Development of Bull Trout Sampling Efficiency Models

Final Report

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TABLE OF CONTENTS

1.0 INTRODUCTION....1
1.1 Objectives....2
2.0 STUDY AREA....3
3.0 METHODS....3
3.1 WDFW Washington Field Protocols....3
3.1.1 Sampling unit selection....3
3.1.2 Blocknets and thermographs....4
3.1.3 Pre-survey fish marking....4
3.1.4 Abundance survey....4
3.1.5 Physical and chemical data....6
3.2 Statistical Analyses....9
3.2.1 Evaluation of range of sampling conditions....9
3.2.2 Modeling capture efficiency....10
3.2.3 Evaluation of model accuracy....12
3.2.4 Evaluation of fish escape....13
4.0 RESULTS....13
4. 1 Range of conditions....14
4. 2 Modeling capture efficiency....15
4. 3 Evaluation of model accuracy....18
4. 4 Evaluation of fish escape....18
4. 5 Evaluation of GIS generated gradients....18
5.0 DISCUSSION....19
5.1 Influences on capture efficiencies....19
5.2 Blocknet effectiveness....22
5.3 Comparison of gradient estimation methods....22
5.4 Limitations and problems encountered during field sampling....23
6.0 REFERENCES....25
7.0 ACKNOWLEDGEMENTS....30

TABLES 31
FIGURES 50
APPENDICES..61

1.0 INTRODUCTION

This report describes results of research conducted in Washington State in 2002 through Interagency Agreement #134100-2-H001 between the U.S. Fish and Wildlife Service (USFWS) and the U.S. Forest Service Rocky Mountain Station (RMRS). This project was a collaborative effort between the USFWS, RMRS, the Washington Department of Fisheries and Wildlife (WDFW), and the U.S. Geological Survey, Biological Resources Division (USGS-BRD). The USFWS established a separate Interagency Agreement with USGS-BRD (Agreement #13410-2-N002; detailed in Peterson et al. 2003) and a Cooperative Agreement with WDFW. The purpose of this agreement was to further develop bull trout sampling protocols by modeling and interpreting the effects of various factors on bull trout capture efficiency and probability of detection.

Bull trout sampling research in 2000 indicated that sampling efficiency in Washington streams was similar to that in Idaho streams. However, the effects of physical and chemical variables appeared to differ between States, which resulted in low predictive ability of Idaho models when applied to streams in Washington (Thurow et al. 2001). As a result of relatively small sample sizes and low numbers of marked fish in 2000, the Washington sampling efficiency models were judged to be inadequate for predicting bull trout capture efficiency Statewide. In response, Interagency Agreement #134100-2-H001 was developed. The intent of the 2002 project was to increase the number of samples and marked fish, and to provide a more thorough coverage of different habitat strata.

Extensive interest in development of bull trout sampling protocols stems from the problematic aspects of sampling bull trout. Behavior of bull trout, their specific habitat requirements, and population characteristics make them difficult to sample. Bull trout appear to have an affinity for stream reaches colder than 15 ^{0}C (Goetz 1994; Rieman and Chandler 1999) and many populations reside in streams with low conductivities (< 100 μS/cm) and high water clarity. Their coloration and cryptic behavior may make bull trout difficult to see (Thurow and Schill 1996). Bull trout frequent areas with instream overhead cover and coarse substrate (Pratt 1984). Juvenile bull trout are closely associated with the streambed and often conceal within substrate (Thurow 1997). Bull trout tend to be in relatively low densities (Schill 1992) and populations may cluster in specific areas of suitable habitat. As a result, common sampling techniques like electrofishing and snorkeling may fail to detect bull trout or underestimate their true abundance (Thurow and Schill 1996).

A critical feature to consider when designing a bull trout sampling or monitoring protocol is the influence of sampling efficiency. In addition to gear type, fish sampling efficiency is influenced by the size and species of fish (Bagenal 1977; Reynolds 1983; Riley et al. 1993) as well as physical habitat features (Bayley and Dowling 1993; Peterson 1996). Presence and absence estimates are similarly affected by sampling efficiency because the probability of detecting species is a function of its probability of capture and its density, both of which are influenced by habitat features that vary (Bayley and Peterson 2001). Therefore, gear and habitat-specific sampling efficiency estimates are required for estimating bull trout detection probabilities and sample size requirements (Peterson et al. 2002).

The ultimate goal of this research is to develop protocols for estimating the sampling effort required to achieve a desired level of accuracy in detecting the presence/absence of native salmonids. Thus, we addressed the following objectives.

1.1 Objectives

1. To estimate the probability of capturing bull trout and other non-anadromous salmonids using day snorkeling, night snorkeling, and electrofishing using an unbiased estimate of the true population.
2. To describe the influence of physical channel features including stream size, water temperature, conductivity, channel complexity, and abundance of cover on probabilities of capturing bull trout and other salmonids.
3. To compare probabilities of capture for different size classes of bull trout and other salmonids.

2.0 STUDY AREA

We selected study streams throughout Washington State, using local knowledge of Washington biologist (State, Federal, Tribal, University). We selected sites within four major regions of Washington: South East, North Central, South Central, and Puget Sound (Figure 1). Eleven river basins were represented: the American, Dungeness, Entiat, Methow, Nooksack, Stillguamish, Tieton, Tucannon, Twisp, Wenatchee, and Yakima. More detailed maps of stream locations within each region are found in Appendices A-D. In section 3.1.1., below, we describe the criteria we applied to select study sites.

3.0 METHODS

3.1 WDFW Washington Field Protocols

The crew protocols described below were designed to estimate capture efficiency through recovery of marked individuals, which was used to predict detection probabilities of detection under different sampling conditions. The rationale for our approach is detailed in Peterson et al. (2004). The ultimate goal of this research is to develop protocols for estimating the sampling effort and techniques required to achieve a desired level of accuracy in detecting the presence/absence of native salmonids. As a central hypothesis we believed that capture efficiencies are related to the sampling method, sampling effort, physical features of the sampling unit, fish species, and fish size. Prior to field data collection, crews were oriented and trained in proper techniques for study site selection, blocknet installation, thermograph installation and downloading, electrofishing and pre-survey fish marking, day- and night-snorkeling, multiple pass electrofishing, habitat surveys, and completion of data forms.

3.1.1 Sampling unit selection

Our intent was to examine fish response to sampling under conditions commonly encountered in Washington State bull trout streams. We worked with local biologists to select and inspect streams meeting criteria including: known bull trout presence, relatively large bull trout densities (>10 fish per 100m), a high likelihood of holding blocknets, good vehicle access, the ability to avoid concentrations of migratory adult bull trout, minimal conflicts with other listed species, and opportunities for being complimentary to other work. Final selection of individual study units was made in the field. We applied the sampling strata developed by Peterson and Banish (2002) to select units covering a broad range of physical habitat conditions.

Our intent was to capture relatively gross differences in conditions (high, medium, low hydraulic complexity, for example) rather than attempting to precisely measure conditions. We selected areas that were readily accessible so more time was spent sampling and less in hauling equipment to the sites. Crews paced an approximately 100 m sampling unit and selected hydraulic controls for upper and lower boundaries. Sampling unit locations were marked on topographic maps and recorded with GPS (Global Position System).

3.1.2 Blocknets and thermographs

Blocknets were installed at upper and lower unit boundaries and nets inspected using snorkeling gear to insure they were barriers to movement. In some locations, crews selected adjacent sampling units separated by a blocknet (i.e. 3 blocknets in 2 sampling units). Blocknets were held for approximately 4 days so care was taken to insure they remained fish tight. Nets were cleaned regularly until all fish sampling was completed. In a subset of sample units (11), crews installed a second set of blocknets approximately 3 m immediately above and below the up and downstream blocknets, respectively, to evaluate potential fish escape from the sample units. Crews installed a thermograph at the lowermost net and recorded hourly temperatures during the sampling period.

3.1.3 Pre-survey fish marking

Crews used electrofishing gear to capture and mark age 1+ salmonids in each unit. They completed one upstream pass and one downstream pass using unpulsed Direct Current (DC) where feasible to reduce the potential for injuring fish. The waveform and voltage were recorded with starting and ending times and water temperatures. Captured fish were placed in live wells, anesthetized, measured, and the species and total lengths recorded to the nearest 10 mm size groups. Crews notched or paper punched the dorsal or caudal fins in a manner that was visible to snorkelers. In adjacent units, differential marks were applied. To reduce the likelihood of injury, when large (>400 mm) bull trout were encountered during the pre-survey marking, crews terminated the survey and selected another sampling unit.

3.1.4 Abundance survey

Day-Snorkeling.-- Crews inspected the sample unit and selected the number of snorkelers necessary to survey the unit in a single pass. Following procedures similar to those outlined by Thurow (1994), crews snorkeled during the daytime between 1000 and 1700 by moving slowly upstream. Snorkelers counted the total number of salmonids by species, estimated size classes to the nearest 100 mm size group, and recorded marks. A data recorder on shore carried a small halogen light that the snorkelers accessed to facilitate spotting fish hidden in shaded locations. Crews recorded starting and ending times, water temperatures with a calibrated hand-held thermometer, and the divers who completed counts.

Snorkelers measured the underwater visibility of a salmonid silhouette at three locations using a secchi disk-like approach as follows. One crewmember suspended the silhouette in the water column and a snorkeler moved away until the marks on the object could not be distinguished. The snorkeler moved back toward the object until it reappears clearly and measured that distance. This procedure was repeated three times and we calculated an average visibility for the survey unit. Visibility was measured in the longest and deepest habitats (i.e. pools or runs) where a diver had the longest unobstructed underwater view. Crews also recorded whether a snorkeler could see from bank to bank underwater.

Crews also recorded the presence of non-salmonid fishes during day and night snorkel surveys and electrofishing surveys and noted whether fish were juveniles or adult. The presence of amphibian adults or juveniles was similarly noted by species.

Night-Snorkeling.-- A nighttime snorkel survey was completed in the same unit between 2230 and 0430. Crews used the identical technique applied during the daytime survey with the aide of a halogen light. Starting and ending times and water temperatures were recorded. On occasion crews varied the sequence by completing the nighttime survey first and the daytime survey the following day.

Electrofishing.-- After the day and night snorkeling were completed, crews electrofished the unit using unpulsed Direct Current (DC) where feasible to reduce the potential for injuring fish. All crews used a Smith-Root LR 24 Electrofisher and applied the following procedure to obtain amps high enough to effectively stun fish: 1.) set the option on automatic; 2.) adjust the duty cycle to 40% (when >50% batteries will drain fast); 3.) set hertz to 30; and 4.) set to 490 volts. In waters with a conductivity of at least 50 *umhos* this produced 40 to 50 amps. Crews completed four upstream passes and record the waveform, voltage, frequency, and starting and ending times and water temperatures. Fish captured during individual passes were placed in live wells along the stream margins. Crews were instructed to sample slowly and deliberately, especially near cover components and to observe captured fish and adjust voltages to reduce the risk of injuring fish. Crews were instructed that fish may be increasingly susceptible to handling stress as water temperatures increase above 16 ^{o}C so during warm days, sampling was sometimes conducted in the early morning and late evening to reduce the risk of injury. In the 11 double blocknet sites, the area between the two sets of blocknets was electrofished following the final pass to determine if any marked fish had escaped from the blocked-off area. All fish were anesthetized, measured, and the species and total lengths and marks of all salmonids recorded to the nearest 10 mm size groups. Data were recorded by individual pass. Crews were instructed to complete a 5th pass if the catch in the 4th pass did not decline by 75% or more from the 3rd pass (i.e. 4th pass catch is 25% or less of the 3rd pass).

3.1.5 Physical and chemical data

Conductivity.-- A calibrated conductivity meter was used to measure conductivity in each unit.

Channel dimensions and substrate.-- As previously stated, our intent was to capture and classify gross differences in physical habitat conditions. As a result, we used an abbreviated habitat inventory procedure. Crews measured unit physical attributes by establishing transects at 7m intervals in 100 units. To establish transects, crews used a tape to measure the unit along the centerline of the stream. At each transect, crews recorded the type of habitat, measured wetted channel width perpendicular to the flow, measured mean and maximum depth and visually classified the substrate into four size classes (Wolman 1954). In each survey unit the water surface area was calculated by averaging the mean wetted widths (at each transect) and multiplying them by the total unit length.

Habitat types.-- are discrete channel units influenced by flow pattern and channel bed shape. At each transect we classified habitats as slow (pools) or fast (riffles, pocket-water, runs, or glides). In each survey unit, we recorded the number of habitat types and the dominant habitat type encountered at the transects.

Mean depth.-- was calculated by measuring the depth at approximately 1/4, 1/2, and 3/4 the channel width and dividing the sum by four to account for zero depth at each bank (Platts et al. 1983). Crews also measured the maximum depth at each transect and at the deepest location in the entire unit.

Substrate.-- in a one meter band parallel to the transect, crews estimated the percent of the substrate in four substrate size classes: fines (< 6 mm), gravel (6-75 mm), cobble (75-150 mm), and rubble (> 150 mm). The percentages of the different substrate classes (fines, gravel, cobble, rubble) at each transect were averaged to calculate the percentage of substrate by size class in the entire survey unit.

Pools.-- In the stream segment between each transect, crews counted the number of pools and measured the length of pools. Pools were defined as either having a length greater than or equal to the wetted channel width, or occupying the entire wetted width. Crews recorded the dominant pool-forming feature in the unit: boulder, large wood, meander, bedrock, beaver, artificial, or other (described). We summed the pool lengths in the survey unit and divided them by the total length of the survey unit to determine the percentage of pools within the unit.

Large Wood.-- In the stream segment between each transect crews counted the number of pieces of large woody debris (LWD). LWD was defined as a piece of wood, lying above or within the active channel, at least 3 m long by 10 cm in diameter. The density of LWD debris in the survey unit was calculated by dividing LWD by the area of the survey unit. Crews also recorded the number of large aggregates (more than four single pieces acting as a single component) and rootwads. Crews did not count the number of individual pieces of wood in aggregates. Since we were interested in the influence of wood on detection of salmonids, we attempted to account for the cumulative amount of wood as follows: we multiplied the number of aggregates x 4 (the minimum number of wood pieces per aggregate) and added that product to the number of individual wood pieces and the number of rootwads to derive the cumulative wood count.

Cover Components.-- Crews measured the total length of the unit from the lower to the upper blocknet by summing the number of transects and adding the length of the final segment. For the entire unit, crews estimated the percent cover for each of four cover types (submerged, turbulent, overhead, undercut). Crews measured the length and average width of undercut and overhanging vegetation along each bank and recorded it. Overhead cover within 0.5 m of the water surface was included. We calculated the total area of undercut banks and overhanging vegetation in the survey unit by summing the length and multiplying by the average width of undercut banks and overhanging vegetation between each transect. We divided the area of undercut banks and overhanging vegetation by the unit surface area to calculate the percentage of the survey unit in each cover type. Crews estimated (to the nearest 10%), the percent of the reach that had turbulence and submerged cover. Turbulence develops where abrupt changes in water velocity occur. Turbulence was typically observed at changes in gradient (riffles), near physical obstructions to flow (LWD or boulders), and along irregular shorelines. Submerged cover included large boulders, bedrock, LWD, etc.

Reach Gradient.-- Two methods were applied to estimate gradient; measured in the field or from a topographic map or DEM, Gradient was measured in the field with a hand level as follows. Provided there were no visual obstructions, the observer with the level stood in the middle of the sampling unit. Another crew member stood at the start of the reach (downstream from the observer), placed a stadia rod on the substrate, held the rod vertically, and placed a pencil horizontally across the stadia rod. The observer with the level looked through the level and signaled the observer with the rod to move the pencil up or down until the bubble in the level was centered. The observer recorded the reading at the pencil (D_1) and the water depth at the edge of the rod (D_2). This procedure was repeated at the upstream edge of the sampling unit. The observer recorded the water depth at the edge of the rod (U_1) and the reading at the pencil (U_2). If the channel meandered or vegetation obstructed the view so the entire unit could not be seen from start to finish, the crews applied the following criteria. If the unit gradient was uniform, they selected the longest portion of the unit that could be seen from end to end. If the length was at least 50 m, they followed the procedures listed above and measured the length between the two stadia rods. If the longest visible portion was less than 50 m long or if the the channel gradient varied across the unit, they measured gradient in multiple increments by repeating measurements #1 and #2 and recording the length.

Reach gradients were also computed using GIS software and compared to gradient measurements obtained in the field. Digital Elevation Model (DEM) data were acquired from the USGS National Elevation Dataset (NED) (http://semless.usgs.gov) for the projection area. In addition, digital, scanned 1:24,000 scale quadrangle maps (Digital Raster Graphics (DRGs)) were aquired from the Northwest Forest Plan, Regional Ecosystem Office at http://www.reo.gov/gis.index.htm. The DEM data have a spatial resolution of 10 meters, while the DRGs consist of pixels that are 2.5 meters in size. The DEM data were compared with the

DRG maps to verify their positional accuracy, as both of theses layers were used to help locate the blocknet locations in the GIS. We applied a "flow accumulation" algorithm to the DEM data to produce a GIS layer that highlighted the stream channels. These channel locations compared favorably with the stream lines present on the DRG maps. Next we plotted GPS locations for the upper and lower boundaries (blocknets) of each study site. As expected, the GPD locations for the blocknets seldom fell directly on the stream channel. This discrepancy occurred because our GPS receivers did not host differential correction capabilities. To minimize the effect of this discrepancy on the gradient calculations results, the blocknet GPS points were manually repositioned in a GIS editor to lie on the stream channels. Both channel layer and the DRG data were used in the registration process.

We estimated stream reach gradients as follows: First, we obtained upper and lower blocknet elevations from the DEM data. Next, we divided the rise or elevational difference between the two blocknets by the run or measured unit length. Finally, we compared gradients derived via the Dem approach with those measured in the field with a hand level.

3.2 Statistical Analyses

3.2.1 Evaluation of range of sampling conditions

Model-based predictions of fish distribution, abundance, and capture efficiency should only be applied to sample units that are similar to those under which the models were parameterized. Thus, we compared the habitat conditions of sample units used during our capture efficiency evaluations to those across the bull trout range in Washington State. Previous analysis of sampling conditions across the Washington bull trout range (Peterson and Banish 2002) suggested 6 - 7 types of streams (stratum) that we used, in part, to select sample units (see above). To determine the adequacy of capture efficiency sample units for depicting bull trout sampling conditions, we classified them into these strata via discriminant analysis. Discriminant analysis can be used to classify observations into one of several groups (e.g., stratum) that they most closely resemble on the basis of a set of measurements (e.g., physical habitat measurements; Stevens 1992). We used this aspect to classify our capture efficiency sample units into strata for each of the four stratification schemes in Peterson and Banish (2002). During this procedure, discriminant functions were fit using the range of conditions data (Peterson and Banish 2002), and the capture efficiency sample units were classified using the fitted models. The distribution of sample units among strata then was used to evaluate the adequacy of the capture efficiency data.

3.2.2 Modeling capture efficiency

The number of recaptured (resighted) and marked individuals were used as dependent variables (i.e., the number of success and trials, respectively) for the beta-binomial regression modeling procedure, described below. Size classes were binary coded (0, 1) for size classes one and three with size class two as the baseline. The number of snorkelers was binary coded to examine the effect of two snorkelers on capture efficiency with one snorkeler as the baseline (Table 1). Observations during full and new moon phases were binary coded to examine the influence of moon phase on night snorkeling efficiency. Cutthroat trout data also were binary coded to examine the differences between cutthroat trout and rainbow trout capture efficiencies. Observations with experienced snorkelers, defined as snorkelers that completed 10 or more efficiency evaluations, were dummy coded to examine the effect of snorkeler experience on snorkeling efficiency. Pearson correlations were run on all pairs of continuous predictor variables (i.e., physical/chemical measurements) prior to analyses. To avoid multicollinearity, predictor variables that were strongly correlated ($r^2 > 0.2$) were not used together in the modeling procedure.

We initially fit capture efficiency models using logistic regression (Agresti 1990). A preliminary examination of the dispersion parameters for logistic regression models indicated that the data were overdispersed (i.e., the variance exceeded the presumed binomial). The excess variance also appeared to be related to the number of marked fish in the site. The best means of accounting for this type of overdispersion is to use a technique that models the variance as a function of the number of marked individuals (Liang and McCullagh 1993). To account for the overdispersion, we modeled capture efficiency using beta-binomial regression fit with R statistical software (Ihaka and Gentleman 1996) and J. Lindsey's nonlinear regression and repeated measurements libraries, available online (http://alpha.luc.ac.be/~jlindsey/rcode.html). Beta-binomial regression is similar to logistic regression, but differs from it in that variance is modeled as a beta distribution that accounts for extra variance related to the number of marked individuals (Prentice 1986) and this variance can be directly incorporated in detection probabilities (Peterson et al. 2002). Thus, we used beta-binomial regression to examine the influence of physical and chemical variables and other factors (Tables 1 and 2) on capture efficiency for day and night snorkeling and backpack electrofishing.

The goal of our sampling efficiency modeling was to obtain the simplest, best fitting (predicting) models, given our data. Thus, we used an information-theoretic approach (Burnham and Anderson 1998), to evaluate the fit of beta binomial regression models relating site characteristics and fish body size to fish capture efficiency. We began our modeling by constructing a global regression model for each species based on our observations (Thurow and Schill 1996) and those of other investigators (Riley et al. 1993) that suggest that salmonid capture efficiency is significantly influenced by stream habitat characteristics, fish body size, and species. We also included variables representing the number of snorkelers, snorkeler experience, and moon phases in the snorkeling efficiency models. We then fit all possible subsets of the global model (including all first order interactions) via beta-binomial regression. To assess the fit of each candidate model, we calculated Akaike's Information Criteria (AIC; Akaike 1973) with the small-sample bias adjustment (AIC_c; Hurvich and Tsai 1989). AIC is an entropy-based measure used to compare candidate models (Burnham and Anderson 1998). We assessed the relative fit of each candidate model by calculating Akaike weights (Burnham and Anderson 1998) that can range from 0 to 1, with the best-fitting candidate model having the greatest Akaike weight. The ratio of the weights for two candidate models also can be used to assess the relative evidence for one model over another (Burnham and Anderson 1998).

We based all inferences and predictions on the best-fitting model. The precision of coefficients for the best-fitting model was assessed by calculating 90% confidence intervals based on a *t*-statistic with n-1 degrees of freedom. We also calculated scaled odds ratios (Hosmer and Lemeshow 1989) for each predictor variable to facilitate interpretation. The odds ratio scalars corresponded to what we believed to be relevant unit changes in the predictors. The relative importance of individual predictor variables also was estimated as the sum of Akaike weights for candidate models in which each predictor occurred (Burnham and Anderson 1998). The ratio of the weights for two candidate models also can be used to assess the relative evidence for one model over another (Burnham and Anderson 1998). Thus, importance weights were only calculated for the predictor variables that occurred in one or more candidate models with weights within 10% of the largest weight, which is similar to the general rule-of-thumb (i.e., 1/8 or 12%) suggested by Royall (1997) for evaluating strength of evidence.

Goodness-of-fit was assessed for global models by examining residual probability plots. Dependence among size-classes was examined by ordering the deviance residuals by size class and sample and conducting a Wald-Wolfowitz runs test (Daniel 1990). The Wald-Wolfowitz runs test can be used to test for a non-random sequence of data about a mean (i.e., zero for the residuals). Thus, a statistically significant test of the ordered residuals would indicate dependence among size classes (Bayley 1993).

Predicted capture efficiency was calculated as:

$$\hat{p} = \{1 + \exp(-(\beta_0 + \beta_i x_i...))\}^{-1} \quad (1)$$

where $\hat{p}$ is the predicted capture efficiency as a fraction, β_0 is the constant, β_i are the model coefficients, and x_i are the corresponding variable values. Abundance estimates can be derived by dividing the number of fish collected (or counted during snorkeling) by the estimated capture efficiency, $\hat{p}$ (Peterson et al. 2004).

3.2.3 Evaluation of model accuracy

We assessed the relative bias and precision of the best fitting capture efficiency model for each species and sampling method using 10-fold cross validation. Cross validation estimates are nearly unbiased estimators of out-of-sample model performance (Funkunaga and Kessel 1971) and provide a measure of overall predictive ability without excessive variance (Efron 1983). Ten-fold cross validation was found to the optimal for estimating the expected error rate of a given model (Brieman and Spector 1992). Hence, it should provide an estimate of the ability of the models to estimate capture efficiency under conditions similar to which models were parameterized. During this procedure, the site-specific data were randomly placed into 10 groups, data from one group were excluded, the beta-binomial regression model was fit with data from the remaining 9 groups, and the capture efficiency for sites in the left out group were predicted using (1). This procedure was repeated for each group (i.e., a total of 10 times) and error was estimated as the difference between the predicted and measured (i.e., number recaptured/ number marked) efficiency. For each species, relative model bias was estimated as the mean difference and precision as the square root of the mean of the squared differences across samples.

3.2.5 Evaluation of fish escape

A potential source of bias in our study was the effect of fish escaping from the block-netted sites. To examine this, we estimated the escape rate of fishes using the number of marked fish captured between the second set of blocknets (as described above) in the 11 double blocknet sites and the total number of marked fish as dependent variables. We then fit beta-binomial regression models relating escape rate to site characteristics. We also used the information-theoretic approach (outlined above) to evaluate the relative fit of various candidate models relating escape rate to physical habitat characteristics. The global model contained a combination of physical habitat features that potentially influenced fish movement and the ability to effectively block off sites (Table 2). The low numbers of escapees (12 individuals from 11 sites) prevented us from examining the influence of fish body size and species on fish escape; hence data were pooled over species and size classes. We fit the global model and all subsets via beta binomial regression. To assess the fit of each candidate model, we then calculated AIC_c (Burnham and Anderson 1998). Similar to the efficiency models, we based our inferences on the best-fitting model and report importance weights for individual variables. Goodness-of-fit was assessed for the global model by examining deviance residual and normal probability plots (Agresti 1990).

4.0 RESULTS

WDFW crews initiated gear calibration evaluations at in 91 sites in 2002 (Table 3). Similar to the 2000 evaluations (Thurow et al. 2001), there were some difficulties in retaining complete population closure at 17 adjacent sites in which fish marked in one unit were recaptured in an adjacent unit. To minimize the influence of this potential source of bias, data collected from these sites were omitted form the analysis. The resulting data were comprised of 73 sample units. Prior to analyses, these data were added to data collected from 33 sample units in 2000 (described in Thurow et al. 2001). The combined data set (106 sites) was used for all evaluations and analyses.

Bull trout were the most numerous salmonid encountered with an average of 15.4 marked individuals per unit present in 103 of the 106 sample units (Table 4). In many instances, marked individuals of other salmonids were not present in a site and the site data could not be used in the capture efficiency modeling procedure. After eliminating these sites, the resulting data consisted of 10 sites with marked brook trout (*Salvelinus fontinalis*), 40 sites with cutthroat trout (*Oncorhynchus clarki spp.*), and 34 sites with rainbow trout (*Oncorhynchus mykiss*). Crews did not attempt to differentiate between different cutthroat trout subspecies or between anadromous and non-anadromous rainbow trout. Of these, only brook trout were collected in insufficient numbers to evaluate and model the influence of physical factors on capture efficiency. Additionally, there were substantially more marked fish in the 100 - 199 mm size class, across all species (Table 4).

Densities of bull trout ranged from 0.001 fish per 100m^2 to 0.43 fish per 100m^2 and averaged 0.058 fish per 100m^2 (Figure 2). Most (64%) of the units supported less than 0.05 fish per 100m^2. Densities of all salmonids ranged from 0.003 fish per 100m^2 to 0.436 fish per 100m^2 and averaged 0.089 fish per 100m^2 (Figure 2). Most (70%) of the units supported less than 0.10 fish per 100m^2.

4.1 Range of conditions

Sample units in 2002 averaged 994 m elevation and were in relatively narrow (average mean wetted width of 5.5 m) and shallow (average depth of 0.17 m) streams (Table 2). Our sites also represented an average of 2.9 different habitat types per unit sampled. The mean surface area of our sites was 539 m. Sample units in the combined 2000 and 2002 data set represented a wide variety of stream types and habitats (Table 2). However, comparison with the range of conditions databases (in Peterson and Banish 2002) indicated some differences (Table 5). All Washington bull trout streams tended to have larger areas of undercut banks and larger wood density than was encountered in units sampled during the capture efficiency evaluations (Table 5). The classification of sample units into the sampling stratum also suggested that the efficiency evaluations may have missed one or two stratum (Table 6) that were generally characterized by larger areas of undercut banks and moderate to high wood densities. The remaining strata appeared to be well represented among the combined sample units.

4.2 Modeling capture efficiency

Day snorkeling.-- Deviance residuals from the global bull trout and cutthroat trout/rainbow trout day snorkeling efficiency models suggested that they adequately fitted the data. Wald-Wolfowitz runs test of the residuals ordered by size class and sample unit indicated no strong dependence among size classes for bull trout and cutthroat trout/rainbow trout (Table 7). Therefore, we assumed that the model fit was adequate for the subsets of the global models. Beta-binomial models of bull trout day snorkeling efficiency indicated that the best fitting model contained undercut banks, rubble substrate, and fish body size (Table 8). Importance weights for these 3 predictors were, on average, 1.85 times greater than the next best predictor, mean water temperature (Table 9). Day snorkeling efficiency was positively related to body size, but negatively to undercut banks, and rubble substrate (Figure 3). The parameter estimates also indicated that day snorkeling efficiency was greatest for the largest size group (200- 350 mm TL). Scaled odds ratios suggested that bull trout day snorkeling efficiency was most strongly and positively related to body size. Snorkeling efficiency for the 200- 350 mm TL size class was more than three times that of the 100-199 mm TL size group (the baseline, Table 8). Day snorkel efficiency also was, on average, 23% lower with each 5% increase in undercut banks and 9% lower with each 10% increase in rubble substrate (Table 8).

Initial fits of the combined cutthroat trout and rainbow trout day snorkeling efficiency models indicated little difference between the two species. Candidate models containing the species binary indicator variable were never among the best fitting models and indicator variable Akaike importance weights were among the lowest for the predictors considered (Table 10). Consequently, the data for the two species were pooled (i.e., one data point per species size group per sample unit) and beta binomial models were fit using the pooled data (henceforth defined as the Oncorhynchus group). The best fitting beta-binomial model of day snorkeling efficiency for Oncorhynchus group contained wood density, mean wetted width, and fish body size (Table 11). Importance weights for these 3 variables were, on average, 1.92 time greater than the next best fitting variable, mean cross-sectional area. Day snorkeling efficiency was most strongly and negatively related to body size and was, on average, 6 times lower for the 60- 99 mm TL size group compared to the baseline 100- 199 mm TL size group. Oncorhynchus group snorkeling efficiency also was negatively related to mean wetted stream width, but positively related to wood density (Figure 4). Scaled odds ratios suggested that day snorkel efficiency was, on average, 10% lower with each 0.5 m increase in mean wetted width and 19% greater with each 0.05 $/m^2$ increase in wood density (Table 11).

Night snorkeling.-- Similar to the day snorkeling models, the deviance residuals from the global bull trout and combined cutthroat trout/rainbow trout day snorkeling efficiency models suggested that they fitted the data. Wald-Wolfowitz runs test of the residuals ordered by size class and sample unit also suggested no strong dependence among size classes for bull trout and cutthroat trout/rainbow trout (Table 7). Therefore, we assumed that model fit was adequate for the candidate models.

The best fitting beta-binomial model of bull trout night snorkeling efficiency contained percent pool habitats and fish body size (Table 8). Importance weights suggested that these predictors were 1.19 times more likely the best compared to the next best-fitting predictor stream gradient (Table 9). Bull trout night snorkeling efficiency was most strongly related to body size and was 2.74 times lower and 2.10 times greater for the 60- 99 mm TL and 200- 350 mm TL size groups, respectively, compared to the 100-199 mm TL size group (Table 8). Night snorkeling efficiency also was positively related to percent pool habitats (Figure 5) and was, on average, 2% greater with each 5% increase in pools.

The combined cutthroat trout/rainbow trout night snorkeling efficiency models that contained the species indicator variable were not among the best fitting. Akaike importance weights for the indicator variables also were among the lowest for the predictors considered (Table 10). Hence, these data were pooled over species and candidate models refit. The best fitting beta binomial model of Oncorhynchus group night snorkeling efficiency contained percent rubble substrate, percent gravel substrate, and fish body size (Table 11). The importance weights for these predictors also were the greatest among the predictor variables considered (Table 10). Oncorhynchus group night snorkeling efficiency also most strongly and negatively related body size and was, on average, 4.37 times lower for the 60- 99 mm TL size group, compared to the 100- 199 mm TL size group (Table 11). Night snorkeling efficiency also was negatively related to rubble and gravel substrate (Figure 6) and was 25% and 28% lower with each 10% increase in rubble and gravel substrate, respectively.

Electrofishing.-- Deviance residuals from the global models of bull trout and combined cutthroat trout/rainbow trout single and three-pass capture efficiency indicated that they adequately fitted the data. Wald-Wolfowitz runs test of residuals ordered by size class and sample also indicated no detectable dependence among size classes for bull trout single pass and three-pass models and cutthroat trout/rainbow trout single pass and three-pass models (Table 7). Hence, we assumed that the model fit was adequate for the candidate models (i.e., the subsets of the global models).

The best fitting beta binomial models of bull trout single and three-pass electrofishing efficiency contained the same set of variables: mean stream cross sectional area, conductivity, and fish body size (Table 12). The Akaike importance weights for these predictors also were the greatest among single and three-pass electrofishing efficiency predictors (Table 9). Bull trout one and three-pass electrofishing capture efficiency was most strongly related to fish body size and was 1.46 and 1.44 times lower, respectively, for the 60-99 mm TL size group than the 100-199 mm TL size group (Table 12). In contrast, one and three-pass efficiency were for the 200-350 mm TL size group were 1.76 and 2.00 times, respectively, greater than the 100-199 mm TL size group. Electrofishing efficiency also was negatively related to stream cross sectional area, whereas it was positively related to stream conductivity (Figures 7 and 8).

Similar to the snorkeling efficiency models, initial fits of single and three-pass electrofishing models indicated no measurable difference between cutthroat trout and rainbow trout. Models containing the species binary indicator parameter were not among the best fitting models and Akaike importance weights were among the lowers for single and three-pass electrofishing. Hence, the data were combined into a single Oncorhynchus group. The best fitting beta-binomial models of electrofishing efficiency for the Oncorhynchus group differed between single and three-pass models. The best fitting single-pass model contained fish size only, whereas the best fitting three-pass model contained mean water temperature, rubble substrate, and fish body size (Table 13). Similar to all other efficiency models, the Akaike importance weights were the greatest for the predictors in the best fitting models (Table 10). Single and three-pass electrofishing efficiency was most strongly related to body size and was 2.26 and 2.31 times lower, respectively, than the 100-199 mm TL size group (Table 13). Three-pass electrofishing efficiency, however, was positively related to mean water temperature and rubble substrate and percent pool habitats (Figure 9). Scaled odds ratios suggested that three-pass efficiency was 6% greater for each 1 ^{0}C increase in temperature and 9% greater with each 10% increase in rubble substrate (Table 13). In contrast to the bull trout models, there were no measurable differences in capture efficiency between the two largest size classes.

4.3 Evaluation of model accuracy

Cross-validation of the capture efficiency models indicated that they were relatively unbiased. For example, the mean difference between predicted and known efficiency was less than 1% and 1.5% for bull trout and Oncorhynchus group, respectively, across methods (Table 14).

4.4 Evaluation of fish escape

Residuals from the global model of fish escape from the blocked off sites indicated that it adequately fitted the data. The best-fitting model contained stream cross-sectional area (Table 15), which was positively related to fish escape from the blocked-off area, but was relatively imprecise as indicated by the wide confidence interval for both the parameter estimate the beta binomial dispersion parameter. The average escape rate at the 11 double blocknet sites was 1.63%, which more than double the, 0.7%, rate measured by Thurow et al. (2001) in Idaho streams.

4.6 Evaluation of GIS generated gradients

We found a substantial difference between the field calculated gradients and those computed using DEM's (Figure 10). The DEM calculated gradients deviated from the field-measured gradients by an average of 292.6% (Table 17). Our results suggest that our DEM-based methods for estimating the elevations of blocknets and for calculating gradients were not sufficiently accurate.

5.0 DISCUSSION

Salmonid capture efficiencies estimates for Washington streams, as estimated from the recapture of marked individuals, were considerably lower than previously reported (range 45%-100%) for other stream-dwelling salmonids (Riley and Fausch 1992; Thompson and Rahel 1996; Thurow and Schill 1996; Heimbuch et al. 1997; Kruse et al. 1998 and references therein), but were similar to those reported for Idaho streams (Peterson et al. 2004) and warmwater stream-dwelling fishes (Bayley and Dowling 1990; Peterson 1996). These differences were likely a result of the use of removal estimates as the baseline for estimating capture efficiencies for previous salmonid studies in contrast to the use of unbiased abundances for this study and Bayley and Dowling (1990), Peterson (1996), and Peterson et al. (2004). Removal estimates are known to be biased by factors such as fish species and size (Mahon 1980; Buttiker 1992; Anderson 1995; Peterson et al. 2004); the number of removal passes and estimator (White et al. 1982; Riley and Fausch 1992; Peterson et al. 2004); and fish abundance and the physical characteristics of the area sampled (Kennedy and Strange 1981; Bohlin 1982; Riley et al. 1993; Peterson et al. 2004). Indeed, Peterson et al. (2004) found that stream-dwelling bull trout and cutthroat trout capture efficiencies in Idaho were overestimated, on average, 57% and 29%, respectively, by the removal estimator. These relatively high biases strongly suggest that biologists should evaluate the efficiency of their sampling protocols prior to their adoption, so that management decisions are based on high quality data.

5.1 Influences on capture efficiencies

We estimate that three-pass electrofishing and night snorkeling efficiency for 100-199 mm TL bull trout under average conditions (e.g., values in Table 2) were 35.5% and 27.0%, respectively, whereas corresponding estimates for Oncorhynchus (combined rainbow trout and cutthroat trout) were 48.7% and 36.0%, respectively. In contrast, bull trout day snorkeling efficiency for 100-199 mm TL size group was higher under average conditions (10.9%) than similar sized Oncorhynchus (9.9%). The day snorkeling results are counter to the results of our prior sampling efficiency studies (Thurow et al. 2001). As in prior years, bull trout were the target species for our evaluations and crews were sent to sampling sites that contained high densities of bull trout. For example, a total of 1,649 bull trout were marked in our sample sites compared to 804 rainbow trout and 447 cutthroat trout. If 2002 crews focused on re-sight of bull trout instead of all species, this may have biased the day snorkeling results. Alternatively, the lower efficiencies for Oncorhynchus during day snorkeling may have been influenced by the increased visibility in Washington streams (2.86 m) compared to those in Idaho (2.23 m). This increase in visibility may have allowed rainbow trout and cutthroat trout that typically hold positions off of the substrate to better detect snorkelers and flee. This is consistent with a recent evaluation of combined Idaho and Washington State data (Peterson *unpublished*), in which bull trout day snorkeling efficiency was negatively influenced by increased visibility when visibility exceeded 2.75 m.

Physical habitat characteristics, individually and in combination, significantly affected day and night snorkeling and electrofishing sampling efficiencies for bull trout, rainbow trout, and cutthroat trout. For example, undercut banks and rubble substrate negatively influenced bull trout day snorkeling efficiencies, whereas mean wetted cross sectional area and undercut banks negatively influenced bull trout electrofishing efficiency. All of these factors contribute to the complexity of the sample unit by increasing fish cover components and potentially decreasing the ability of the snorkelers to effectively spot fish or electrofishers to capture fish. Undercut banks also can provide complex habitats that are difficult to sample or count fishes, whereas large sampling units may provide more opportunities for fish to avoid capture.

Temperature was positively related to electrofishing efficiency for Oncorhynchus. Positive effect temperatures on sampling efficiencies have been attributed to the effects of temperature on fish activity (Bayley and Dowling 1990; Rodgers et al. 1992; Peterson and Rabeni 2001). Fish metabolism and activity levels are positively related to water temperature (Fry 1971). At very low temperatures, metabolic rates were reduced and fish tended to become lethargic, with decreased feeding and movement (Windell 1978). As temperatures warm, fish metabolism increases which lead to increased activity. Because bull trout were the target species for our evaluations, most sample sites were located at cold, high elevation streams at the periphery of rainbow trout and cutthroat trout distributions. Thus, the very low water temperature may have caused a greater proportion of fish to move into in protective cover and become less vulnerable to capture.

We found a strong positive relationship between efficiency and fish body size across species and methods, which was consistent with previously cited studies. Larger individuals were more vulnerable to electrofishing, presumably due to the hypothesized greater voltage differential across larger fish, and the greater visibility of larger fish (Bagenal 1977; Buttiker 1992; Reynolds 1996). Similarly, larger fish are more visible to snorkelers making them easier to detect and count, whereas smaller individuals may be better able to conceal.

There were no detectable differences in capture efficiency between rainbow trout and cutthroat trout, across sampling methods. Although presence of hybrids and mis-identification of rainbow and cutthroat trout could influence the lack of detectable differences, we hypothesize that similarities in capture efficiencies for rainbow and cutthroat trout are real and correctly reflect similarities in behavior and morphology. This is consistent with previous evaluations of capture efficiency for warmwater fishes (Bayley and Dowling 1990; Peterson 1996; Peterson and Rabeni 2001; Bayley and Austen 2002) that found that, in general, capture efficiency did not detectably differ between closely related species. For example, electrofishing efficiency for stream-dwelling black basses (*Micropterus* spp.) were not detectably different. Capture efficiency is influenced by morphological and behavioral traits. These traits are similar in closely related species; hence capture efficiencies are likely similar. Indeed, in an evaluation of rotenone efficiencies, Bayley and Austen (1990) found that previously reported species differences were actually due to body size and habitat differences; untested factors in the previous studies. In our case, although rainbow trout tend to prefer moderate or faster water velocities (Everest 1969), and cutthroat trout tend to prefer lower water velocities, both rainbow and cutthroat behave similarly by maintaining positions in the water column above the substrate or other submerged cover. That similar species have similar capture efficiencies also suggests that the results of previous capture efficiency studies may be useful as starting points for evaluating capture efficiencies of other species. For example, Bayley and Dowling (1990) evaluated the efficiency of various sampling methods for multiple warmwater species using rotenone-adjusted abundance data as a benchmark. Given that body shape, size, and behavior influence sampling efficiency, we would hypothesize that bull trout capture efficiency is similar to the catfishes and madtoms (e.g., *Noturus* spp.). This is probably not unrealistic given that both: (1) can attain similar sizes, (2) are nocturnally active, (3) are benthic, and (4) tend to use crevices or cavities. Using the catfish models in Bayley and Dowling (1990), we estimate that single pass electrofishing efficiency for 70-100 mm TL catfishes averages about 10%, which is similar to 12.4% estimate for similar sized bull trout under average conditions.

5.2 Blocknet effectiveness

Population closure is essential for estimating snorkeling and electrofishing efficiencies (Peterson et al. 2004). Marked fishes leaving sampling units would prevent their recapture, negatively biasing efficiency estimates. In 2002, fish movement rates through blocknets in

Washington streams averaged 1.63%, which was more than double the 0.7% rate measured in Idaho (Peterson et al. 2004). Half of the 12 fish that were observed moving occurred at a single sampling unit that contained large amounts of boulder and bedrock substrate. These conditions made it difficult to seal off the streambed and close the site. This highlights the importance of carefully selecting blocknet locations in future evaluations to ensure closure. The single, high movement event also skewed escape rates higher due to the relatively low number of double blocknetted sites (11) and the greater leverage of the single event. Further, the relatively low number of double blocknetted sites also decreased our ability to detect potential effects on fish movement. To avoid these problems, we recommend that crews be thoroughly trained in the various factors influencing blocknet closure and that the necessity of closure be emphasized. Additionally, we suggest that biologists conduct a greater number of double blocknet evaluations to ensure accurate estimates of fish movement.

5.3 Comparison of gradient estimation methods

We believe that there were two primary causes for the discrepancy between field measured gradients and those derived from DEMs: 1) the inaccuracy of the original GPS locations made it difficult to determine the exact blocknet locations. As expected, the GPS collected locations for the blocknets seldom fell directly in the stream channel. This discrepancy occurred because the GPS receivers did not host differential correction capabilities, and 2) the spatial resolution of the DEM data may have been too course for the relatively short stream reaches that were sampled. Initially, this appeared to be the limiting factor on our calculated accuracies. However, after analyzing our results it appears that accuracy was a random event. For example, in South Creek none of the points fell directly one the stream layer so they had to be moved at least five to ten pixels to the stream. The results of the DEM calculated gradients for units 1, 2, and 3 were; 2.94%, 1.95%, and 2.30%. Compared to field measured gradients of 2.92%, 2.12%, and 2.92%, respectively. In contrast, when points fell directly on the stream or within one pixel the results were not always accurate compared to our field measured gradients. For example in units one through three on Whistler Creek points were on or within one pixel of the stream channel. The results of the DEM calculated gradients for units 1, 2, and 3 were; 9.22%, 15.32%, and 11.42%. Compared to the field measured gradients of 3.64%, 6.08%, and 6.74%.

5.6 Limitations and problems encountered during field sampling

As we have detailed previously (Thurow et al. 2001; Peterson and Bayley *in press*), capture efficiency models should only be applied under conditions that are similar to those used to develop the models. Unfortunately, crews were unable to conduct gear evaluations under all of the conditions typically encountered in Washington bull trout streams, placing limitations of the usefulness of the models in this report. For example, there were probably an insufficient number of samples from sites with large amounts of undercut banks. This likely resulted in an underestimation of the effect of undercut banks on efficiencies. For example, Peterson et al. (2004) report strong negative effect of undercut banks on bull trout electrofishing efficiency, whereas undercut banks were not in the best fitting Washington State models. Similarly, previous studies reported that bull trout day snorkeling efficiency was positively related to stream temperature (Thurow and Schill 1996; Thurow et al. 2001). However, temperature was not in the best fitting Washington State snorkeling efficiency model. Additionally, body size is known to influence electrofishing and snorkeling efficiencies, but on several occasions differences were not detected between size classes in the current study. To remedy the potential problems and increase the ability to detect additional habitat, species, and body size effects, we suggest that future efforts include the Idaho data (Thurow et al. 2001) in modeling.

At the start of the field season, we encountered numerous problems associated with achieving desirable settings with the LR Smith-Root Electrofishers. Most of the streams we sampled had low conductivities (mean of 53.4 *umhos*), which required high amps (> 40amps) in order to effectively capture fish. At the start of the field season we had difficulty producing enough amps without overloading the electrofisher and depleting our batteries. After experimenting and talking to engineers at Smith-Root we were able to establish a process for setting our electrofishers to produce enough amps to effectively capture fish (see section 3.1.4)

We also encountered numerous breakdowns. During the course of the field season, six out of six new electrofishers had to be repaired at least once and three had to be repaired twice. The required repairs ranged from broken wires in the anode, melted wires in the anode, and motherboards overheating and melting. We also encountered chronic design problems including: anode and cathode cables that become pinched because of the location and size of the exit hole; battery covers that constantly came loose, activating a safety switch and shutting down the unit;

the on/off switch on the top of the unit would shut off while moving over log jams, through bushes, etc.; lifting the anode or cathode out of the water while the trigger was pressed would cause the electrofisher to shut down making it extremely difficult to sample shallow waters; and the shocker would overload and shut down when moving from shallower to deeper water. We have communicated these concerns and design flaws to Smith-Root engineers and they have been very responsive and helpful.

Early in the field season, we were unable to sample some streams known to support high densities of bull trout because stream flows were unfavorable for setting and holding our blocknets. After flows subsided, returning adult chinook salmon, and large (>400 mm) bull trout prevented us from sampling. For example, in the Puget Sound area runoff did not subside until late August so we were only able to sample one stream.

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List of Tables

Table 1. The distribution of number of snorkelers, snorkeler experience defined as the number of snorkel runs completed, moon phases, and bank-to bank visibility observations among sampling gear calibrations. Snorkeler number-specific means, standard deviations and ranges of site dimensions are included for comparison.

Table 2. Means, standard deviations, and ranges of habitat measurements for sample units used during gear calibration procedure.

Table 3. Basins, streams, and number of sample units completed during 2002 capture efficiency field studies in Washington State.

Table 4. Number of sites with marked individuals and the mean, standard deviation, and range of the number of marked individuals, by species and total length size class

Table 5. Number of observations, mean, standard deviation, and range of stream physiochemical data in Washington state bull trout streams, by dataset.

Table 6. Percent of calibration sample units classified in each stratum for each of the four stratification schemes detailed in Peterson and Banish (2002).

Table 7. Results of Wald-Wolfowitz runs test of ordered residuals from beta binomial regression of day and night snorkeling efficiency and one and three-pass electrofishing for bull trout, cutthroat trout and rainbow trout, and the Oncorhynchus group.

Table 8. Parameter estimates, standard errors, and associated upper lower 90% confidence limits for the best-fitting beta-binomial regression models of bull trout day and night snorkeling efficiency.

Table 9. Akaike importance weights for parameters in confidence set of beta-binomial regression models for Oncorhynchus group day and night snorkeling efficiency and one and three-pass electrofishing efficiency. Importance weights for cutthroat trout binary indicator variable are from analysis of cutthroat trout and rainbow trout efficiencies and are shown for comparison.

Table 10. Parameter estimates, standard errors, and associated upper lower 90% confidence limits for the best-fitting beta-binomial regression models of bull trout single pass and three-pass electrofishing efficiency.

Table 11. Parameter estimates, standard errors, and associated upper lower 90% confidence limits for the best-fitting beta-binomial regression models of Oncorhynchus group day and night snorkeling efficiency.

Table 12. Akaike importance weights for parameters in confidence set of beta-binomial regression models for bull trout day and night snorkeling efficiency and one and three-pass electrofishing efficiency.

Table 13. Parameter estimates, standard errors, and associated upper lower 90% confidence limits for the best-fitting beta-binomial regression models of Oncorhynchus group single pass and three-pass electrofishing efficiency.

Table 14. Cross-validation results for best-fitting beta-binomial regression models of bull trout and Oncorhynchus group capture efficiency.

Table 15. Akaike importance weights for parameters in confidence set of beta-binomial regression models of fish escape from blocked off sites.

Table 16. Parameter estimates, standard errors, and associated upper and lower confidence limits for best-fitting beta binomial regression model of fish escape from blocked off sites.

Table 17. Comparisons of hand calculated gradients and DEM calculated gradients by basins and streams. 2002 sampling efficiency field studies in Washington.

Table 1. The distribution of number of snorkelers, snorkeler experience defined as the number of snorkel runs completed, moon phases, and bank-to bank visibility observations among sampling gear calibrations. Snorkeler number-specific means, standard deviations (in parenthesis) and ranges of site dimensions are included for comparison.

	One snorkeler	Two snorkelers
Percent of observations	74.7	25.2
Unit length (m)	96.6 (20.48)	96.2 (17.70)
	43 - 153	65 - 140
Mean width (m)	5.00 (1.58)	6.98 (1.46)
	2.7 - 10.4	5.2 - 10.5
Mean depth (m)	0.16 (0.06)	0.19 (0.04)
	0.1 - 0.3	0.1- 0.3
Snorkeler experience	Number of snorkelers	
1 to 4	11	
5 to 9	10	
10 to 14[a]	9	
15 or more[a]	1	
Moon phase	Percent of observations	
New moon	25.2	
First quarter	19.4	
Last quarter	33.0	
Full moon	22.3	
Bank-to bank visibility	99.0	

[a]Classified as experienced snorkelers.

Table 2. Means, standard deviations (in parenthesis), and ranges of habitat measurements for the 106 sample units used during gear calibration procedure. Predictors with abbreviations (Abbr.) were uncorrelated and were used in the candidate capture efficiency models.

Predictor	Abbr.	Mean (SD)	Range
Unit elevation (m)		994 (273.8)	169 - 1479
Unit length (m)		98 (28.1)	44 - 300
Mean wetted width (m)	MWID	5.50 (1.77)	2.7 - 10.5
Mean depth (m)	MDEP	0.17 (0.05)	0.1 - 0.4
Mean maximum depth (m)		0.34 (0.08)	0.2 - 0.6
Mean cross sectional area (m^2)	CRX	1.00 (0.56)	0.2 - 2.5
Field measured gradient (%)	UNIT_GR	3.46 (2.00)	0.4 - 11.1
Mean water temperature (^{0}C)	MWT	9.27 (2.24)	4.5 - 14.3
Mean visibility - day (m)	MVSBD	2.85 (1.14)	1.1 - 7.8
- night (m)	MVSBN	2.94 (0.91)	1.4 - 5.0
Conductivity (µohms)	CONDUCT	54.4 (31.36)	10 - 148
% Surface turbulence		30.6 (22.00)	0 - 90
% Submerged cover		40.1 (25.00)	0 - 90
% undercut banks	PCTUCT	1.6 (3.67)	0 - 33
% overhanging vegetation	PCTVEG	4.5 (9.79)	0 - 80
Cumulative wood density (no./m^2)	DENCWC	0.06 (0.07)	0 - 0.4
Substrate composition			
% fine		12.2 (11.49)	0 - 55
% gravel	PCTGRAV	25.0 (12.04)	5.5 - 56
% cobble	PCTCOBB	32.0 (10.13)	7 - 56
% rubble	PCTRUBB	30.5 (18.62)	1 - 76
Number of habitat types		2.86 (0.96)	1 - 5
Total pool lengths (m)		6.52 (7.36)	0 - 40
% pools	PCTPL	6.9 (7.94)	0 - 40
Voltage (electrofishing)	VOLTS	547 (213.4)	100 - 1000

Table 3. Basins, streams, and number of sample units completed during 2002 capture efficiency field studies in Washington State.

River Basin	Stream	Number of sample units
American	Deep Creek	6[a]
Dungeness	Gold Creek	3[a]
Entiat	Mad River	2
Methow	E. Fork Buttermilk Creek	4
	Goat Creek	7
	Pine Creek	3
	Reynolds Creek	2
	Robinson Creek	3[b]
	W. Fork Buttermilk Creek	6[b]
Nooksak	Canyon Creek	3
	Shellneck Creek	2
	Bell Creek	7[a]
	Wanlick Creek	2
	Whistler Creek	3
Stillaguamish	Unknown Tributary	1
	Palmer Creek	3
Tieton	Bear Creek	2
Tucannon	Spangler Creek	5
	Meadow Creek	2
	N. Fork Touchet	4[a]
	Panjab Creek	2
Twisp	N. Fork Twisp	1
	South Creek	3
Wenatchee	Willow Creek	1
Yakima	Gold Creek	2
	Indian Creek	8
	M. Fork Ahtanum	4

[a] Two sample units were excluded from analysis due to high escape rate.

[b] All sample units were excluded from analysis due to high escape rate.

Table 4. Number of sites with marked individuals (N) and the mean, standard deviation (in parenthesis), and range of the number of marked individuals, by species and total length size class.

Species	N	Size class (mm)	Mean	Range
Brook trout	10	60 - 99	1.00 (1.15)	0 - 4
		100 - 199	4.40 (2.55)	1 - 9
		200 - 350	-	-
		ALL	5.40 (2.67)	2 - 10
Bull trout	103	60 - 99	2.97 (4.87)	0 - 28
		100 - 199	11.67 (18.21)	0 - 105
		200 - 350	0.78 (1.56)	0 - 7
		ALL	15.42 (21.43)	1 - 116
Cutthroat trout	40	60 - 99	2.23 (2.76)	0 - 11
		100 - 199	6.03 (5.86)	0 - 21
		200 - 350	1.03 (1.42)	0 - 6
		ALL	9.28 (8.72)	1 - 36
Rainbow trout	34	60 - 99	8.09 (8.17)	0 - 25
		100 - 199	19.18 (12.94)	0 - 45
		200 - 350	1.76 (2.30)	0 - 8
		ALL	29.03 (19.07)	1 - 66

Table 5. Number of observations, mean, standard deviation (SD), and range of stream physiochemical data in Washington state bull trout streams (Peterson and Banish 2002), by dataset.

	Number of observations	Mean wetted width (m)	Gradient (%)	% undercut banks	Wood density (no/m^2)	Conductivity (μohms)
Present study						
Mean (SD)	114	5.50 (1.77)	3.5 (2.00)	1.6 (3.67)	0.06 (0.07)	54.4 (31.36)
Range		2.7 - 10.5	0.4 - 11.1	0 - 33	0.00-0.38	9 - 148
All potential bull trout streams						
Mean (SD)	1478	6.35 (4.29)	3.1 (2.10)	7.0 (16.25)	0.04 (0.07)	49.1 (28.09)
Range		0.3 - 29.6	0.1 - 16.6	0 - 88	0.0 - 0.50	9 - 199
All potential streams < 7.5 m wide						
Mean (SD)	1064	4.25 (1.69)	3.4 (2.08)	7.9 (17.21)	0.04 (0.07)	46.1 (25.06)
Range		0.3 - 7.5	0.2 - 16.6	0 - 88	0.0 - 0.50	9 - 199
All streams verified by WDFW						
Mean (SD)	276	9.30 (5.71)	2.5 (2.24)	5.4 (12.90)	0.08 (0.08)	70.0 (41.75)
Range		1.0 - 29.6	0.1 - 11.8	0 - 77	0.0 - 0.50	9 - 197
WDFW verified streams < 7.5 m wide						
Mean (SD)	141	5.09 (1.69)	3.5 (2.32)	6.9 (15.94)	0.07 (0.09)	64.0 (41.25)
Range		1.0 - 7.5	0.3 - 11.8	0 - 77	0.0 - 0.50	9 - 197

Table 6. Percent of calibration sample units classified in each stratum for each of the four stratification schemes detailed in Peterson and Banish (2002).

	Stratum						
Stratification scheme	1	2	3	4	5	6	7
All streams	33.0	30.1	1.0	31.1	0.0	4.9	0.0
All streams < 7.5m	5.8	0.0	1.0	30.1	0.0	31.1	32.0
WDFW verified	7.8	0.0	48.5	0.0	40.8	2.9	-
WDFW verified < 7.5m	4.9	0.0	0.0	33.0	31.1	31.1	-

Table 7. Results of Wald-Wolfowitz runs test of ordered residuals from beta binomial regression of day and night snorkeling efficiency and 1 and 3 pass electrofishing for bull trout, cutthroat trout and rainbow trout, and Oncorhynchus group (cutthroat trout and rainbow trout combined).

	Runs	Z	P-value
Bull trout			
Day snorkeling	63	-0.705	0.240
Night snorkeling	90	-0.381	0.351
Single pass electrofishing	88	-0.903	0.183
Three pass electrofishing	92	-0.345	0.365
Cutthroat trout and rainbow trout			
Day snorkeling	53	-0.691	0.245
Night snorkeling	70	-1.022	0.153
Single pass electrofishing	83	0.850	0.802
Three pass electrofishing	81	0.671	0.749
Oncorhynchus group			
Day snorkeling	49	-1.020	0.154
Night snorkeling	75	-0.560	0.288
Single pass electrofishing	77	0.934	0.825
Three pass electrofishing	71	0.091	0.536

Table 8. Parameter estimates, standard errors (in parenthesis), and associated upper lower 90% confidence limits (CL) for the best-fitting beta-binomial regression models of bull trout day (top) and night snorkeling efficiency. The size class with total lengths (TL) between 100 - 199 mm was used as the baseline in the regression.

Parameter	Estimate	Upper 90% CL	Lower 90% CL	Odds ratio unit change	Odds ratio
Day snorkeling					
Intercept	-1.337 (0.272)	-0.891	-1.783		
% undercut banks	-0.221 (0.110)	-0.042	-0.401	5	0.80148
% rubble substrate	-0.022 (0.008)	-0.009	-0.034	10	0.97854
200- 350 mm TL	1.306 (0.342)	1.867	0.745	1	3.69012
Dispersion	0.258 (0.049)				
Night snorkeling					
Intercept	-1.113 (0.152)	-0.864	-1.362		
% pools	0.017 (0.010)	0.034	0.000	5	1.0171
60 - 99 mm TL	-1.007 (0.258)	-0.583	-1.431	1	0.36533
200- 350 mm TL	0.742 (0.287)	1.213	0.272	1	2.10085
Dispersion	0.138 (0.019)				

Table 9. Akaike importance weights for parameters in confidence set of beta-binomial regression models for bull trout day and night snorkeling efficiency and one and three-pass electrofishing efficiency. Bold values identify variables in best-fitting models.

	Snorkeling		Electrofishing	
Parameter	Day	Night	1 pass	3 pass
Mean wetted width	0.423	0.581	0.477	0.398
Mean depth	0.440	0.490	0.411	0.437
Mean cross sectional area	0.259	0.465	**1.000**	**0.998**
Field measured gradient	0.423	0.763	0.308	0.263
Mean water temperature	0.462	0.503	0.271	0.261
Mean visibility	0.270	0.260	-	-
Conductivity	-	-	**0.997**	**0.981**
% undercut banks	**0.975**	0.259	0.596	0.370
% overhanging vegetation	-	-	0.345	0.313
Cumulative wood density	0.332	0.318	0.287	0.371
% gravel substrate	0.353	0.276	0.524	0.321
% rubble substrate	**0.819**	0.324	0.319	0.321
% pools	0.258	**0.840**	0.296	0.307
Voltage	-	-	0.304	0.270
Full moon	-	0.691	-	-
60 - 99 mm TL	0.457	**1.000**	**0.762**	**0.593**
200- 350 mm TL	**0.771**	**0.876**	**0.889**	**0.747**

Table 10. Akaike importance weights for parameters in confidence set of beta-binomial regression models for Oncorhynchus group day and night snorkeling efficiency and one and three-pass electrofishing efficiency (top). Bold values identify variables in best-fitting models. Importance weights for cutthroat trout binary indicator variable (bottom) are from analysis of cutthroat trout and rainbow trout efficiencies and are shown for comparison.

	Snorkeling		Electrofishing	
Parameter	Day	Night	1 pass	3 pass
Mean wetted width	**0.751**	0.288	0.298	0.280
Mean depth	0.289	0.264	0.473	0.266
Mean cross sectional area	0.432	0.295	0.365	0.272
Field measured gradient	0.389	0.410	0.292	0.271
Mean water temperature	0.280	0.265	0.295	**0.598**
Mean visibility	0.330	0.256	-	-
Conductivity	-	-	0.264	0.256
% undercut banks	0.335	0.271	0.255	0.270
% overhanging vegetation	-	-	0.345	0.313
Cumulative wood density	**0.741**	0.318	0.248	0.262
% gravel substrate	0.429	**0.435**	0.282	0.341
% rubble substrate	0.370	**0.670**	0.292	**0.591**
% pools	0.263	0.397	0.252	0.466
Voltage	-	-	0.331	0.285
Full moon	-	0.332	-	-
60 - 99 mm TL	**1.000**	**1.000**	**1.000**	**1.000**
200- 350 mm TL	0.424	0.250	0.243	0.249
Cutthroat trout binary indicator variable	0.272	0.270	0.279	0.363

Table 11. Parameter estimates, standard errors (in parenthesis), and associated upper lower 90% confidence limits (CL) for the best-fitting beta-binomial regression models of Oncorhynchus group day (top) and night snorkeling efficiency. The size class with total lengths (TL) between 100 - 199 mm was used as the baseline in the regression.

Parameter	Estimate	Upper 90% CL	Lower 90% CL	Odds ratio unit change	Odds ratio
Day snorkeling					
Intercept	-1.322 (0.553)	-0.416	-2.229		
Mean wetted width	-0.198 (0.097)	-0.039	-0.357	0.5	0.906
Cumulative wood density	3.458 (1.908)	6.588	0.328	0.05	1.189
60 - 99 mm TL	-1.835 (0.470)	-1.065	-2.606	1	0.160
Dispersion	0.061 (0.010)				
Night snorkeling					
Intercept	0.726 (0.603)	1.714	-0.262		
% rubble substrate	-0.023 (0.008)	-0.009	-0.036	10	0.798
% gravel substrate	-0.024 (0.016)	0.002	-0.051	10	0.783
60 - 99 mm TL	-1.474 (0.229)	-1.098	-1.849	1	0.229
Dispersion	0.072 (0.010)				

Table 12. Parameter estimates, standard errors (in parenthesis), and associated upper lower 90% confidence limits (CL) for the best-fitting beta-binomial regression models of bull trout single pass (top) and three-pass electrofishing efficiency. The size class with total lengths (TL) between 100 - 199 mm was used as the baseline in the regression.

Parameter	Estimate	Upper 90% CL	Lower 90% CL	Odds ratio unit change	Odds ratio
Single-pass					
Intercept	-1.328 (0.284)	-0.863	-1.793		
Conductivity	0.011 (0.003)	0.015	0.006	20	1.304
Mean cross sectional area	-0.846 (0.238)	-0.456	-1.237	0.25	0.809
60 - 99 mm TL	-0.377 (0.227)	-0.004	-0.750	1	0.686
200- 350 mm TL	0.564 (0.305)	1.064	0.064	1	1.758
Dispersion	0.070 (0.010)				
Three-pass					
Intercept	-0.389 (0.263)	0.043	-0.820		
Conductivity	0.008 (0.003)	0.012	0.004	20	1.220
Mean cross sectional area	-0.642 (0.198)	-0.316	-0.967	0.25	0.852
60 - 99 mm TL	-0.366 (0.201)	-0.036	-0.696	1	0.694
200- 350 mm TL	0.687 (0.292)	1.166	0.209	1	1.989
Dispersion	0.138 (0.017)				

Table 13. Parameter estimates, standard errors (in parenthesis), and associated upper lower 90% confidence limits (CL) for the best-fitting beta-binomial regression models of Oncorhynchus group single pass (top) and three-pass electrofishing efficiency. The size class with total lengths (TL) between 100 - 199 mm was used as the baseline in the regression.

Parameter	Estimate	Upper 90% CL	Lower 90% CL	Odds ratio unit change	Odds ratio
Single-pass					
Intercept	-0.743 (0.083)	-0.607	-0.879		
60 - 99 mm TL	-0.814 (0.180)	-0.520	-1.109	1	0.443
Dispersion	0.028 (0.005)	0.035	0.020		
Three-pass					
Intercept	-0.825 (0.398)	-0.173	-1.478		
Mean water temperature	0.054 (0.036)	0.113	-0.005	1	1.055
% rubble substrate	0.009 (0.004)	0.015	0.002	10	1.089
60 - 99 mm TL	-0.837 (0.172)	-0.555	-1.119	1	0.433
Dispersion	0.065 (0.008)				

Table 14. Cross-validation results for best-fitting beta-binomial regression models of bull trout (top) and Oncorhynchus group (combined cutthroat trout and rainbow trout) capture efficiency.

	Mean error	Root mean squared error
Bull trout		
Day snorkeling	0.009	0.243
Night snorkeling	0.002	0.292
Single-pass electrofishing	0.015	0.242
Three-pass electrofishing	0.002	0.323
Oncorhynchus group		
Day snorkeling	0.014	0.154
Night snorkeling	-0.008	0.289
Single-pass electrofishing	-0.006	0.261
Three-pass electrofishing	0.004	0.281

Table 15. Akaike importance weights for parameters in confidence set of beta-binomial regression models of fish escape from blocked off sites. Bold values identify variables in best-fitting models.

Parameter	Importance weight
Mean cross sectional area	**0.303**
Field measured gradient	0.183
% undercut banks	0.181
Cumulative wood density	0.115
Mean water temperature	0.111
% pools	0.111
% rubble substrate	0.104
% gravel substrate	0.101
% overhanging vegetation	0.100

Table 16. Parameter estimates, standard errors (in parenthesis), and associated upper and lower confidence limits (CL) for best-fitting beta binomial regression model of fish escape from blocked off sites (N = 11 streams).

Parameter	Estimate	Upper 90% CL	Lower 90% CL	Odds ratio unit change	Odds ratio
Intercept	-5.143 (0.990)	-6.766	-3.520		
Mean cross sectional area	1.275 (0.785)	-0.013	2.563	0.250	1.375
Dispersion parameter	0.020 (0.140)				

Table 17. Comparisons of hand calculated gradients and DEM calculated gradients by basins and streams. 2002 sampling efficiency field studies in Washington.

River Basin	Stream	Survey Unit	Elevation meters	Hand Calculated Gradient %	GIS Calculated Gradient %	% Difference
American	Deep Creek	1	1062.23	1.22	2.13	74.27
		2	1142.24	0.90	1.87	107.91
		3	1140.26	2.02	1.76	12.85
		4	1138.28	1.92	1.69	12.02
		5	1145.74	0.36	1.54	327.79
		6	1147.27	0.02	3.93	19548.40
Entiat	Mad River	1	1378.46	4.66	5.30	13.68
		2	1392.94	4.16	3.48	16.33
Methow	EF Buttermilk Creek	1	874.93	2.36	5.39	128.37
		2	880.41	3.90	5.63	44.40
		3	960.88	1.84	3.86	109.79
		4	962.86	3.30	4.49	36.18
	Goat Creek	1	1193.29	3.82	4.00	4.66
		2	1197.86	3.38	4.50	33.04
		3	1214.78	5.78	2.91	49.71
		4	1222.86	4.16	5.08	22.06
		5	1209.90	3.00	2.62	12.76
		6	1289.91	2.70	7.31	170.72
		7	1282.45	4.02	5.92	47.32
	Pine Creek	1	1104.75	4.11	7.57	84.08
		2	1109.78	5.08	2.73	46.19
		3	1111.91	8.93	9.38	5.05
	Robinson Creek	1	829.82	5.84	6.70	14.65
		2	776.33	6.86	4.47	34.86
		3	782.88	7.36	9.49	28.93
	WF Buttermilk Creek	1	1168.45	3.86	6.66	72.60
		2	1167.84	5.88	8.83	50.14
		3	1164.34	6.05	6.61	9.22
		4	1177.90	6.06	6.43	6.06
		5	1188.42	5.22	5.27	0.96
		6	1200.30	6.05	5.30	12.41
NF Ahtanum	Shellneck Creek	1	1396.29	5.90	5.77	2.22
		2	1401.32	7.04	6.11	13.18
Nooksack	Bell Creek	1	770.23	3.38	2.74	18.95
		2	773.28	2.78	2.37	14.60
		3	775.87	0.94	2.57	173.01
		4	777.85	2.49	3.90	56.54
		5	776.94	1.52	5.16	239.64
		6	764.44	3.38	3.25	3.90
		7	766.42	2.08	2.83	35.84

Table 17. continued

River Basin	Stream	Survey Unit	Elevation meters	Hand Calculated Gradient %	GIS Calculated Gradient %	% Difference
Nooksack	Canyon Creek	1	1040.89	1.24	2.12	70.66
		2	1042.87	1.40	2.16	54.36
		3	1045.46	1.64	2.20	34.03
	Wanlick Creek	1	586.89	2.26	2.56	13.43
		2	590.40	1.78	2.60	46.20
	Whistler Creek	1	888.80	3.64	9.22	153.38
		2	923.85	6.08	15.32	152.06
		3	941.37	6.74	11.42	69.42
Stillaguamish	Palmer Creek	1	558.24	1.70	5.98	252.04
		2	575.46	2.16	2.37	9.71
		3	569.98	1.72	2.17	26.23
	Unknown Tributary	1	568.30	0.57	1.31	129.84
Tieton	Bear Creek	1	1126.85	5.50	12.98	136.00
		2	1133.25	4.04	4.56	12.89
Tucanon	Spangler Creek	1	1014.83	5.94	7.35	23.77
		2	1023.37	7.74	7.38	4.62
		3	1032.36	6.22	8.81	41.63
		4	1052.32	11.10	9.09	18.15
		5	1060.40	5.74	8.97	56.23
	Meadow Creek	1	1110.23	4.29	6.58	53.39
		2	1109.78	1.74	4.49	158.29
	NF Touchet	1	1269.34	2.62	5.50	109.79
		2	1274.37	0.51	6.07	1089.77
		3	1252.88	4.28	3.39	20.87
		4	1260.81	4.06	3.21	20.94
	Panjab	1	977.80	1.47	1.93	31.29
		2	978.71	3.18	2.01	36.86
Twisp	NF Twisp	1	1130.81	3.74	5.10	36.35
	South Creek	1	964.84	2.92	2.94	0.55
		2	968.81	2.12	1.95	8.16
		3	973.23	2.92	2.30	21.19
Wenatchee	Willow Creek	1	808.33	4.58	1.99	56.55
Yakima	Gold Creek	1	800.86	1.01	0.80	20.37
		2	768.71	0.41	0.73	77.22
	Indian Creek	1	950.37	2.18	2.76	26.66
		2	947.93	0.94	2.21	134.96
		4	1012.85	3.86	3.37	12.60
		5	1012.85	3.04	3.40	11.72
		6	1016.97	3.04	3.16	3.96
		7	1020.93	3.85	3.00	22.20
		8	1095.91	3.04	4.12	35.66
		9	1019.86	2.60	3.11	19.56

Table 17. continued

River Basin	Stream	Survey Unit	Elevation meters	Hand Calculated Gradient %	GIS Calculated Gradient %	% Difference
Wenatchee Yakima	MF Ahtanum	1	1463.19	3.19	3.49	9.38
		2	1470.81	2.18	4.19	92.14
		3	1474.77	3.26	1.93	40.75
		4	1479.19	4.17	4.60	10.42

List of Figures

Figure 1. Sampling efficiency study stream locations in four major regions of Washington, 2002. Each dot represents multiple study sites.

Figure 2. Density of Bull Trout and all Salmonids, Washington, 2002

Figure 3. Predicted day snorkeling efficiency for two total length size classes of bull trout versus percent rubble substrate and percent undercut banks.

Figure 4. Predicted day snorkeling efficiency for two total length size classes of Oncorhynchus group versus mean wetted width and cumulative wood density.

Figure 5. Predicted night snorkeling efficiency for three total length size classes of bull trout versus percent pool.

Figure 6. Predicted night snorkeling efficiency for two total length size classes of Oncorhynchus group versus percent gravel substrate and percent rubble substrate.

Figure 7. Predicted single-pass electrofishing capture efficiencies for three total length size classes of bull trout versus stream cross-sectional area and conductivity.

Figure 8. Predicted three-pass electrofishing capture efficiencies for three total length size classes of bull trout versus stream cross-sectional area and conductivity.

Figure 9. Predicted three-pass electrofishing capture efficiencies for two total length size classes of Oncorhynchus group versus stream water temperature and percent rubble substrate.

Figure 10. Comparison of hand measured gradients and Dem measured gradient in Washington, 2002.

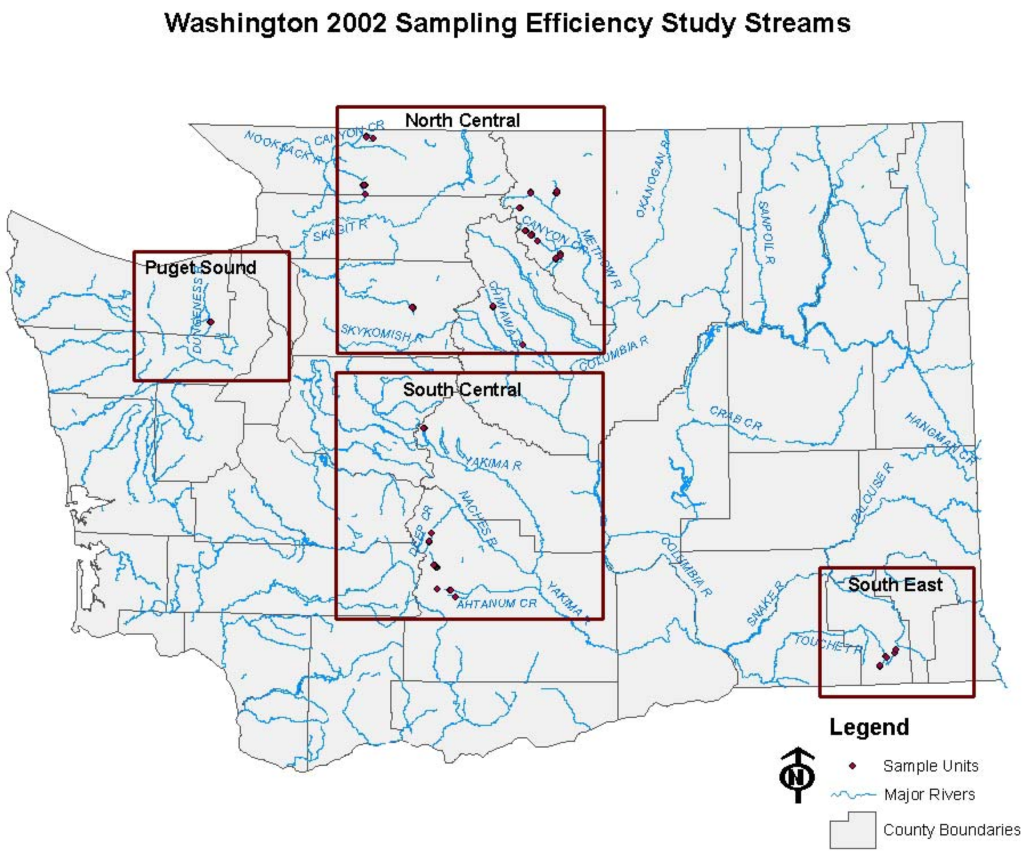
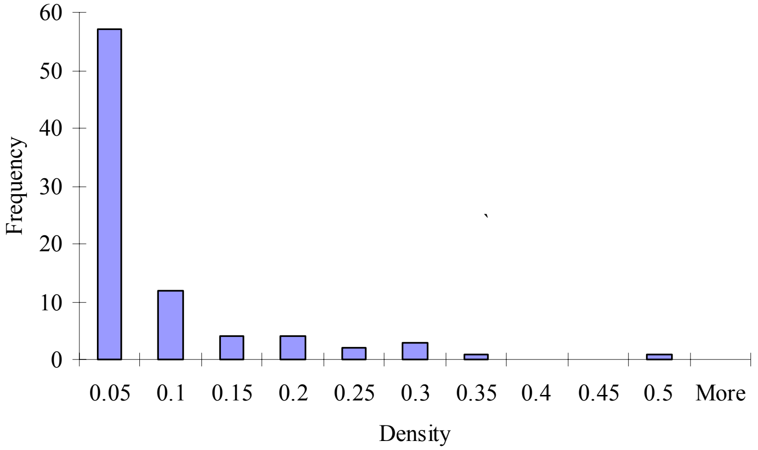


Figure 1. Sampling efficency study stream locations in four major regions of Washington, 2002. Each dot represents multiple study sites.

Bull Trout Washington, 2002



Salmonids Washington, 2002

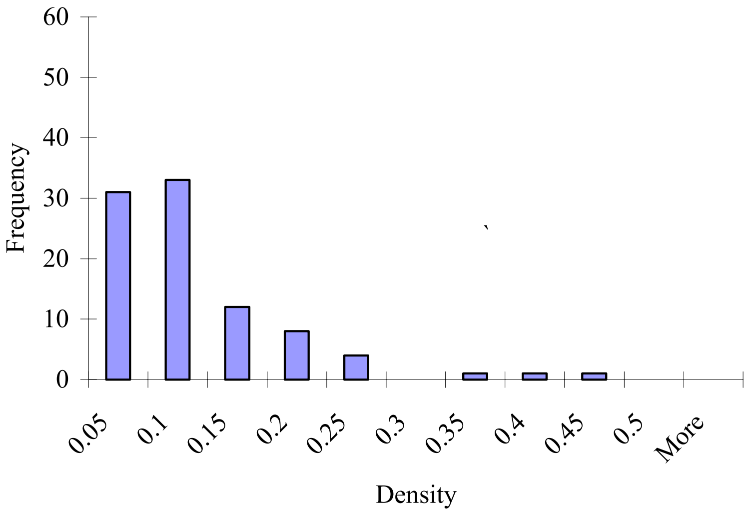


Figure 2. Density of Bull Trout and all Salmonids, Washington, 2002

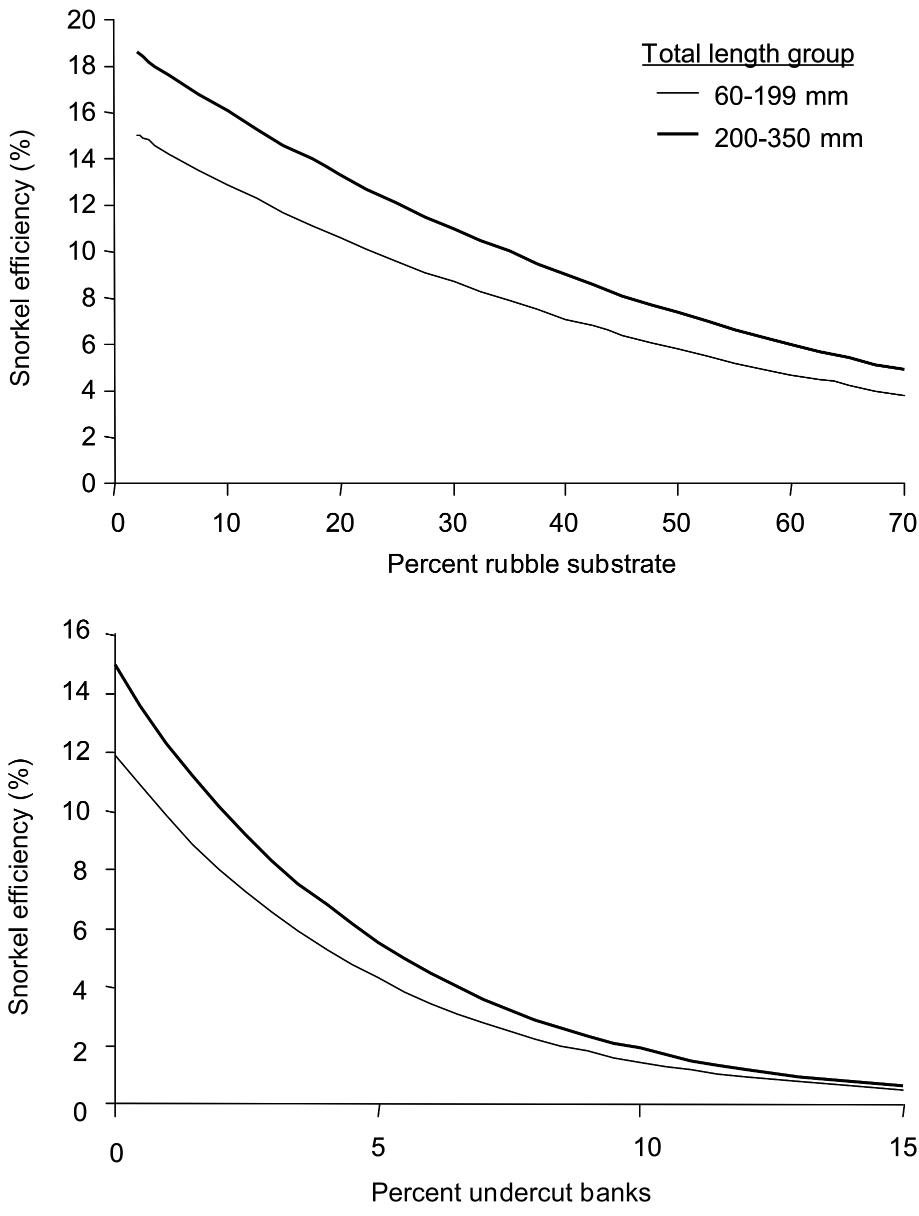


Figure 3. Predicted day snorkeling efficiency for two total length size classes of bull trout versus percent rubble substrate (top) and percent undercut banks (bottom). Predictions based on best fitting best-fitting beta binomial model and assuming 1.6% percent undercut banks (top) and 30% rubble substrate (bottom).

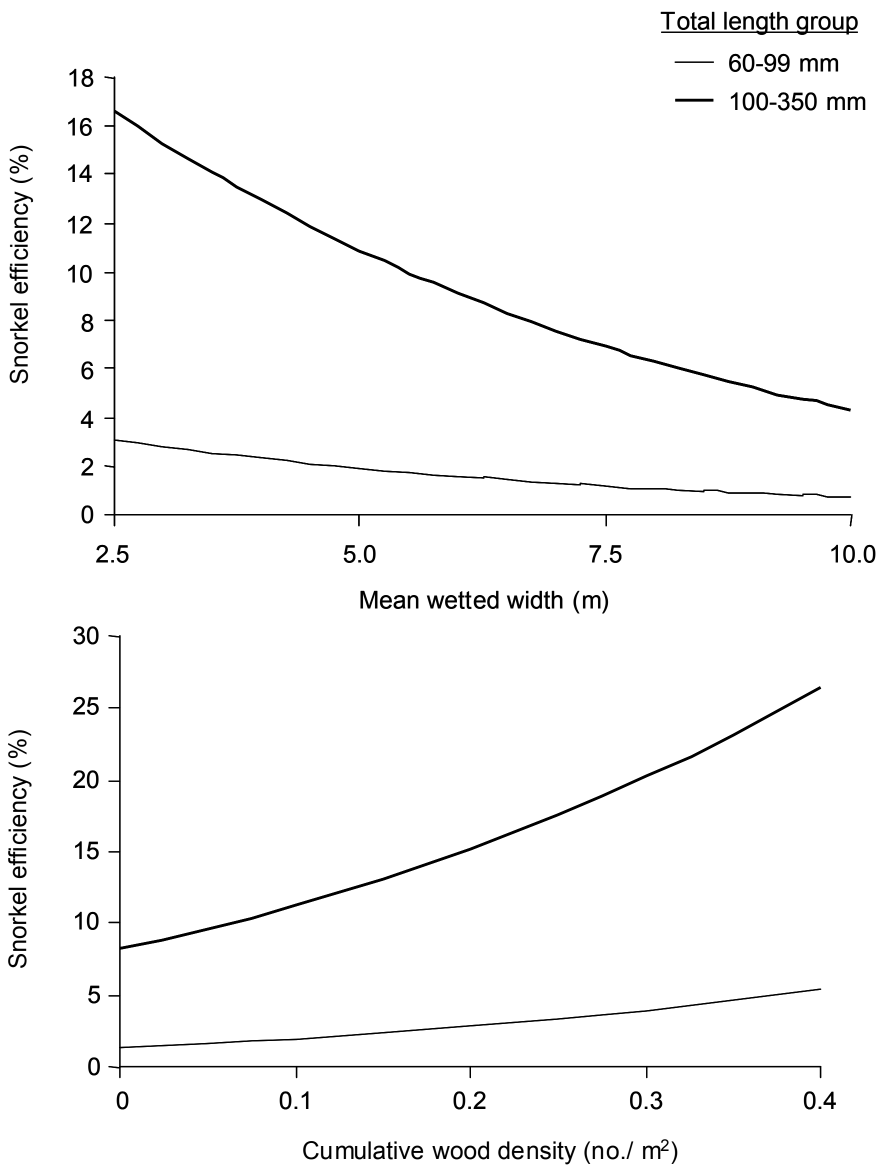


Figure 4. Predicted day snorkeling efficiency for two total length size classes of Oncorhynchus group versus mean wetted width (top) and cumulative wood density (bottom). Predictions based on best fitting best-fitting beta binomial model and assuming 0.06 no./m^2 cumulative wood density (top) and 5.5 m mean wetted width (bottom).

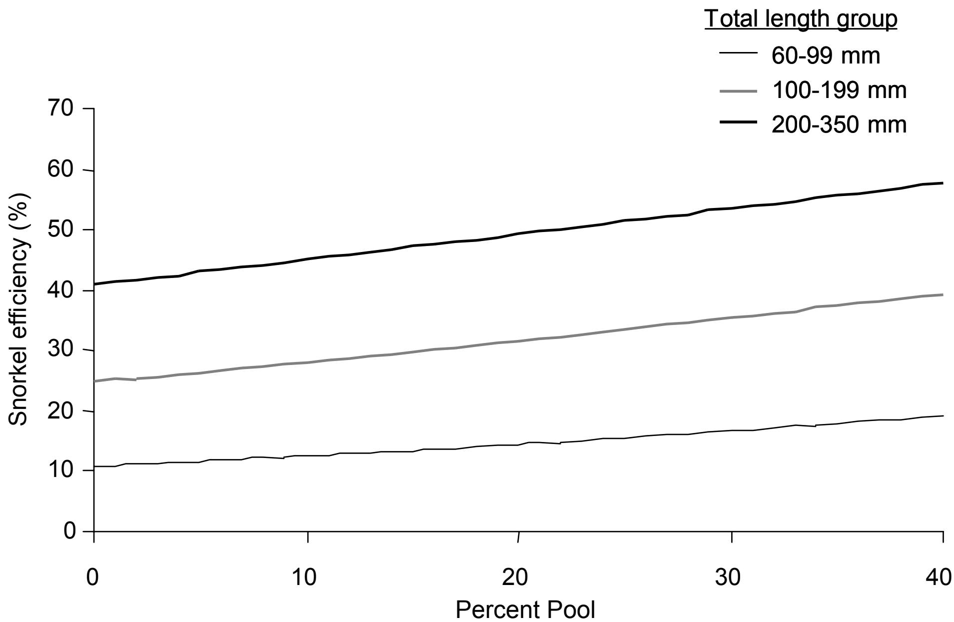


Figure 5. Predicted night snorkeling efficiency for three total length size classes of bull trout versus percent pool. Predictions based on best fitting best-fitting beta binomial model.

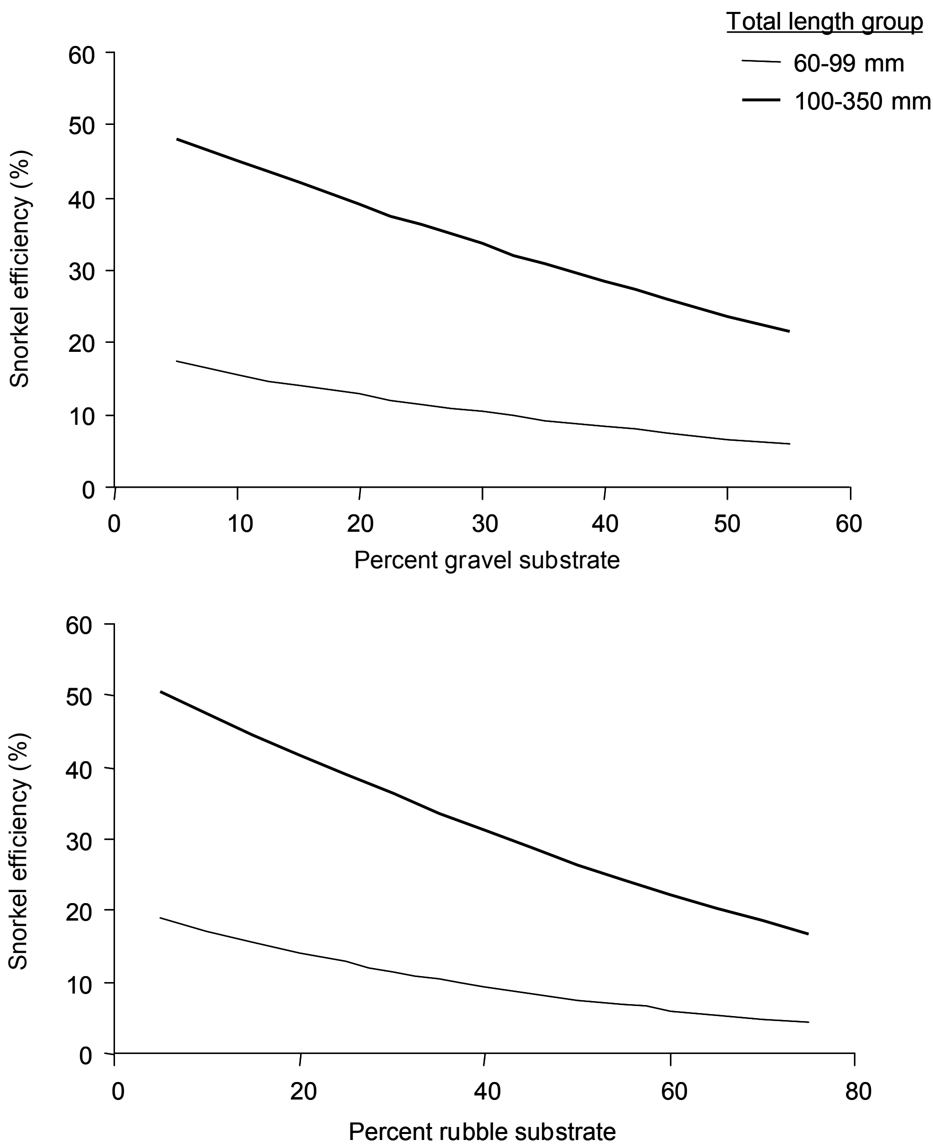


Figure 6. Predicted night snorkeling efficiency for two total length size classes of Oncorhynchus group versus percent gravel substrate (top) and percent rubble substrate (bottom). Predictions based on best fitting best-fitting beta binomial model and assuming 30% rubble substrate (top) and 25% gravel substrate (bottom).

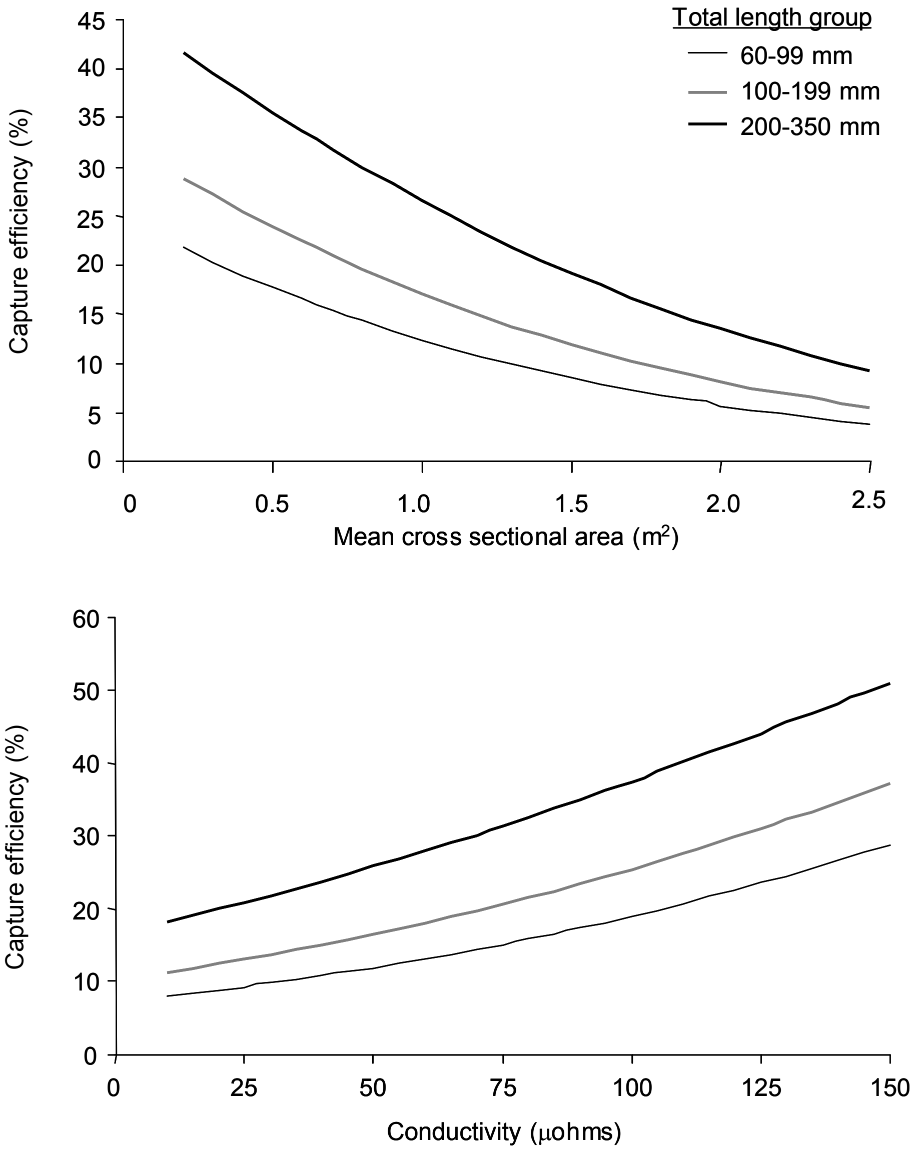


Figure 7. Predicted single-pass electrofishing capture efficiencies for three total length size classes of bull trout versus stream cross-sectional area (top) and conductivity (bottom). Predictions based on best fitting best-fitting beta binomial model and assuming conductivity of 54 (top) and 1 m^2 cross-sectional area (bottom).

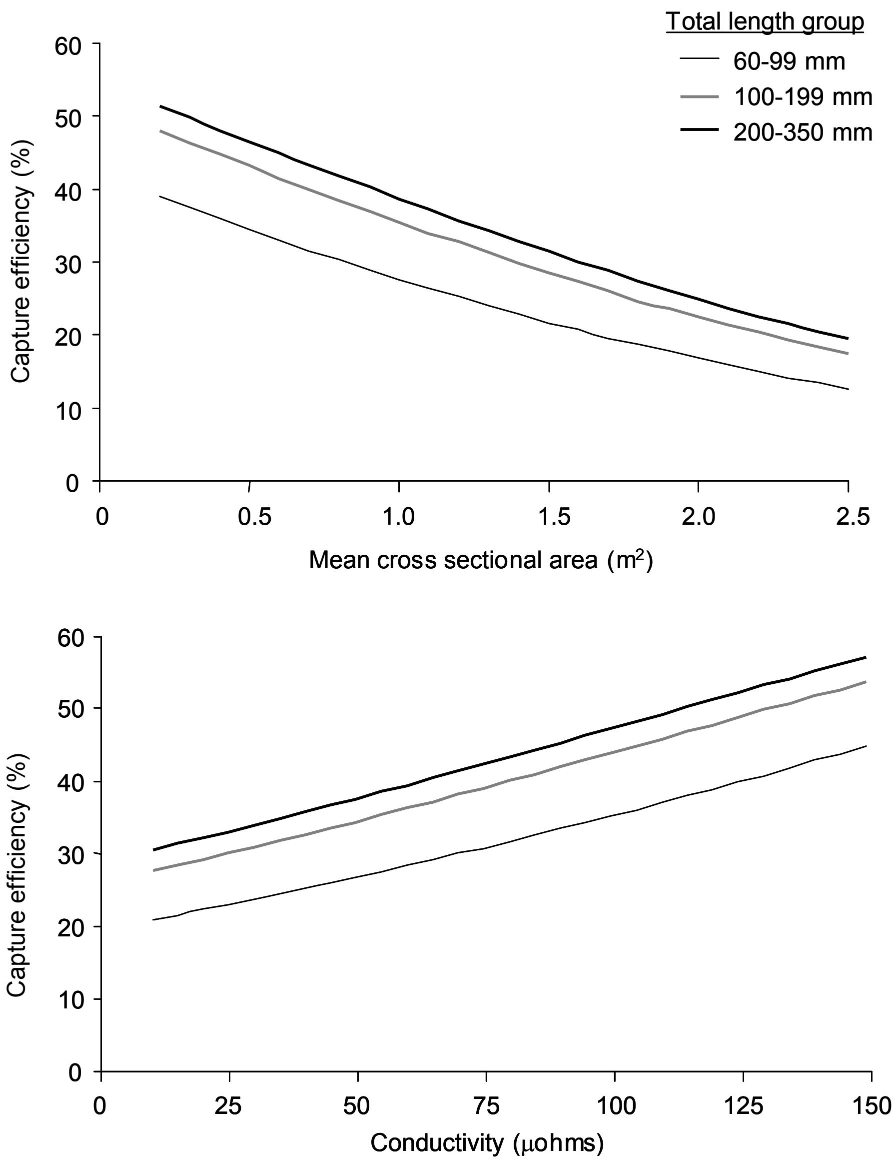


Figure 8. Predicted three-pass electrofishing capture efficiencies for three total length size classes of bull trout versus stream cross-sectional area (top) and conductivity (bottom). Predictions based on best fitting best-fitting beta binomial model and assuming conductivity of 54 (top) and 1 m^2 cross-sectional area (bottom).

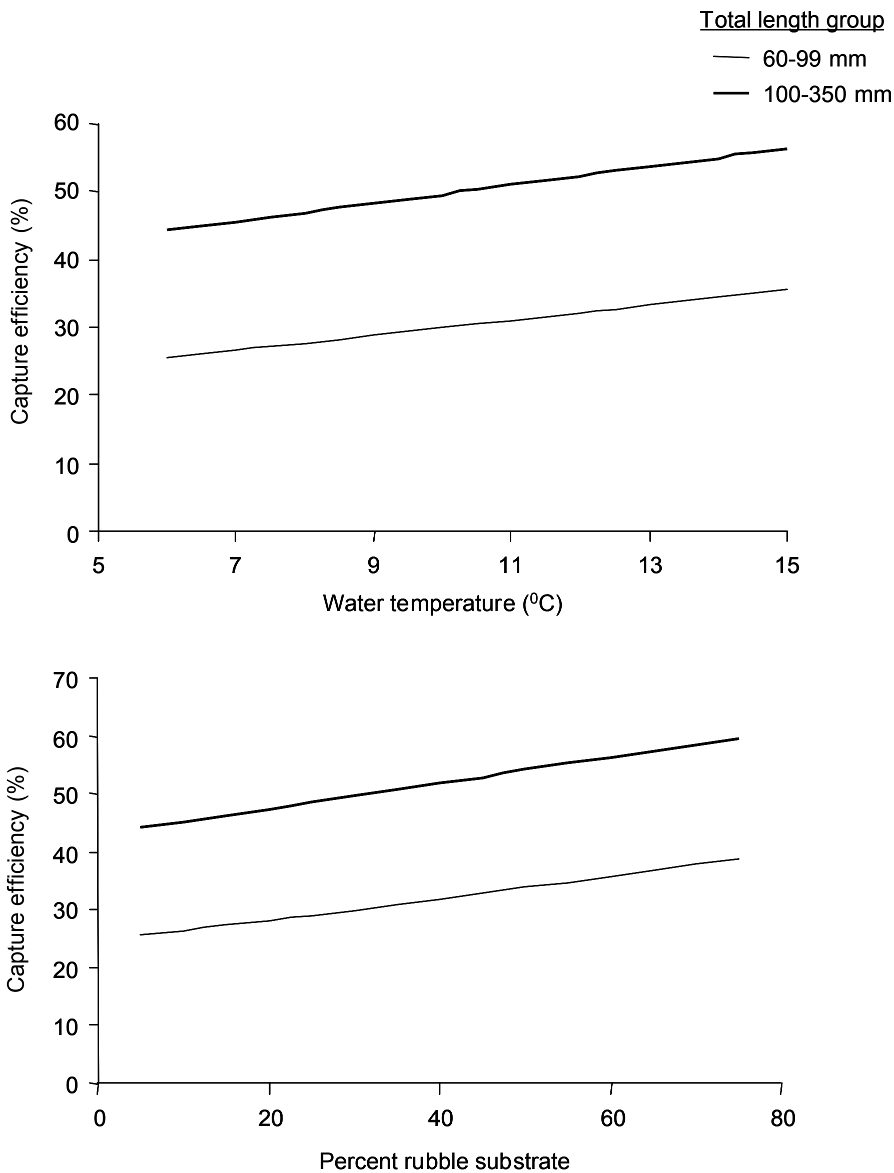


Figure 9. Predicted three-pass electrofishing capture efficiencies for two total length size classes of Oncorhynchus group versus stream water temperature (top) and percent rubble substrate (bottom). Predictions based on best fitting best-fitting beta binomial model and assuming 30% rubble substrate (top) and 10 ^{0}C stream water temperature (bottom).

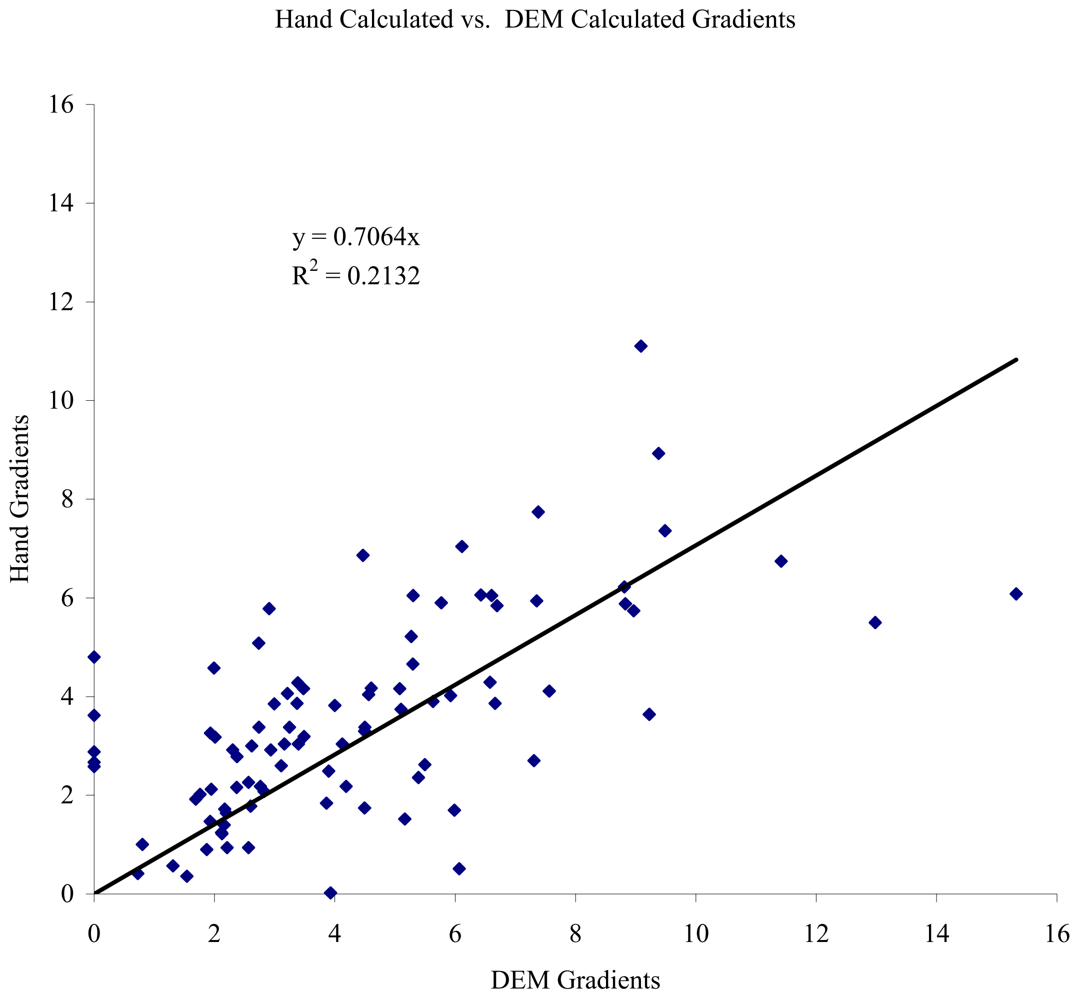


Figure 10. Comparison of hand measured gradients and Dem measured gradient in Washington, 2002.

List of Appendices

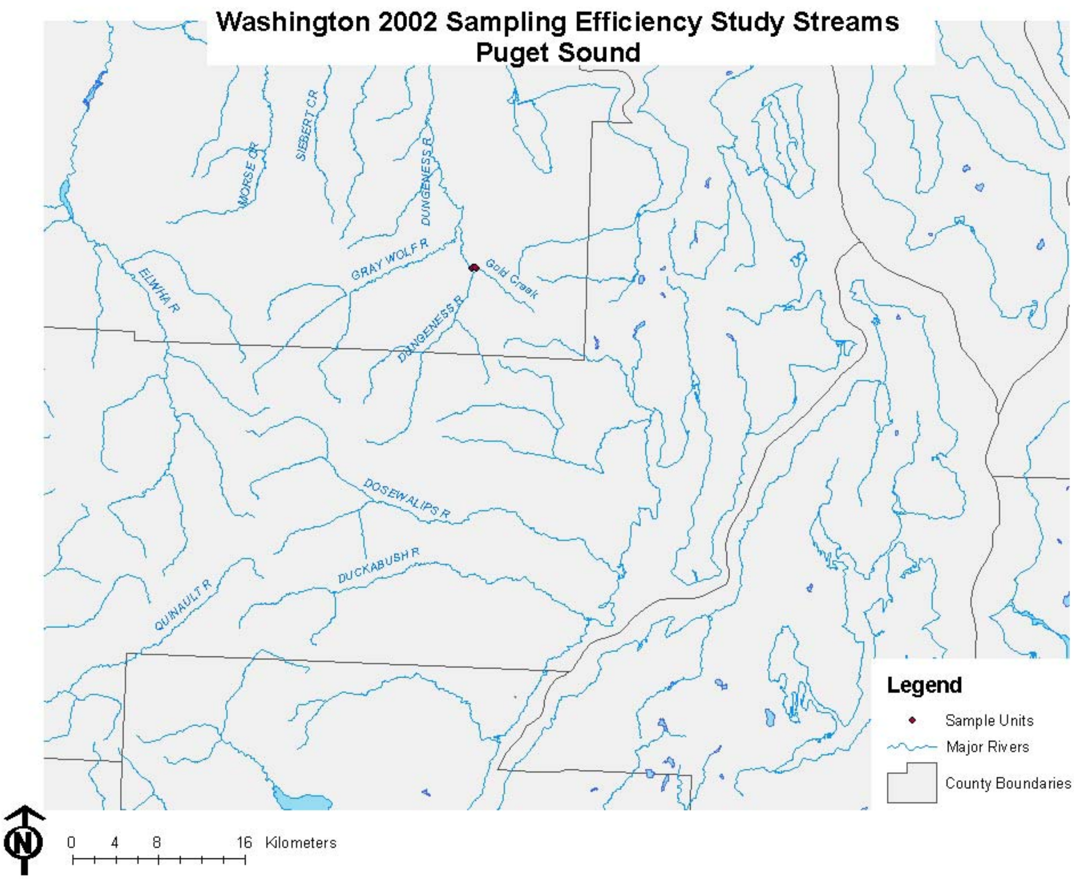
Appendix A. Sampling efficiency study stream locations in the Puget Sound Region of Washington, 2002. Each dot represents multiple study sites.

Appendix B. Sampling efficiency study stream locations in the North Central Region of Washington, 2002. Each dot represents multiple study sites.

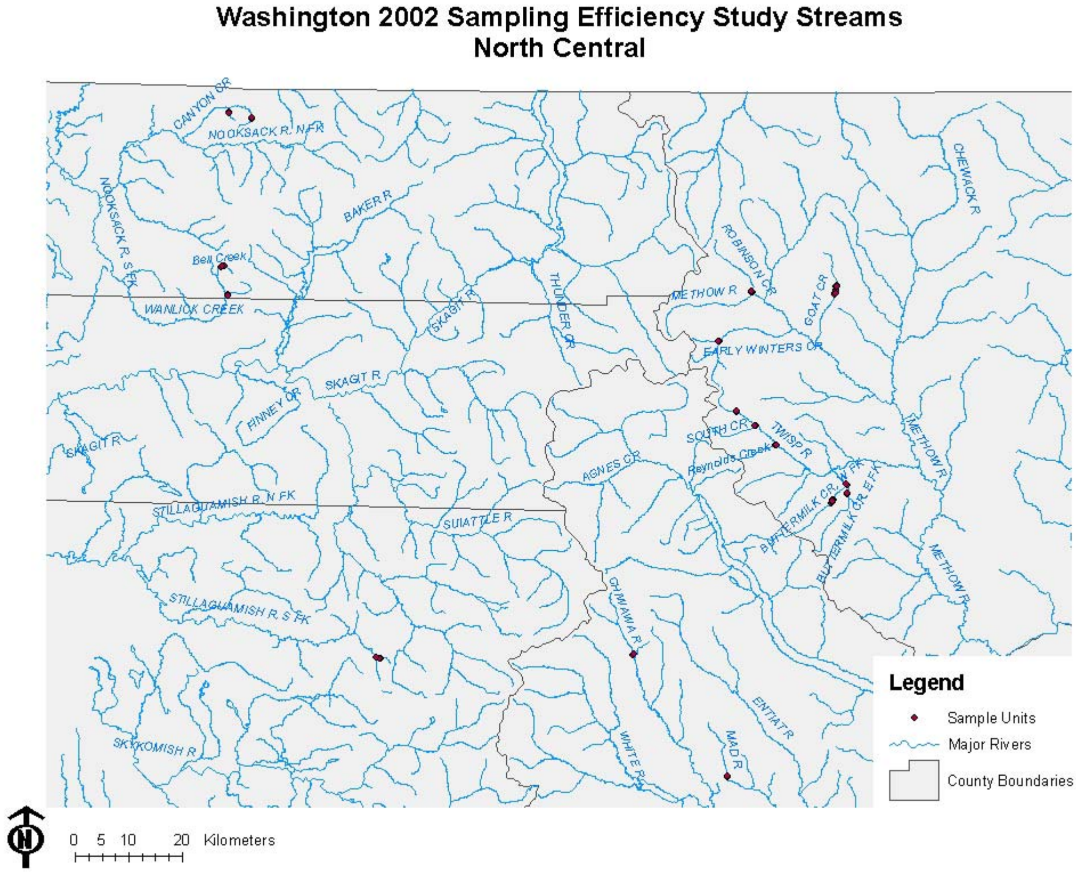
Appendix C. Sampling efficiency study stream locations in the South Central Region of Washington, 2002. Each dot represents multiple study sites.

Appendix D. Sampling efficiency study stream locations in the South East Region of Washington, 2002. Each dot represents multiple study sites.

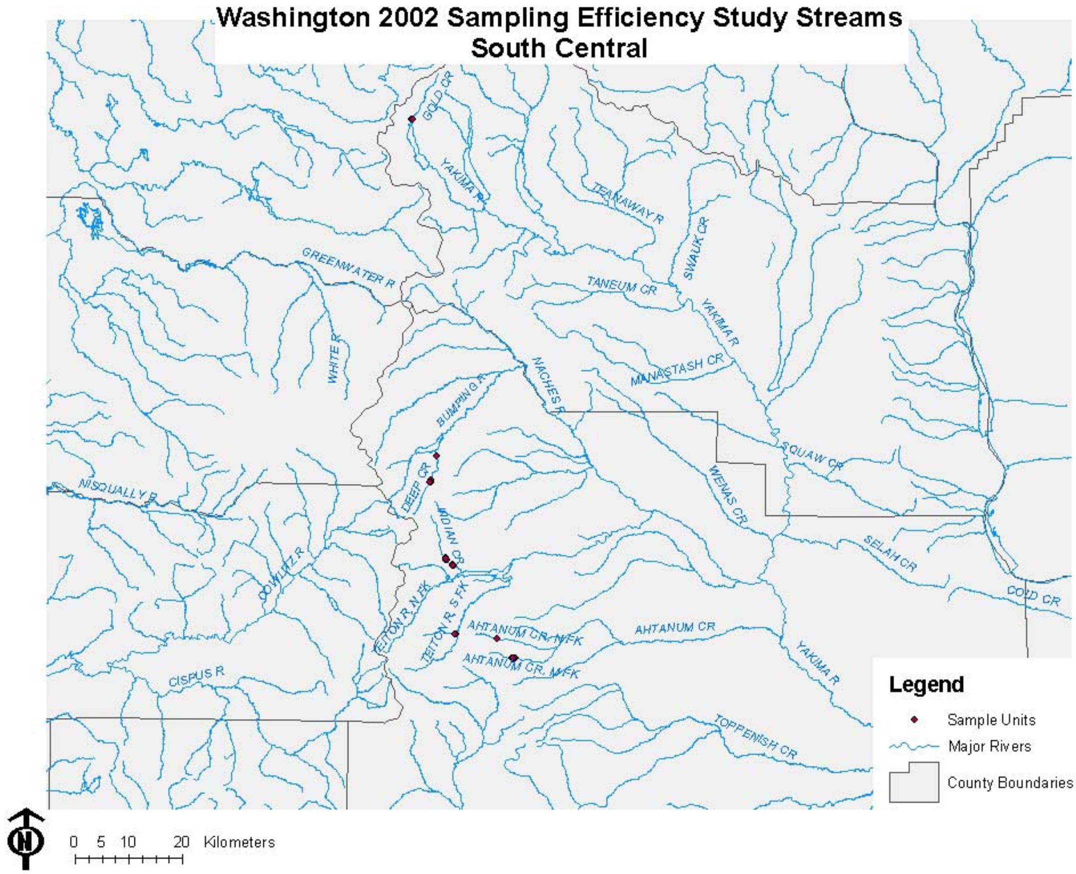
Appendix E. Basins, streams, GPS coordinates (upper blocknet) , location of stream (page number) in the Washington Atlas & Gazetteer for the 2002 sampling efficiency field studies in Washington.



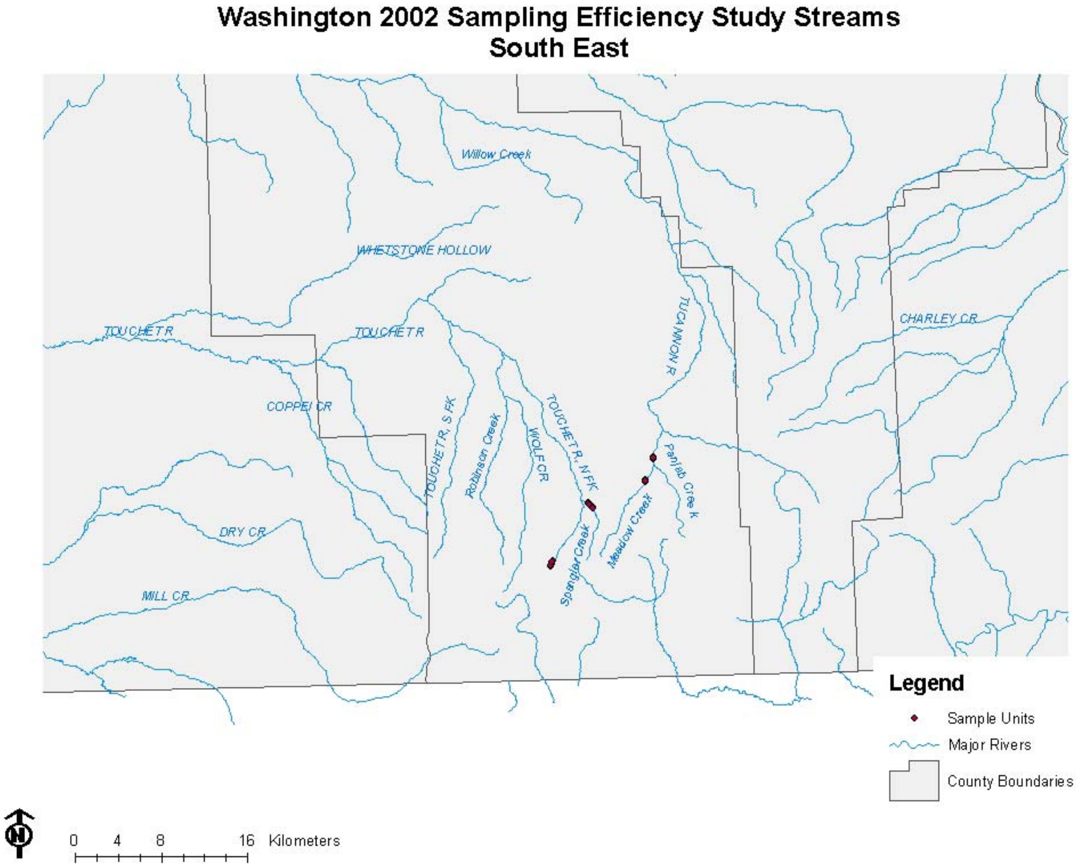
Appendix A. Sampling efficiency study stream locations in the Puget Sound Region of Washington, 2002. Each dot represents multiple study sites.



Appendix B. Sampling efficiency study stream locations in the North Central Region of Washington, 2002. Each dot represents multiple study sites.



Appendix C. Sampling efficiency study stream locations in the South Central Region of Washington, 2002. Each dot represents multiple study sites.



Appendix D. Sampling efficiency study stream locations in the South East Region of Washington, 2002. Each dot represents multiple study sites.

Appendix E. Basins, streams, GPS coordinates (upper blocknet) , location of stream (page number) in the Washington Atlas & Gazetteer for the 2002 sampling efficiency field studies in Washington. (* = no GPS signal was obtained)

River Basin	Stream	Survey Unit	GPS Latitude (degrees)	GPS Longitude (degrees)	Page # in Washington Atlas & Gazetteer	Region
Entiat	Mad River	1	47.77400	-120.55298	82	North Central
		2	47.84830	-120.59839	82	
Methow	EF Buttermilk Creek	1	48.33931	-120.30147	99	North Central
		2	48.33838	-120.30073	99	
		3	48.32387	-120.29896	99	
		4	49.00000	-122.00000	99	
Methow	Goat Creek	1	48.65899	-120.32976	113	North Central
		2	48.65986	-120.02953	113	
		3	48.66321	-120.32725	113	
		4	48.66515	-120.32744	113	
		5	48.66208	-120.32744	113	
		6	48.67207	-120.32540	113	
		7	48.67296	-120.32519	113	
Methow	Pine Creek	1	48.57941	-120.62410	112	North Central
		2	48.57957	-120.62555	112	
		3	48.58007	-120.62646	112	
Methow	Reynolds Creek	1	*	*	99	North Central
		2	*	*	99	
Methow	Robinson Creek	1	48.66270	-120.54043	112	North Central
		2	48.66382	-120.54032	112	
		3	48.66439	-120.53984	112	
Methow	WF Buttermilk Creek	1	48.31244	-120.33767	99	North Central
		2	48.31291	-120.33620	99	
		3	48.31291	-120.33662	99	
		4	48.31116	-120.33722	99	
		5	48.30849	-120.33884	99	
		6	48.30853	-120.33969	99	
Nooksack	Bell Creek	1	48.69754	-121.88369	110	North Central
		2	48.69757	-121.88278	110	
		3	48.69761	-121.88143	110	
		4	48.69755	-121.88032	110	
		5	49.00000	-122.00000	110	
		6	48.69691	-121.88624	110	
		7	48.69758	-121.88566	110	

River Basin	Stream	Survey Unit	GPS Latitude (degrees)	GPS Longitude (degrees)	Page # in Washington Atlas & Gazetteer	Region
Nooksack	Canyon Creek	1	48.94832	-121.81683	110	North Central
		2	48.94749	-121.81688	110	
		3	48.94652	-121.81718	110	
Nooksack	Wanlick Creek	1	48.64898	-121.86946	110	North Central
		2	48.64971	-121.86916	110	
Nooksack	Whistler Creek	1	48.95803	-121.87351	110	North Central
		2	48.95238	-121.87339	110	
		3	48.95439	-121.87416	110	
Stillaguamish	Palmer Creek	1	48.04351	-121.47117	97	North Central
		2	48.04244	-121.47352	97	
		3	48.04268	-121.47375	97	
Stillaguamish	Tributary	1	48.04395	-121.48168	97	North Central
Twisp	NF Twisp	1	48.46161	-120.57739	98	North Central
	South Creek	1	48.46724	-120.53117	98	North Central
		2	48.43753	-120.53080	98	
		3	48.43701	-120.53293	98	
Wenatchee	Willow Creek	1	48.05227	-120.83495	98	North Central
American	Deep Creek	1	46.83499	-121.31071	49	South Central
		2	46.79266	-121.32522	49	
		3	46.79306	-121.32512	49	
		4	46.79403	-121.32510	49	
		5	46.79141	-121.32611	49	
		6	46.79062	-121.32593	49	
NF Ahtanum	Shellneck Creek	1	46.53072	-121.15935	49	South Central
		2	46.53001	-121.16050	49	
Tieton	Bear Creek	1	46.53830	-121.25993	49	South Central
		2	46.53753	-121.26133	49	
Yakima	Gold Creek	1	47.39817	-121.37200	65	South Central
		2	47.39820	-121.37790	65	

River Basin	Stream	Survey Unit	GPS Latitude (degrees)	GPS Longitude (degrees)	Page # in Washington Atlas & Gazetteer	Region
Yakima	Indian Creek	1	46.65258	-121.26703	49	South Central
		2	49.00000	-122.00000	49	
		4	46.66259	-121.28488	49	
		5	46.66259	-121.28488	49	
		6	46.66395	-121.28542	49	
		7	46.66439	-121.28639	49	
		8	46.66005	-121.28731	49	
		9	46.66433	-121.28609	49	
Yakima	MF Ahtanum	1	46.49681	-121.11687	35	South Central
		2	46.49653	-121.11919	35	
		3	46.49753	-121.12130	35	
Yakima	MF Ahtanum	1	46.49681	-121.11687	35	South Central
		2	46.49653	-121.11919	35	
		3	46.49753	-121.12130	35	
		4	46.49845	-121.12303		
Tucannon	Meadow Creek	1	46.16000	-117.72700	42	South East
		2	46.16214	-117.72700	42	
	Panjab	1	46.18182	-117.71715	42	South East
		2	46.18140	-117.71771	42	
Tucannon	Spangler Creek	1	46.14609	-117.79699	42	South East
		2	46.14479	-117.79566	42	
		3	46.14423	-117.79534	42	
		4	46.14342	-117.79343	42	
		5	46.14264	-117.79297	42	
Tucannon	NF Touchet	1	46.09536	-117.84536	42	South East
		2	46.09462	-117.84577	42	
		3	46.09856	-117.84326	42	
		4	46.09697	-117.84490	42	