study indicate the distribution of juvenile bull trout is strongly tied to summer maximum stream temperatures. As water temperatures exceed a single daily maximum of 20 C, it becomes increasingly unlikely that juvenile bull trout will be found using a given habitat. Other variables do not appear to be likely, in terms of explaining the distribution of bull trout within streams. These results apply at the scale this study was conducted (100 m sites), and may not apply at different scales, or to responses other than occurrence. Cold water is a necessary, but perhaps not sufficient condition for bull trout habitat use. Other factors, including the amounts and locations of cold water on landscapes may be important (Dunham and Rieman 1999), but remain uninvestigated in Washington State. Summer maximum stream temperatures also appear to be highly predictable. Summer maximum temperatures are strongly tied to elevation gradients, and the relationship is strongly dependent on spatial location. This implies the temperature-elevation relationship varies according to local factors, such as climate, land use, and geomorphology. Future work should seek to provide useful models for predicting stream temperatures at large scales.

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Appendix 1.

Description of the regional bull trout – temperature database (see Rieman and Chandler 1999 for further details)

The general approach was to accumulate thermograph records throughout the current range of bull trout in the United States. Data were received from biologists throughout Oregon, Idaho, and western Montana, with limited representation from Washington State. Temperature records for analysis of bull trout distributions spanned from July 15-August 31. The minimum requirements for temperature measurements were uniform sampling interval of not less than 4 instantaneous observations per day. Site locations with temperature data were resolvable within 1 minute of longitude and latitude. Information on occurrence of bull trout within 500 m of the site (unknown was a potential response) was also required for all records. Records for bull trout were classified for presence of small juvenile or resident (non-migratory) fish (<150 mm) and spawning use.

Several steps were taken to consider the accuracy and quality of the data. All records were plotted and inspected visually to identify potential outlying observations and unusual observations that might indicate malfunction of the thermograph (e.g., rapid rise in temperature associated with dewatering). Numeric filters identified observations >30 ^{o}C or <-1 ^{o}C, or any series of observations with a rate of change >3 ^{o}C per hour. All records with observations falling in the upper or lower 5% of observations in any day were flagged as potential outliers. Temperature records with flagged observations, were returned to the original source for inspection and verification. Each source was asked to consider the flagged observations and justify their inclusion/exclusion from the data set. Each source was also asked to review their protocols for thermograph calibration and deployment (all records) with special reference to known problems (e.g. lack of calibration, clear housings, placement subject to unusual conditions).

Potential bias in the daily summary observations of temperature based on the minimum of only four instantaneous observations per day was considered by resampling data at varying sampling intervals in selected sites. Two sites with 96 observations per day were resampled repeatedly at the rate of four observations of uniform interval. The summary statistics were compared between the complete and subsampled data sets. The absolute error for any of the metrics ranged from 0.00 to 0.03 ^{o}C. The potential bias was greatest for the summer maximum. This magnitude of error was considered to be insignificant and retained all observations with the minimum interval.

Appendix 2.

Observations used in "Washington-spatial" dataset (Table 2).

Site	Stream name	Presence of small bull trout	Maximum summer water temperature
1	Chiwawa	0	17.14
2	Chiwawa	0	16.92
3	Chiwawa	1	16.55
4	Chiwawa	0	15.88
5	Chiwawa	0	15.6
6	Chiwawa	0	15.47
7	Chiwawa	1	14.95
8	Chiwawa	0	14.87
9	Chiwawa	0	14.68
10	Chiwawa	0	14.26
11	Chiwawa	1	14.04
12	Chiwawa	1	13.75
13	Chiwawa	1	13.76
14	Chiwawa	1	13.78
15	Chiwawa	1	14.08
16	Chiwawa	1	14.05
17	Chiwawa	1	14.18
18	Chiwawa	1	14.13
19	Chiwawa	1	14.26
20	Chiwawa	1	14.39
21	Chiwawa	1	14
22	Chiwawa	1	14.69
23	Chiwawa	1	14.7
24	Chiwawa	1	14.53
25	Chiwawa	1	14.56
26	Chiwawa	1	14.2
27	Chiwawa	0	13.88
1	Main Ahtanum	0	25.74
2	Main Ahtanum	0	25.22
1	N.F. Ahtanum	0	25.8
2	N.F. Ahtanum	0	21.81
3	N.F. Ahtanum	0	21.82
4	N.F. Ahtanum	0	20.99
5	N.F. Ahtanum	0	19.76
6	N.F. Ahtanum	0	18.31
7	N.F. Ahtanum	1	17.53
8	N.F. Ahtanum	0	16.73
9	N.F. Ahtanum	1	15.21
10	N.F. Ahtanum	0	15.36

Site	Stream name	Presence of small bull trout	Maximum summer water temperature
11	N.F. Ahtanum	1	14.82
1	S.F. Skokomish	0	19.27
2	S.F. Skokomish	0	19.39
10	S.F. Skokomish	0	18.36
11	S.F. Skokomish	0	17.54
12	S.F. Skokomish	0	17.52
13	S.F. Skokomish	1	16.72
14	S.F. Skokomish	1	16.02
15	S.F. Skokomish	0	15.5
16	S.F. Skokomish	1	14.97
17	S.F. Skokomish	0	14.51
18	S.F. Skokomish	0	14.32
19	S.F. Skokomish	1	13.46
20	S.F. Skokomish	1	10.82
21	S.F. Skokomish	0	9.43
22	S.F. Skokomish	0	10.23
23	S.F. Skokomish	0	13.18
8	Tucannon	0	14.16
9	Tucannon	0	14.85
10	Tucannon	1	15.93
11	Tucannon	1	16.94
12	Tucannon	0	18.19
13	Tucannon	0	18.82
14	Tucannon	0	19.2
15	Tucannon	0	19.87
16	Tucannon	0	20.07
17	Tucannon	0	20.94
18	Tucannon	0	20.6
19	Tucannon	0	20.59
20	Tucannon	0	21.12
22	Tucannon	0	22.18
11	Twisp	0	16.63
13	Twisp	0	15.65
15	Twisp	0	15.68
16	Twisp	0	15.31
17	Twisp	1	14.02
18	Twisp	1	13.48
19	Twisp	1	13.57
20	Twisp	1	13.86
22	Twisp	1	12.69
23	Twisp	1	12.2

Appendix 3.
List of sites sampled during 2000.

Appendix 3. Washington bull trout sampling sites.

STREAM	SITE	Site ID	X - COOR	Y - COOR	Habitat	Fish	Temperature
AHTANUM	1	43	671152.6892	5155121.2251	Yes	Yes	Yes
AHTANUM	2	44	668478.7804	5154926.3653	Yes	Yes	Yes
AHTANUM	3	219			Yes	Yes	No
AHTANUM	4	45	665194.311	5154406.7393	No	No	Yes
BURNT CR.	1	89	888228.7358	5116848.7326	No	No	Yes
BURNT CR.	2	90	889314.6489	5116289.7596	No	No	Yes
BUTTERMILK	1	152	697184.8852	5359816.1647	Yes	Yes	Yes
BUTTERMILK	2	153	698454.1035	5358543.4109	Yes	Yes	Yes
BUTTERMILK	2A	154	698450.5681	5358543.4109	No	No	Yes
BUTTERMILK	3	155	699825.8492	5357542.8851	Yes	Yes	No
CHIKAMIN	1	39	669734.038	5307926.232	Yes	Yes	Yes
CHIKAMIN	2	40	670848.0301	5309222.4062	Yes	Yes	Yes
CHIKAMIN	2.1	213			Yes	No	No
CHIKAMIN	2A	41	670853.7936	5309228.1696	No	No	Yes
CHIKAMIN	3	42	670773.9061	5311193.6864	Yes	Yes	Yes
CHIWAWA	1	1	675448.7456	5295233.6169	Yes	Yes	Yes
CHIWAWA	10	11	672473.4518	5306592.4368	Yes	Yes	Yes
CHIWAWA	11	12	671085.39	5307196.0752	Yes	Yes	Yes
CHIWAWA	12	13	669501.2222	5307986.627	Yes	Yes	Yes
CHIWAWA	13	14	668952.7386	5308887.4884	Yes	Yes	Yes
CHIWAWA	14	15	668441.0248	5310033.4821	Yes	Yes	Yes
CHIWAWA	15	16	667877.2204	5311207.0531	Yes	Yes	Yes
CHIWAWA	15A	17	667877.2204	5311207.0531	No	No	Yes
CHIWAWA	16	18	666810.8947	5312613.5	Yes	Yes	Yes
CHIWAWA	17	19	665925.3542	5313633.8633	Yes	Yes	Yes
CHIWAWA	18	20	664632.281	5314323.298	Yes	Yes	Yes
CHIWAWA	19	21	664123.6314	5315334.469	Yes	Yes	Yes
CHIWAWA	2	2	676646.83	5295236.6811	Yes	Yes	Yes

Appendix 3. Continued.

STREAM	SITE	Site ID	X - COOR	Y - COOR	Habitat	Fish	Temperature
CHIWAWA	20	22	663486.2873	5316137.2774	Yes	Yes	Yes
CHIWAWA	21	23	663143.1021	5317638.713	Yes	Yes	Yes
CHIWAWA	21.1	214			Yes	No	No
CHIWAWA	21.2	215			Yes	No	No
CHIWAWA	22	24	662594.6185	5318977.7484	Yes	Yes	Yes
CHIWAWA	22.1	216			Yes	No	No
CHIWAWA	22.2	217			Yes	No	No
CHIWAWA	23	25	661865.3497	5320319.848	Yes	Yes	Yes
CHIWAWA	24	26	661776.4893	5321956.1064	Yes	Yes	Yes
CHIWAWA	25	27	661399.5983	5323681.2252	Yes	Yes	Yes
CHIWAWA	25A	28	661399.5983	5323681.2252	No	No	Yes
CHIWAWA	26	29	660869.4996	5325351.1893	Yes	Yes	Yes
CHIWAWA	26.1	218			Yes	No	No
CHIWAWA	27	30	660124.9101	5326068.2014	Yes	Yes	Yes
CHIWAWA	3	3	677124.838	5296713.6034	Yes	Yes	Yes
CHIWAWA	4	4	676398.6335	5298083.2804	Yes	Yes	Yes
CHIWAWA	5	5	676463.0776	5299409.9623	Yes	Yes	Yes
CHIWAWA	5A	7	676480.6711	5299409.7686	No	No	Yes
CHIWAWA	6	6	675586.6326	5300712.3247	Yes	Yes	Yes
CHIWAWA	7	8	674581.59	5301873.6392	Yes	Yes	Yes
CHIWAWA	8	9	673049.5128	5302878.6818	Yes	Yes	Yes
CHIWAWA	9	10	672887.1127	5304355.6042	Yes	Yes	Yes
CHURCH CR.	1	179	466344.5825	5256038.8614	Yes	Yes	Yes
GLACIER CR.	1	202	620076.8	5315816.6564	Yes	Yes	No
GLACIER CR.	1A	203	620073.8339	5315819.6225	No	No	Yes
GLACIER CR.	2	204	620898.416	5315570.4682	Yes	Yes	Yes
GOBLIN CR.	1	189	626430.3074	5308457.1207	No	No	Yes
GOBLIN CR.	2	190	626130.1147	5309705.0646	No	No	Yes
GOBLIN CR.	2A	191	626130.1147	5309705.0646	No	No	Yes
GOBLIN CR.	3	192	626022.903	5311025.9124	No	No	Yes

Appendix 3. Continued

STREAM	SITE	Site ID	X - COOR	Y - COOR	Habitat	Fish	Temperature
GOBLIN CR.	4	193	626130.1147	5312951.434	No	No	Yes
GREEN FK.	1	91	886833.7058	5116251.3202	No	No	Yes
GREEN FK.	2	92	886804.8763	5114705.7359	No	No	Yes
GRIFFIN FK.	0	93	888427.6063	5119524.1813	No	No	Yes
GRIFFIN FK.	1	87	889409.1458	5118959.6964	No	No	Yes
GRIFFIN FK.	2	88	890623.1902	5119099.0392	No	No	Yes
M.F. AHTANUM	1	62	651731.3291	5152142.8479	Yes	Yes	Yes
M.F. AHTANUM	2	63	649417.3696	5150332.9527	Yes	Yes	Yes
M.F. AHTANUM	3	64	646612.8777	5150765.9743	Yes	Yes	Yes
M.F. AHTANUM	3A	65	646612.8777	5150771.6578	No	No	Yes
M.F. AHTANUM	4	66	644735.7287	5150901.5643	Yes	Yes	Yes
M.F. AHTANUM	5	121	642870.2254	5151048.0755	Yes	Yes	Yes
MEADOW CR.	6	118	907030.2412	5125236.9137	No	No	Yes
N.F. AHTANUM	1	46	664568.5947	5154378.5929	Yes	Yes	Yes
N.F. AHTANUM	10	55	645185.2594	5154067.7646	Yes	Yes	Yes
N.F. AHTANUM	11	120	643441.2212	5154354.7313	Yes	Yes	Yes
N.F. AHTANUM	1A	57	664552.83	5154382.3819	No	No	Yes
N.F. AHTANUM	2	47	661646.8487	5157125.9801	Yes	Yes	Yes
N.F. AHTANUM	3	48	659248.3146	5158536.6835	Yes	Yes	Yes
N.F. AHTANUM	4	49	657276.0362	5157521.789	Yes	Yes	Yes
N.F. AHTANUM	5	50	654407.2677	5155735.5746	Yes	Yes	Yes
N.F. AHTANUM	6	51	652861.245	5153929.0623	Yes	Yes	Yes
N.F. AHTANUM	7	52	651643.3716	5153029.1892	Yes	Yes	Yes
N.F. AHTANUM	8	53	650033.0722	5152704.4229	Yes	Yes	Yes
N.F. AHTANUM	9	54	647729.2616	5153299.8277	Yes	Yes	Yes
N.F. AHTANUM	9A	56	647746.1766	5153306.5937	No	No	Yes
N.F. SKYKOMISH	1	194	619441.1252	5305831.4405	No	No	Yes
N.F. SKYKOMISH	2	195	621230.2184	5305322.9614	No	No	Yes
N.F. SKYKOMISH	3	196	622994.2014	5304823.8986	No	No	Yes
N.F. SKYKOMISH	4	197	624968.4814	5305012.2242	No	No	Yes

Appendix 3. Continued.

STREAM	SITE	Site ID	X - COOR	Y - COOR	Habitat	Fish	Temperature
N.F. SKYKOMISH	4A	198	624968.4814	5305012.2242	No	No	Yes
N.F. SKYKOMISH	5	199	625690.3961	5306245.7568	No	No	Yes
N.F. SKYKOMISH	6	200	626318.1481	5307730.3902	No	No	Yes
N.F. SKYKOMISH	7	201	628333.2319	5309127.1383	No	No	Yes
N.F. TOUCHET	1	74	897694.2206	5116856.4196	No	No	Yes
N.F. TOUCHET	2	73	897983.6463	5116340.1373	No	No	Yes
N.F. TOUCHET	3	72	899180.9287	5115802.0328	No	No	Yes
N.F. TOUCHET	4	71	898777.3503	5117961.177	No	No	Yes
N.F. TOUCHET	5	70	899818.3029	5119712.6795	No	No	Yes
N.F. TOUCHET	5A	69	899821.0865	5119723.8139	No	No	Yes
N.F. TOUCHET	6	68	901018.0349	5121505.3184	No	No	Yes
N.F. TOUCHET	7	67	901095.9757	5123445.4882	No	No	Yes
NORTH CR.	1	148	680408.5445	5369477.6448	Yes	Yes	Yes
NORTH CR.	2	149	680656.0229	5371074.28	No	No	Yes
NORTH CR.	2A	150	680656.0229	5371078.2715	No	No	Yes
NORTH CR.	3	151	680867.5771	5373193.8131	No	No	Yes
PANJAB	1	114	908461.0234	5130204.5199	Yes	Yes	Yes
PANJAB	2	115	907807.795	5128456.4245	No	No	Yes
PANJAB	3	116	907994.5382	5126720.0022	No	No	Yes
PANJAB	4	117	909142.5023	5125286.8567	No	No	Yes
PHELPS	1	31	660066.6912	5326230.6016	Yes	Yes	No
PHELPS	2	32	661347.5077	5327805.5769	Yes	Yes	Yes
PHELPS	2A	33	661347.5077	5327808.641	No	No	Yes
PHELPS	3	34	661718.2703	5329074.1367	Yes	Yes	Yes
ROCK	1	35	664542.5805	5314496.418	Yes	Yes	Yes
ROCK	2	36	665517.8484	5315928.2398	Yes	Yes	Yes
ROCK	2A	38	665538.6214	5315931.0345	No	No	Yes
ROCK	3	37	666285.202	5317700.8695	Yes	Yes	Yes
S.F. AHTANUM	1	58	664529.1491	5154196.3179	Yes	Yes	Yes
S.F. AHTANUM	2	59	662485.8281	5154064.3816	Yes	Yes	Yes

Appendix 3. Continued.

STREAM	SITE	Site ID	X - COOR	Y - COOR	Habitat	Fish	Temperature
S.F. AHTANUM	3	60	660401.9114	5152971.6785	Yes	Yes	Yes
S.F. AHTANUM	4	61	658483.7607	5151459.4856	Yes	Yes	No
S.F. AHTANUM	5	122	656958.8527	5150574.7886	Yes	Yes	Yes
S.F. SAUK	1	180	617033.0845	5322986.2429	No	No	Yes
S.F. SAUK	2	181	616509.3895	5321394.2099	No	No	Yes
S.F. SAUK	3	182	616219.1128	5319649.5572	No	No	Yes
S.F. SAUK	4	183	616440.561	5317620.6128	Yes	Yes	Yes
S.F. SAUK	4A	184	617030.092	5322986.2429	No	No	Yes
S.F. SAUK	5	205	618149.8349	5316913.6548	Yes	Yes	No
S.F. SAUK	6	206	619538.9772	5316106.0912	Yes	Yes	No
S.F. SKOKOMISH	1	162	480601.5104	5240750.7964	Yes	Yes	Yes
S.F. SKOKOMISH	10	164	476697.3578	5250359.2976	Yes	Yes	Yes
S.F. SKOKOMISH	11	165	476016.7896	5250560.4718	Yes	Yes	Yes
S.F. SKOKOMISH	12	166	474796.9032	5251643.3885	Yes	Yes	Yes
S.F. SKOKOMISH	13	167	473388.6836	5252418.1233	Yes	Yes	Yes
S.F. SKOKOMISH	14	168	472215.8806	5253415.4339	Yes	Yes	Yes
S.F. SKOKOMISH	15	169	470884.7064	5254173.0475	Yes	Yes	Yes
S.F. SKOKOMISH	15A	170	470884.7064	5254173.0475	No	No	Yes
S.F. SKOKOMISH	16	171	469604.8958	5254669.5627	Yes	Yes	Yes
S.F. SKOKOMISH	17	172	468539.1003	5254819.3733	Yes	Yes	Yes
S.F. SKOKOMISH	18	173	467391.9792	5255367.252	Yes	Yes	Yes
S.F. SKOKOMISH	19	174	466240.5777	5256702.7065	Yes	Yes	Yes
S.F. SKOKOMISH	2	163	479764.8841	5242178.5173	Yes	Yes	Yes
S.F. SKOKOMISH	20	175	466390.3883	5258299.2595	Yes	Yes	Yes
S.F. SKOKOMISH	21	176	465414.4792	5259561.9489	Yes	Yes	Yes
S.F. SKOKOMISH	22	177	464481.4599	5260940.1872	Yes	Yes	Yes
S.F. SKOKOMISH	23	178	463176.2953	5262020.231	Yes	Yes	Yes
S.F. TOUCHET	0	86	887692.1858	5117958.6703	No	No	Yes
S.F. TOUCHET	1	85	888360.0704	5119155.0967	No	No	Yes
S.F. TOUCHET	2	84	888638.7561	5120758.3401	No	No	Yes

Appendix 3. Continued.

STREAM	SITE	Site ID	X - COOR	Y - COOR	Habitat	Fish	Temperature
S.F. TOUCHET	3	83	888244.7522	5122550.5772	No	No	Yes
S.F. TOUCHET	3A	82	888252.7604	5122550.5772	No	No	Yes
S.F. TOUCHET	4	81	888364.8753	5123976.0383	No	No	Yes
S.F. TOUCHET	5	80	888840.5629	5125494.3947	No	No	Yes
S.F. TOUCHET	6	79	889220.152	5127227.3711	No	No	Yes
SPANGLER CR.	0	75	901185.6397	5123472.4348	No	No	Yes
SPANGLER CR.	1	76	902645.9982	5121984.074	No	No	Yes
SPANGLER CR.	2	77	902379.4258	5120475.4765	No	No	Yes
SPANGLER CR.	3	78	902040.9019	5118635.342	No	No	Yes
TROUBLESOME	1	185	619754.4987	5306319.8481	No	No	Yes
TROUBLESOME	2	186	620212.0941	5307498.5029	No	No	Yes
TROUBLESOME	3	187	621276.3501	5309048.0874	No	No	Yes
TROUBLESOME	3A	188	621272.8835	5309044.6207	No	No	Yes
TUCANNON	1	94	921038.2453	5126743.823	No	No	Yes
TUCANNON	10	102	908222.6231	5130691.7635	Yes	Yes	Yes
TUCANNON	11	103	907167.0464	5132059.4054	Yes	Yes	Yes
TUCANNON	11.1	212			Yes	Yes	No
TUCANNON	12	104	908101.148	5133234.3628	Yes	Yes	Yes
TUCANNON	13	105	909435.2796	5134530.7953	Yes	Yes	Yes
TUCANNON	14	106	910696.1073	5135789.5285	Yes	Yes	Yes
TUCANNON	15	107	911431.241	5137439.9143	Yes	Yes	Yes
TUCANNON	16	108	911743.3063	5138929.0314	Yes	Yes	Yes
TUCANNON	17	109	911996.7285	5140621.305	Yes	Yes	Yes
TUCANNON	18	110	911284.6331	5142185.8205	Yes	Yes	Yes
TUCANNON	19	111	910373.5699	5143790.1294	Yes	Yes	Yes
TUCANNON	2	95	919875.8543	5126997.2451	No	No	Yes
TUCANNON	20	112	909468.79	5145239.453	Yes	Yes	Yes
TUCANNON	22	113	908383.8917	5148496.2421	Yes	Yes	Yes
TUCANNON	3	96	918273.6397	5127696.7741	No	No	Yes
TUCANNON	4	97	916767.7675	5128375.3591	No	No	Yes

Appendix 3. Continued.

STREAM	SITE	Site ID	X - COOR	Y - COOR	Habitat	Fish	Temperature
TUCANNON	6	98	914878.6204	5128790.0499	No	No	Yes
TUCANNON	7	99	913125.6091	5129060.2273	No	No	Yes
TUCANNON	8	100	911383.0699	5129447.691	Yes	Yes	Yes
TUCANNON	9	101	909550.4715	5129661.3196	Yes	Yes	Yes
TURKEY	5	119	908401.8628	5123557.6725	No	No	Yes
TWISP R.	1	123	713319.1859	5361063.3778	No	No	Yes
TWISP R.	10	133	698586.2353	5360316.9508	No	No	Yes
TWISP R.	11	134	697480.5655	5360145.3126	Yes	Yes	Yes
TWISP R.	12	135	696338.9714	5359159.3904	No	No	Yes
TWISP R.	13	136	694890.025	5358616.5344	Yes	Yes	Yes
TWISP R.	14	137	693281.4151	5359362.9614	Yes	Yes	No
TWISP R.	15	138	692119.8631	5360520.5218	Yes	Yes	Yes
TWISP R.	16	139	690658.9419	5361274.9319	Yes	Yes	Yes
TWISP R.	16A	140	690658.9419	5361278.9235	No	No	Yes
TWISP R.	17	141	689345.7095	5362552.24	Yes	Yes	Yes
TWISP R.	18	142	687749.0744	5363606.0192	Yes	Yes	Yes
TWISP R.	19	143	686240.2542	5364835.4282	Yes	Yes	Yes
TWISP R.	2	124	711395.2405	5361239.0076	No	No	Yes
TWISP R.	20	144	684775.3415	5366056.8541	Yes	Yes	Yes
TWISP R.	21	145	683434.168	5367234.3725	No	No	Yes
TWISP R.	22	146	681889.4235	5368240.2526	Yes	Yes	Yes
TWISP R.	23	147	680444.4687	5369317.9813	Yes	Yes	Yes
TWISP R.	3	125	709642.9335	5361195.1002	No	No	Yes
TWISP R.	4	126	707703.0218	5360931.6554	No	No	Yes
TWISP R.	5	127	706621.3015	5361646.1496	No	No	Yes
TWISP R.	6	128	705383.9093	5361825.771	No	No	Yes
TWISP R.	7	129	703280.3425	5362149.0896	No	No	Yes
TWISP R.	8	130	701607.8673	5361690.057	No	No	Yes
TWISP R.	8A	131	701603.8757	5361686.0655	No	No	Yes
TWISP R.	9	132	699883.5013	5361239.0076	No	No	Yes

Appendix 3. Continued.

STREAM	SITE	Site ID	X - COOR	Y - COOR	Habitat	Fish	Temperature
W.F. BUTTERMILK	1	156	699893.0223	5357235.3029	Yes	Yes	Yes
W.F. BUTTERMILK	2	157	698680.3708	5355877.6989	Yes	Yes	Yes
W.F. BUTTERMILK	2A	158	698680.3708	5355874.1635	No	No	Yes
W.F. BUTTERMILK	3	159	697492.4674	5354208.9774	Yes	Yes	Yes
W.F. BUTTERMILK	4	160	696159.6114	5352996.3259	Yes	Yes	Yes
W.F. BUTTERMILK	5	161	694717.1571	5351787.2098	Yes	Yes	Yes
WOLF CR.	1	207			No	No	Yes
WOLF CR.	2	208			No	No	Yes
WOLF CR.	3	209			No	No	Yes
WOLF CR.	3A	210			No	No	Yes
WOLF CR.	4	211			No	No	Yes

Appendix 4.
Summary of summer (seasonal) temperature metrics.
An "A" after the site number indicates an air data logger, all others are water.

Appendix 4. Washington bull trout seasonal temperature metrics.

		Summer		Number of days temperature exceeded:				
STREAM	**SITE**	**Mean**	**Max**	**12C**	**14C**	**16C**	**18C**	**20C**
AHTANUM	1	18.01	25.74	48	48	48	46	44
AHTANUM	2	17.15	25.22	48	48	48	46	38
BURNT CR.	1	11.71	15.62	42	23	0	0	0
BURNT CR.	2	10.78	14.23	26	1	0	0	0
BUTTERMILK	1	11.81	16.27	45	20	1	0	0
BUTTERMILK	2	11.04	15.03	36	8	0	0	0
BUTTERMILK	2A	17.41	34.75	48	48	48	48	47
CHIKAMIN	1	10.78	16.02	37	13	1	0	0
CHIKAMIN	2	10.13	14.25	18	1	0	0	0
CHIKAMIN	2A	14.63	32.38	48	48	47	46	45
CHIKAMIN	3	9.76	13.22	9	0	0	0	0
CHIWAWA	1	12.67	17.14	43	30	11	0	0
CHIWAWA	10	11.07	14.26	26	2	0	0	0
CHIWAWA	11	10.91	14.04	25	1	0	0	0
CHIWAWA	12	10.75	13.75	21	0	0	0	0
CHIWAWA	13	10.47	13.76	16	0	0	0	0
CHIWAWA	14	10.38	13.78	16	0	0	0	0
CHIWAWA	15	10.41	14.08	18	1	0	0	0
CHIWAWA	15A	14.45	34.74	45	45	45	45	39
CHIWAWA	16	10.16	14.05	17	1	0	0	0
CHIWAWA	17	10.19	14.18	19	1	0	0	0
CHIWAWA	18	9.86	14.13	17	1	0	0	0
CHIWAWA	19	9.82	14.26	17	1	0	0	0
CHIWAWA	2	12.48	16.92	43	30	10	0	0
CHIWAWA	20	9.81	14.39	19	1	0	0	0
CHIWAWA	21	9.50	14.00	13	1	0	0	0
CHIWAWA	22	9.69	14.69	23	3	0	0	0
CHIWAWA	23	9.61	14.70	22	3	0	0	0

Appendix 4. Continued.

		Summer		Number of days temperature exceeded:				
STREAM	**SITE**	**Mean**	**Max**	**12C**	**14C**	**16C**	**18C**	**20C**
CHIWAWA	24	9.31	14.53	17	2	0	0	0
CHIWAWA	25	9.38	14.56	19	2	0	0	0
CHIWAWA	25A	13.97	31.97	45	45	45	42	39
CHIWAWA	26	9.07	14.20	15	1	0	0	0
CHIWAWA	27	9.00	13.88	13	0	0	0	0
CHIWAWA	3	12.25	16.55	43	28	7	0	0
CHIWAWA	4	12.15	15.88	43	23	0	0	0
CHIWAWA	5	11.81	15.60	41	18	0	0	0
CHIWAWA	5A	15.81	34.42	43	43	43	42	41
CHIWAWA	6	12.17	15.47	22	11	0	0	0
CHIWAWA	7	11.58	14.95	35	10	0	0	0
CHIWAWA	8	11.51	14.87	33	9	0	0	0
CHIWAWA	9	11.36	14.68	31	7	0	0	0
CHURCH CR.	1	10.67	13.58	23	0	0	0	0
GLACIER CR.	2	6.24	9.41	0	0	0	0	0
GOBLIN CR.	1	8.02	11.25	0	0	0	0	0
GOBLIN CR.	2	7.93	11.09	0	0	0	0	0
GOBLIN CR.	2A	12.87	24.97	48	41	37	34	31
GOBLIN CR.	4	7.08	11.12	0	0	0	0	0
GREEN FK.	1	14.22	23.31	48	48	48	44	29
GREEN FK.	2	11.86	16.10	41	25	1	0	0
GRIFFIN FK.	0	12.54	18.21	48	48	30	4	0
GRIFFIN FK.	1	10.93	14.87	40	18	0	0	0
GRIFFIN FK.	2	10.41	13.17	24	0	0	0	0
M.F. AHTANUM	1	11.08	16.95	39	23	5	0	0
M.F. AHTANUM	2	9.39	13.93	19	0	0	0	0
M.F. AHTANUM	3	8.16	12.37	2	0	0	0	0
M.F. AHTANUM	4	7.37	12.07	1	0	0	0	0
M.F. AHTANUM	5	8.01	13.45	10	0	0	0	0
MEADOW	6	9.93	13.41	20	0	0	0	0

CR.

Appendix 4. Continued.

		Summer		Number of days temperature exceeded:				
STREAM	**SITE**	**Mean**	**Max**	**12C**	**14C**	**16C**	**18C**	**20C**
N.F. AHTANUM	1	18.41	25.80	45	45	43	35	25
N.F. AHTANUM	10	9.89	15.36	21	11	0	0	0
N.F. AHTANUM	11	9.36	14.82	16	3	0	0	0
N.F. AHTANUM	2	15.17	21.81	48	47	42	29	14
N.F. AHTANUM	3	14.31	21.82	48	48	42	29	13
N.F. AHTANUM	4	13.55	20.99	48	45	36	21	6
N.F. AHTANUM	5	12.75	19.76	48	43	30	12	0
N.F. AHTANUM	6	11.96	18.31	35	26	14	1	0
N.F. AHTANUM	7	11.59	17.53	37	23	12	0	0
N.F. AHTANUM	8	11.14	16.73	30	17	3	0	0
N.F. AHTANUM	9	10.12	15.21	19	9	0	0	0
N.F. AHTANUM	9A	17.05	36.68	38	38	38	38	36
N.F. SKYKOMISH	1	11.45	15.50	39	18	0	0	0
N.F. SKYKOMISH	2	11.00	15.13	35	14	0	0	0
N.F. SKYKOMISH	3	10.69	14.54	32	9	0	0	0
N.F. SKYKOMISH	4	10.29	13.93	26	0	0	0	0
N.F. SKYKOMISH	4A	13.91	20.17	47	41	20	13	2
N.F. SKYKOMISH	5	10.14	13.65	21	0	0	0	0
N.F. SKYKOMISH	6	9.42	13.07	11	0	0	0	0
N.F. SKYKOMISH	7	10.00	15.18	27	4	0	0	0
N.F. TOUCHET	1	5.86	8.03	0	0	0	0	0
N.F. TOUCHET	2	7.99	11.10	0	0	0	0	0
N.F. TOUCHET	3	8.02	12.50	10	0	0	0	0
N.F. TOUCHET	4	7.52	12.09	1	0	0	0	0
N.F. TOUCHET	5	8.57	13.13	16	0	0	0	0
N.F. TOUCHET	5A	13.08	27.35	48	48	46	41	35
N.F. TOUCHET	6	9.49	13.92	22	0	0	0	0
N.F. TOUCHET	7	26.04	29.05	48	48	48	48	48
NORTH CR.	1	9.05	12.64	4	0	0	0	0

Appendix 4. Continued.

		Summer		Number of days temperature exceeded:				
STREAM	**SITE**	**Mean**	**Max**	**12C**	**14C**	**16C**	**18C**	**20C**
NORTH CR.	2	8.53	12.22	1	0	0	0	0
NORTH CR.	2A	13.87	28.39	48	45	42	41	34
NORTH CR.	3	8.25	12.82	5	0	0	0	0
PANJAB	1	11.71	16.38	46	28	2	0	0
PANJAB	2	11.23	15.69	44	23	0	0	0
PANJAB	3	10.54	13.57	20	0	0	0	0
PANJAB	4	10.06	12.67	10	0	0	0	0
PHELPS	2	8.19	13.26	8	0	0	0	0
PHELPS	2A	12.61	27.79	48	48	43	38	30
PHELPS	3	7.97	13.00	5	0	0	0	0
ROCK	1	9.76	14.91	27	7	0	0	0
ROCK	2	9.17	13.93	14	0	0	0	0
ROCK	2A	13.38	32.87	48	48	47	43	41
ROCK	3	8.94	13.55	13	0	0	0	0
S.F. AHTANUM	1	15.50	23.75	48	48	46	40	23
S.F. AHTANUM	2	14.02	20.85	48	46	36	19	2
S.F. AHTANUM	3	13.34	19.79	48	42	27	11	0
S.F. AHTANUM	5	11.58	17.84	47	32	16	0	0
S.F. SAUK	1	9.80	13.56	24	0	0	0	0
S.F. SAUK	2	9.52	13.01	18	0	0	0	0
S.F. SAUK	3	9.24	12.47	15	0	0	0	0
S.F. SAUK	4	8.76	12.04	1	0	0	0	0
S.F. SAUK	4A	14.36	27.15	47	44	40	35	28
S.F. SKOKOMISH	1	15.22	19.27	48	48	44	13	0
S.F. SKOKOMISH	10	13.71	18.36	48	45	28	5	0
S.F. SKOKOMISH	11	13.29	17.54	48	44	20	0	0
S.F. SKOKOMISH	12	13.38	17.52	48	45	20	0	0
S.F. SKOKOMISH	13	12.81	16.72	47	41	11	0	0
S.F. SKOKOMISH	14	12.44	16.02	47	37	1	0	0
S.F. SKOKOMISH	15	11.84	15.50	46	23	0	0	0

Appendix 4. Continued.

		Summer		Number of days temperature exceeded:				
STREAM	**SITE**	**Mean**	**Max**	**12C**	**14C**	**16C**	**18C**	**20C**
S.F. SKOKOMISH	15A	16.53	25.59	48	47	44	36	30
S.F. SKOKOMISH	16	11.14	14.97	43	19	0	0	0
S.F. SKOKOMISH	17	10.26	14.51	36	8	0	0	0
S.F. SKOKOMISH	18	10.35	14.32	37	8	0	0	0
S.F. SKOKOMISH	19	9.68	13.46	26	0	0	0	0
S.F. SKOKOMISH	2	15.39	19.39	48	48	42	13	0
S.F. SKOKOMISH	20	8.82	10.82	0	0	0	0	0
S.F. SKOKOMISH	21	8.00	9.43	0	0	0	0	0
S.F. SKOKOMISH	22	8.47	10.23	0	0	0	0	0
S.F. SKOKOMISH	23	10.92	13.18	12	0	0	0	0
S.F. TOUCHET	0	13.19	19.38	48	48	37	16	0
S.F. TOUCHET	1	14.68	22.01	48	48	48	42	23
S.F. TOUCHET	2	14.63	21.28	48	48	48	36	21
S.F. TOUCHET	3	16.13	23.96	48	48	48	48	43
S.F. TOUCHET	3A	18.22	34.18	48	48	48	48	48
S.F. TOUCHET	4	16.61	23.84	48	48	48	48	42
S.F. TOUCHET	5	17.51	24.57	48	48	48	48	46
S.F. TOUCHET	6	18.21	24.48	48	48	48	48	43
SPANGLER CR.	0	11.27	14.86	30	5	0	0	0
SPANGLER CR.	1	10.21	13.75	17	0	0	0	0
SPANGLER CR.	2	9.28	13.58	17	0	0	0	0
SPANGLER CR.	3	8.79	13.18	9	0	0	0	0
TROUBLESOME	2	7.95	10.18	0	0	0	0	0
TROUBLESOME	3	8.54	10.49	0	0	0	0	0
TROUBLESOME	3A	10.58	19.64	35	22	10	3	0
TUCANNON	1	9.20	12.69	5	0	0	0	0
TUCANNON	10	11.51	15.93	43	25	0	0	0
TUCANNON	11	11.90	16.94	48	35	12	0	0
TUCANNON	12	12.47	18.19	48	45	26	2	0
TUCANNON	13	12.86	18.82	48	47	32	11	0

Appendix 4. Continued.

		Summer		Number of days temperature exceeded:				
STREAM	**SITE**	**Mean**	**Max**	**12C**	**14C**	**16C**	**18C**	**20C**
TUCANNON	14	13.24	19.20	48	48	35	16	0
TUCANNON	15	14.29	19.87	48	48	40	22	0
TUCANNON	16	14.40	20.07	48	48	40	24	1
TUCANNON	17	15.14	20.94	48	48	47	34	13
TUCANNON	18	15.23	20.60	48	48	47	31	8
TUCANNON	19	15.74	20.59	48	48	48	33	9
TUCANNON	2	9.22	13.14	11	0	0	0	0
TUCANNON	20	16.08	21.12	48	48	48	39	17
TUCANNON	22	16.69	22.18	48	48	48	44	26
TUCANNON	3	9.90	13.52	14	0	0	0	0
TUCANNON	4	10.19	14.12	22	1	0	0	0
TUCANNON	6	10.57	14.60	27	2	0	0	0
TUCANNON	7	10.37	14.27	26	2	0	0	0
TUCANNON	8	10.49	14.16	30	2	0	0	0
TUCANNON	9	10.90	14.85	38	12	0	0	0
TURKEY	5	9.38	12.65	5	0	0	0	0
TWISP R.	10	12.35	17.73	48	42	17	0	0
TWISP R.	11	11.64	16.63	46	27	7	0	0
TWISP R.	12	11.97	17.11	42	33	8	0	0
TWISP R.	13	11.35	15.65	44	16	0	0	0
TWISP R.	15	10.96	15.68	46	21	0	0	0
TWISP R.	16	10.63	15.31	41	12	0	0	0
TWISP R.	16A	16.99	37.03	48	48	48	48	47
TWISP R.	17	9.94	14.02	35	2	0	0	0
TWISP R.	18	9.49	13.48	15	0	0	0	0
TWISP R.	19	9.76	13.57	17	0	0	0	0
TWISP R.	2	14.60	19.56	48	48	38	15	0
TWISP R.	20	9.93	13.86	16	0	0	0	0
TWISP R.	22	9.59	12.69	9	0	0	0	0
TWISP R.	23	9.21	12.20	1	0	0	0	0
TWISP R.	3	14.35	19.41	48	48	38	13	0

Appendix 4. Continued.

		Summer		Number of days temperature exceeded:				
STREAM	**SITE**	**Mean**	**Max**	**12C**	**14C**	**16C**	**18C**	**20C**
TWISP R.	4	13.93	19.29	48	46	34	8	0
TWISP R.	5	13.75	19.35	48	46	32	11	0
TWISP R.	6	13.48	19.32	48	47	33	9	0
TWISP R.	7	13.37	19.68	48	47	35	12	0
TWISP R.	8	13.07	19.45	48	47	34	10	0
TWISP R.	8A	18.57	37.10	48	48	48	48	48
TWISP R.	9	12.69	18.83	48	46	30	6	0
W.F. BUTTERMILK	1	10.05	13.72	15	0	0	0	0
W.F. BUTTERMILK	2	9.41	12.95	7	0	0	0	0
W.F. BUTTERMILK	2A	14.37	32.79	48	48	45	41	39
W.F. BUTTERMILK	3	8.59	11.40	0	0	0	0	0
W.F. BUTTERMILK	4	7.78	10.96	0	0	0	0	0
W.F. BUTTERMILK	5	7.08	10.53	0	0	0	0	0
WOLF CR.	1	12.92	17.54	39	31	12	0	0
WOLF CR.	2	12.21	16.65	34	18	7	0	0
WOLF CR.	3	11.66	16.43	33	15	2	0	0
WOLF CR.	3A	16.50	35.83	44	44	44	41	38
WOLF CR.	4	11.02	15.98	33	14	0	0	0

Appendix 5. Washington bull trout habitat summary metrics.

Appendix 5. Washington Bull Trout Habitat Summary. All measurements are in meters unless otherwise noted.

							Large Woody Debris (per meter)					
Stream	**Site**	**Length**	**Mean width**	**Max depth**	**Gradient**	**Conductivity**	**Single**	**Rootwads**	**Aggregates**	**Total**	**Wood class**	**Percent fines**
ahtanum												
	1	150.00	7.38	0.70	0.00	18.2	0.01	0.01	0.00	0.02	2	5.60
	2	102.70	9.21	0.51	0.56		0.02	0.00	0.01	0.03	1	12.50
buttermilk												
	1	110.00	5.95	0.31	0.60		0.00	0.00	0.00	0.00	0	6.50
	2	100.00	7.15	0.56	3.11	107.3	0.02	0.00	0.01	0.03	4	6.50
chikamin												
	1	89.80	8.38	0.77	0.00	42.2	0.04	0.04	0.02	0.11	4	12.00
	2	116.60	5.99	0.80	0.00	40.5	0.11	0.03	0.02	0.15	4	7.40
	3	90.50	6.17	0.46	0.00	42.6	0.14	0.00	0.02	0.17	4	2.90
chiwawa												
	1	104.43	17.42	1.60	0.19	29.3	0.05	0.00	0.01	0.06	1	33.33
	10	100.00	30.58	1.06	0.49	19.4	0.14	0.00	0.01	0.15	1	25.00
	11	101.50	26.89	1.84	0.00	22.5	0.05	0.00	0.00	0.05	1	6.00
	12	110.40	29.05	2.10	0.00	22	0.11	0.00	0.00	0.11	2	27.00
	13	100.00	20.25	2.20	0.00	35.3	0.07	0.01	0.03	0.11	4	29.40
	14	100.00	19.11	1.95	0.08	19.7	0.15	0.04	0.05	0.24	3	68.00
	15	100.00	18.61	1.50	0.12	28.4	0.08	0.02	0.01	0.11	4	31.80
	16	100.00	23.99	2.36	0.02	22.2	0.11	0.00	0.00	0.11	3	74.00
	17	100.00	19.73	1.50	0.14	35.7	0.05	0.01	0.01	0.07	2	29.40
	18	111.80	22.71	0.85	0.06	41	0.05	0.00	0.00	0.05	1	19.00

Appendix 5. Continued.

Stream	Site	Length	Mean width	Max depth	Gradient	Conductivity	Large Woody Debris (per meter) Single	Rootwads	Aggregates	Total	Wood class	Percent fines
	19	105.30	17.19	1.61	0.09	17.8	0.09	0.00	0.02	0.10	2	30.50
	2	100.00	22.12	0.93	0.66	32.1	0.01	0.01	0.01	0.03	1	5.00
	20	100.00	16.53	2.25	0.02	31.4	0.05	0.01	0.03	0.09	4	28.80
	21	105.00	19.24	1.08	0.00	16.8	0.10	0.00	0.02	0.11	1	18.60
	22	100.00	15.87	2.65	0.47	26.9	0.03	0.02	0.03	0.08	4	30.40
	23	115.00	20.00	2.00	0.53	30.5	0.06	0.03	0.03	0.11	4	27.20
	24	100.00	12.22	0.91	0.71	22	0.15	0.03	0.02	0.20	2	8.10
	25	100.00	14.22	1.00	0.14	28.8	0.03	0.00	0.00	0.03	1	4.40
	26	100.00	14.56	1.23	0.26	12.6	0.23	0.01	0.05	0.29	3	26.50
	27	94.30	16.66	1.00	0.69		0.03	0.00	0.02	0.05	3	5.50
	3	105.00	30.43	0.67	0.82	26.5	0.03	0.00	0.00	0.03	1	1.30
	4	100.00	27.98	1.35	0.43	40.5	0.05	0.03	0.01	0.09	2	9.00
	5	102.00	22.68	1.75	0.55	46.3	0.00	0.00	0.00	0.00	1	15.50
	6	98.00	29.63	0.72	0.16	43.9	0.03	0.00	0.00	0.03	1	11.50
	7	100.00	24.16	0.78	0.29	42	0.03	0.00	0.01	0.04	2	10.10
	8	100.00	26.98	0.95	1.47	51.1	0.06	0.00	0.02	0.08	3	5.90
	9	100.00	24.35	0.90	0.15	41.8	0.02	0.01	0.00	0.03	1	17.20
church cr.												
	1	100.00	6.96	1.01	2.16	34.7	0.12	0.06	0.01	0.19	2	12.00
glacier cr.												
	2	100.00	5.40	1.50	10.02	26.8	0.02	0.01	0.00	0.03	1	1.50
m.f. ahtanum												
	1	100.00	6.20	0.51	2.86	50.2	0.13	0.06	0.02	0.21	3	5.00
	2	93.50	5.53	0.44	3.11	40.7	0.09	0.01	0.02	0.12	4	4.20

Appendix 5. Continued.

							Large Woody Debris (per meter)					
Stream	**Site**	**Length**	**Mean width**	**Max depth**	**Gradient**	**Conductivity**	**Single**	**Rootwads**	**Aggregates**	**Total**	**Wood class**	**Percent fines**
	3	102.50	4.96	0.50	4.71	41.8	0.07	0.03	0.01	0.11	3	4.20
	4	89.00	6.09	0.59	3.47	41.5	0.20	0.02	0.09	0.31	4	36.56
	5	105.00	4.39	0.63	5.22	21.5	0.19	0.04	0.03	0.26	4	18.00
n.f. ahtanum												
	1	109.05	8.13	0.66	0.99	62.8	0.01	0.03	0.00	0.04	1	21.00
	10	97.70	5.92	1.20	3.33	43.5	0.03	0.00	0.03	0.06	4	7.60
	11	70.00	5.40	0.90	0.00	38.8	0.41	0.00	0.00	0.41	4	38.13
	2	90.00	7.91	0.66	1.12	14.2	0.01	0.00	0.00	0.01	1	1.67
	3	90.00	8.59	0.84	1.18	60	0.02	0.02	0.01	0.06	2	5.00
	4	119.00	9.22	0.57	0.86	47.2	0.00	0.00	0.00	0.00	0	4.00
	5	90.00	9.15	0.67	1.03	58.3	0.04	0.02	0.01	0.08	3	6.22
	6	90.00	7.49	0.76	1.70	13.1	0.03	0.02	0.02	0.08	2	11.67
	7	127.30	6.97	0.60	1.12	51.1	0.11	0.00	0.02	0.13	3	6.88
	8	115.90	7.40	0.66	2.91	50.3	0.08	0.01	0.01	0.09	3	7.40
	9	81.80	5.04	0.46	3.39	47.9	0.09	0.00	0.00	0.09	2	3.33
north cr.												
	1	100.00	3.61	0.78	0.00	48.5	0.15	0.02	0.06	0.23	2	2.50
panjab												
	1	103.00	6.99	0.60	1.35	53.4	0.12	0.00	0.01	0.13	2	13.50
phelps												
	2	90.00	8.71	0.80	4.96		0.09	0.00	0.04	0.13	3	5.56
	3	103.00	8.42	0.60	1.82	15.7	0.03	0.02	0.01	0.06	2	0.00
rock												
	1	116.80	6.67	1.45	0.00	42.9	0.12	0.01	0.01	0.14	4	4.70

Appendix 5. Continued.

Stream	Site	Length	Mean width	Max depth	Gradient	Conductivity	Large Woody Debris (per meter) Single	Rootwads	Aggregates	Total	Wood class	Percent fines
	2	112.00	7.72	1.00	2.79	30.5	0.02	0.00	0.00	0.02	1	4.50
	3	96.00	7.88	0.57	0.00		0.04	0.01	0.01	0.06	3	5.50
s.f. ahtanum												
	1	103.60	3.63	0.65	0.98	70.1	0.00	0.01	0.00	0.01	0	18.20
	2	106.40	4.99	0.64	2.00	51.1	0.08	0.01	0.03	0.11	3	9.50
	3	90.00	4.37	0.73	0.03	67.3	0.08	0.02	0.03	0.13	2	12.33
	5	102.00	4.95	0.38	2.56	36.6	0.06	0.02	0.01	0.09	3	8.40
s.f. sauk												
	4	100.00	15.43	0.74	0.72	20.9	0.06	0.01	0.03	0.10	2	7.60
s.f. skokomish												
	1	100.00	15.71	1.40	0.31	62.9	0.07	0.03	0.01	0.11	3	31.50
	10	108.00	14.89	1.35	0.18	56.5	0.08	0.02	0.00	0.10	2	25.90
	11	100.00	37.65	0.65	0.99	60.6	0.15	0.04	0.03	0.22	2	9.00
	12	97.00	10.07	1.65	0.00	37.3	0.09	0.02	0.01	0.12	2	32.00
	13	102.00	13.16	1.35	0.95	35.1	1.47	0.49	0.17	2.13	4	25.00
	14	100.00	14.24	0.73	0.19	33.7	0.10	0.01	0.01	0.12	3	4.60
	15	100.00	19.59	0.83	0.24	31.6	0.02	0.00	0.00	0.02	1	15.50
	16	115.50	10.87	1.43	0.24	63.1	0.02	0.00	0.00	0.02	1	18.80
	17	80.00	10.59	1.80	1.54	59.3	0.01	0.00	0.01	0.03	1	3.80
	18	110.00	10.80	0.73	0.79	54.8	0.08	0.01	0.00	0.09	1	10.00
	19	100.00	11.80	1.12	1.74	59.8	0.03	0.01	0.01	0.05	1	2.50
	2	100.00	19.91	1.10	0.45	64	0.05	0.00	0.01	0.06	4	7.00
	20	103.20	13.98	3.00	0.52	35.4	0.04	0.01	0.01	0.06	2	24.70
	21	80.00	7.16	1.36	1.75	55.4	0.15	0.00	0.01	0.16	2	10.67

Appendix 5. Continued.

Stream	Site	Length	Mean width	Max depth	Gradient	Conductivity	Large Woody Debris (per meter) Single	Rootwads	Aggregates	Total	Wood class	Percent fines
	22	155.00	7.28	0.55	1.46	31.2	0.14	0.01	0.07	0.21	2	4.50
	23	100.00	5.85	0.73	8.11	42.7	0.06	0.01	0.03	0.10	4	2.80
tucannon												
	10	100.00	10.72	0.70	0.86	61.2	0.15	0.01	0.00	0.16	3	2.60
	11	123.00	12.35	0.70	1.64	58.2	0.07	0.04	0.01	0.12	3	1.90
	12	114.60	11.71	0.60	0.88	40.1	0.05	0.00	0.03	0.08	3	4.30
	13	103.80	9.42	0.86	0.69	36.6	0.06	0.02	0.05	0.13	4	9.90
	14	190.00	12.34	0.64	1.40	58.4	0.02	0.02	0.01	0.05	2	7.50
	15	96.00	11.76	0.69	0.76	38.2	0.05	0.01	0.00	0.06	1	10.20
	16	99.00	9.83	0.87	1.25	44.8	0.02	0.02	0.01	0.05	2	6.30
	17	103.60	11.07	1.10	1.50	42.7	0.04	0.00	0.01	0.05	3	3.10
	18	107.50	13.78	1.60	1.49	61.7	0.05	0.02	0.01	0.07	4	8.60
	19	100.00	7.58	6.00	1.53	66.6	0.04	0.03	0.01	0.08	2	2.10
	20	105.60	14.84	0.50	0.67	62.3	0.01	0.01	0.00	0.02	1	11.00
	22	105.00	10.09	0.90	0.86	65.3	0.01	0.00	0.00	0.01	1	3.50
	8	100.00	7.83	0.62	1.53	56.3	0.13	0.00	0.01	0.14	3	5.50
	9	100.00	7.23	0.68	1.33	57.7	0.17	0.00	0.01	0.18	3	2.40
twisp r.												
	11	90.00	17.10	0.57	0.22	131.9	0.01	0.00	0.00	0.01	1	12.00
	13	97.00	10.85	0.95	0.26	99	0.02	0.00	0.01	0.03	1	5.10
	15	100.00	13.74	0.84	0.76	88.5	0.06	0.03	0.03	0.12	3	6.10
	16	100.00	12.28	0.68	0.88	86.2	0.01	0.00	0.04	0.05	3	5.80
	17	108.40	10.59	0.58	0.65	77.5	0.04	0.00	0.02	0.06	4	3.00
	18	100.00	11.10	0.51	0.62	77	0.00	0.00	0.00	0.00	1	1.50

Appendix 5. Continued.

							Large Woody Debris (per meter)					
Stream	**Site**	**Length**	**Mean width**	**Max depth**	**Gradient**	**Conductivity**	**Single**	**Rootwads**	**Aggregates**	**Total**	**Wood class**	**Percent fines**
	19	100.00	9.74	0.92	0.00	36.8	0.04	0.01	0.01	0.06	2	1.50
	20	100.00	7.71	1.15	1.24	34	0.03	0.03	0.02	0.08	3	16.00
	22	100.00	8.46	0.80	2.40	36.3	0.08	0.00	0.01	0.09	2	5.50
	23	100.00	5.81	0.54	2.71	27.6	0.05	0.01	0.04	0.10	2	1.00
w.f. buttermilk												
	1	100.00	5.76	0.55	4.19	58	0.08	0.00	0.01	0.09	4	5.50
	2	100.00	5.02	0.57	4.88	61.7	0.05	0.00	0.01	0.06	1	8.00
	3	100.00	6.49	0.61	6.79	37.3	0.31	0.00	0.01	0.32	2	5.50
	4	99.00	5.44	0.69	6.03	16.8	0.02	0.01	0.02	0.05	2	6.00
	5	100.00	4.43	0.60	3.47	9.5	0.05	0.00	0.00	0.05	1	3.00

Appendix 6. Washington bull trout fish snorkel summary.

Appendix 6. Washington bull trout fish summary.

Stream	Site	Bull Trout Presence/Absence	Density (per square meter) Bull Trout Juvenile	Bull Trout Adult	Brook Trout Juvenile	Brook Trout Adult	Rainbow/Cutthroat Trout Juvenile	Rainbow/Cutthroat Trout Adult	Other Salmonids Adult
ahtanum									
	1	0	0.00	0.00	0.00	0.00	0.03	0.01	0.01
	2	0	0.00	0.00	0.00	0.00	0.00	0.01	0.01
buttermilk									
	1	0	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	2	0	0.00	0.00	0.00	0.00	0.02	0.02	0.02
chikamin									
	1	0	0.00	0.00	0.01	0.00	0.00	0.00	0.01
	2	1	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	3	1	0.01	0.00	0.00	0.00	0.01	0.00	0.01
chiwawa									
	1	0	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	10	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	11	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 6. Continued.

			Density (per square meter)						
		Bull Trout	Bull Trout		Brook Trout		Rainbow/Cutthroat Trout		Other Salmonids
Stream	Site	Presence/Absence	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Adult
	13	1	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	14	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	15	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	16	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	17	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	18	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	19	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	2	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	20	1	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	21	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	22	1	0.01	0.00	0.00	0.00	0.00	0.00	0.00
	23	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	24	1	0.01	0.01	0.00	0.00	0.00	0.00	0.01
	25	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	26	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	27	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	3	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 6. Continued.

			Density (per square meter)						
		Bull Trout	Bull Trout		Brook Trout		Rainbow/Cutthroat Trout		Other Salmonids
Stream	Site	Presence/Absence	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Adult
	4	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	5	0	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	6	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	7	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	8	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	9	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
church cr.									
	1	0	0.00	0.00	0.00	0.00	0.06	0.01	0.01
glacier cr.									
	2	0							
m.f. ahtanum									
	1	0	0.00	0.00	0.00	0.00	0.03	0.04	0.04
	2	0	0.00	0.01	0.00	0.00	0.02	0.05	0.06
	3	1	0.00	0.01	0.00	0.00	0.01	0.02	0.03
	4	1	0.01	0.01	0.00	0.00	0.08	0.03	0.04
	5	0	0.00	0.00	0.00	0.00	0.05	0.07	0.07
n.f. ahtanum									

Appendix 6. Continued.

			Density (per square meter)						
		Bull Trout	Bull Trout		Brook Trout		Rainbow/Cutthroat Trout		Other Salmonids
Stream	Site	Presence/Absence	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Adult
	1	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	10	0	0.00	0.00	0.00	0.00	0.02	0.08	0.08
	11	1	0.02	0.00	0.00	0.00	0.03	0.02	0.02
	2	0	0.00	0.00	0.00	0.00	0.03	0.03	0.03
	3	0	0.00	0.00	0.00	0.00	0.02	0.01	0.01
	4	0	0.00	0.00	0.00	0.00	0.01	0.02	0.02
	5	0	0.00	0.00	0.00	0.00	0.02	0.02	0.02
	6	0	0.00	0.00	0.00	0.00	0.04	0.03	0.03
	7	1	0.00	0.00	0.00	0.00	0.03	0.01	0.01
	8	0	0.00	0.00	0.00	0.00	0.04	0.08	0.08
	9	1	0.00	0.00	0.00	0.00	0.01	0.05	0.05
north cr.									
	1	1	0.01	0.01	0.00	0.00	0.01	0.01	0.02
panjab									
	1	1	0.00	0.00	0.00	0.00	0.02	0.02	0.03
phelps									
	2	1	0.00	0.00	0.00	0.00	0.01	0.01	0.01

Appendix 6. Continued.

			Density (per square meter)						
		Bull Trout	Bull Trout		Brook Trout		Rainbow/Cutthroat Trout		Other Salmonids
Stream	Site	Presence/Absence	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Adult
	3	1	0.01	0.01	0.00	0.00	0.03	0.02	0.03
rock									
	1	1	0.01	0.01	0.00	0.00	0.00	0.00	0.01
	2	1	0.00	0.00	0.00	0.00	0.00	0.00	0.01
	3	0	0.00	0.00	0.00	0.00	0.00	0.01	0.01
s.f. ahtanum									
	1	0	0.00	0.00	0.00	0.00	0.03	0.00	0.00
	2	0	0.00	0.00	0.00	0.00	0.07	0.01	0.01
	3	0	0.00	0.00	0.00	0.00	0.03	0.02	0.02
	5	0	0.00	0.00	0.00	0.00	0.05	0.06	0.06
s.f. sauk									
	4	1	0.01	0.00	0.00	0.00	0.01	0.01	0.01
s.f. skokomish									
	1	0	0.00	0.00	0.00	0.00	0.06	0.01	0.01
	10	0	0.00	0.00	0.00	0.00	0.09	0.00	0.00
	11	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	12	0	0.00	0.00	0.00	0.00	0.03	0.01	0.01

Appendix 6. Continued.

			Density (per square meter)						
		Bull Trout	Bull Trout		Brook Trout		Rainbow/Cutthroat Trout		Other Salmonids
Stream	Site	Presence/Absence	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Adult
	13	1	0.00	0.00	0.00	0.00	0.12	0.04	0.04
	14	1	0.00	0.00	0.00	0.00	0.03	0.01	0.01
	15	0	0.00	0.00	0.00	0.00	0.03	0.00	0.00
	16	1	0.00	0.00	0.00	0.00	0.08	0.01	0.01
	17	0	0.00	0.00	0.00	0.00	0.07	0.02	0.02
	18	0	0.00	0.00	0.00	0.00	0.03	0.01	0.01
	19	1	0.00	0.00	0.00	0.00	0.02	0.02	0.02
	2	0	0.00	0.00	0.00	0.00	0.06	0.01	0.01
	20	1	0.00	0.00	0.00	0.00	0.02	0.01	0.01
	21	0	0.00	0.00	0.00	0.00	0.00	0.01	0.04
	22	0	0.00	0.00	0.00	0.00	0.03	0.02	0.02
	23	0	0.00	0.00	0.00	0.00	0.00	0.00	0.00
tucannon									
	10	1	0.00	0.00	0.00	0.00	0.03	0.01	0.02
	11	1	0.01	0.01	0.00	0.00	0.02	0.02	0.03
	12	0	0.00	0.00	0.00	0.00	0.01	0.02	0.02
	13	0	0.00	0.01	0.00	0.00	0.02	0.03	0.04

Appendix 6. Continued.

			Density (per square meter)						
		Bull Trout	Bull Trout		Brook Trout		Rainbow/Cutthroat Trout		Other Salmonids
Stream	Site	Presence/Absence	Juvenile	Adult	Juvenile	Adult	Juvenile	Adult	Adult
	14	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	15	0	0.00	0.00	0.00	0.00	0.02	0.01	0.01
	16	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	17	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	18	0	0.00	0.00	0.00	0.00	0.05	0.02	0.02
	19	0	0.00	0.00	0.00	0.00	0.03	0.02	0.03
	20	0	0.00	0.00	0.00	0.00	0.00	0.01	0.01
	22	0	0.00	0.00	0.00	0.00	0.00	0.03	0.03
	8	0	0.00	0.01	0.00	0.00	0.01	0.04	0.05
	9	0	0.00	0.01	0.00	0.00	0.04	0.03	0.04
twisp r.									
	11	0	0.00	0.00	0.00	0.00	0.02	0.00	0.00
	13	0	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	15	0	0.00	0.00	0.01	0.00	0.01	0.01	0.01
	16	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	17	1	0.00	0.00	0.00	0.00	0.01	0.02	0.02
	18	1	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 6. Continued.

			Density (per square meter)						
		Bull Trout	**Bull Trout**		**Brook Trout**		**Rainbow/Cutthroat Trout**		**Other Salmonids**
Stream	**Site**	**Presence/Absence**	**Juvenile**	**Adult**	**Juvenile**	**Adult**	**Juvenile**	**Adult**	**Adult**
	19	1	0.01	0.00	0.01	0.01	0.00	0.01	0.02
	20	1	0.06	0.02	0.00	0.00	0.01	0.01	0.03
	22	1	0.01	0.00	0.00	0.00	0.01	0.01	0.02
	23	1	0.01	0.01	0.00	0.00	0.00	0.01	0.02
w.f. buttermilk									
	1	0	0.00	0.00	0.00	0.00	0.01	0.01	0.01
	2	1	0.03	0.01	0.00	0.00	0.00	0.01	0.02
	3	1	0.02	0.01	0.00	0.00	0.00	0.00	0.01
	4	0	0.00	0.01	0.00	0.00	0.00	0.00	0.01
	5	0							