Analysis of Movement Patterns of Stream-dwelling Salmonids in Response to Three Survey Methods

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Disclaimer

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

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Final Report

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1.0 INTRODUCTION

This report describes the results of research conducted through Agreement #13410-2-N002 between the U.S. Fish and Wildlife Service (USFWS) and the U.S. Geological Survey, Georgia Cooperative Fish and Wildlife Research Unit. The purpose of this agreement was to evaluate and estimate the movement of stream-dwelling salmonids in response to sampling with three methods. In this report, we build on previous bull trout capture efficiency research conducted in Washington (Thurow et al. 2001; Thurow et al. 2003).

Sampling surveys are commonly used to assess presence, abundance, and status of populations of stream-dwelling fishes. These surveys are often conducted with the use of blocknets to prevent the movement of individuals into or out of a sample unit (Li and Li 1996). However, blocknets are not always feasible to install and maintain, particularly in larger streams or those with high water velocities. Financial (e.g., manpower) or logistical (e.g., stream access) constraints also can prevent the use of blocknets during surveys.

Blocknets are believed to be essential for ensuring fish population closure. Violations of population closure can lead to biased estimates of fish abundance. For example, fish movement can negatively bias sampling data and removal estimates (Kendall 1999), the magnitude depending on the relative numbers of fish moving out of the sampling unit. Fish movement out of sampling sites also can influence species presence and absence data because species detection depends, in part, on fish abundance (Bayley and Peterson 2001). If fish movement is affected by the size and species of fish or physical habitat characteristics, fish-habitat and multi-species studies may be confounded. Thus, failure to use blocknets may lead to biased data and hence, poor management decisions.

With few exceptions (Nordwall 1999; Dunham et al. 2002), there currently is no information on the movement of stream-dwelling fishes in response to sampling activities. Such information is critical to evaluate the potential biases when blocknets are not used and develop methods for adjusting sample data, if necessary. Therefore, we studied the movement of stream-dwelling salmonids in response to sampling activities with the following objectives.

1.1 Objectives

1. To measure the distance and direction bull trout (*Salvelinus confluentus*) and other salmonids move during surveys using day snorkeling, night snorkeling, and electrofishing.
2. To describe the influence of physical channel features including stream size, water temperature, channel complexity, and abundance of cover on the response of stream-dwelling salmonids to sampling activities.
3. To compare probabilities of detection for different salmonid species and size classes with and without the use of blocknets.

2.0 METHODS

2.1 Field Protocols

The ultimate goal of our research was to develop methods for estimating fish movement and incorporating these into sample size requirements for detecting the presence of native salmonids. Thus, we designed the crew protocols, described below, to estimate the movement of stream-dwelling salmonids in response to sampling activities through the recovery or resight of marked individuals. Our central hypothesis was that the sampling method, physical features of the sampling unit, and fish density influence salmonid movement.

2.1.1 Sampling unit selection

Our intent was to examine fish response to sampling under conditions commonly encountered in Washington State bull trout streams. Consequently, crews were instructed to select sampling units (during 2002) in areas that (1) supported relatively high densities of age 1+ bull trout and (2) had physical characteristics similar to those in sampling strata developed by Peterson and Banish (2002). Site selection also was coordinated with Washington Department of Fish and Wildlife (WDFW) sampling efficiency crews to minimize potential disturbances due to sampling. Sampling unit locations were marked on topographic maps and recorded with a Global Position System. We sampling during June - September 2001 and 2002 on the declining limb of the hydrograph with most sites sampled at or near base flow. More detailed stream locations and sampling dates can be found in Appendix A.

2.1.2 Blocknet installation

The blocknet evaluation crews followed protocols similar to those of the sampling efficiency crews (detailed in Thurow et al. 2003). However, in this study, multiple blocknets were installed in and adjacent to 150-m sampling units. Upon arriving at a sample site, crews paced a 150-m sample unit along the streambank and selected hydraulic controls for upper and lower boundaries. They then installed blocknets at the upper and lower boundaries of the 150-m unit (two blocknets in place), paced 25-m along the streambank upstream and 25-m downstream from the initial set of blocknets, and installed a blocknet at each of those adjacent locations (i.e., four blocknets total). Because our objective was to simulate situations where blocknets were not used during sampling, the 25-m subunits were intended to provide fishes with escape areas outside of the 150-m sampling area. With these four blocknets in place, two additional 50-m subunits were paced off along the streambank within the 150-m unit (i.e., at 50, 100-m intervals) and blocknets were installed for a total of six blocknets (Figure 1). Crews inspected the nets using snorkeling gear to insure they were barriers to movement. To classify the locations where marked fish were observed or captured, crews placed consecutively numbered flagging along one stream bank at 25-m intervals beginning at the lowermost blocknet 25-m below the 150-m unit boundary (Figure 1).

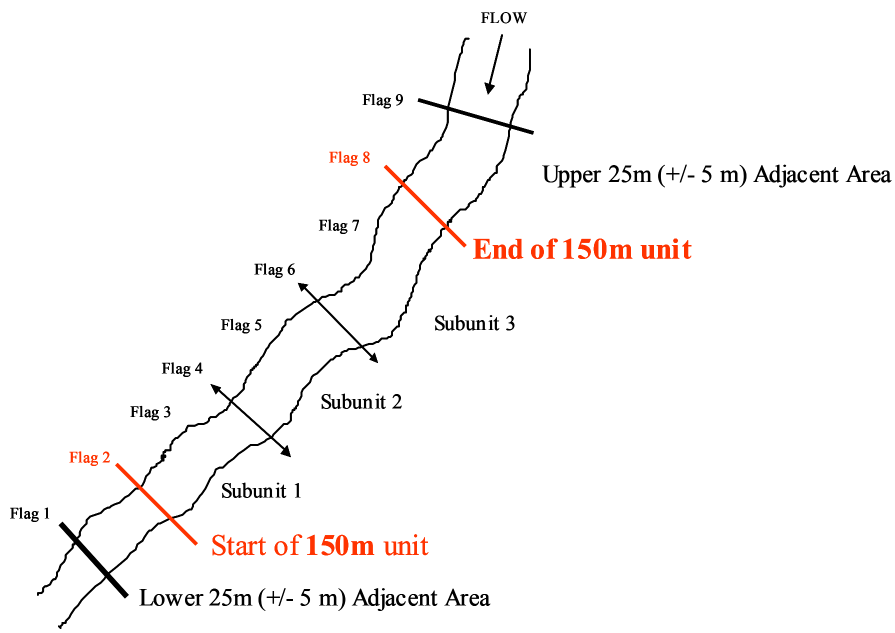

Figure 1: An example of unit, subunit, and adjacent area boundaries used during the evaluation of salmonid movement.

2.1.3 Pre-survey fish marking

Following blocknet and flag installation, crews captured and differentially marked age 1+ salmonids in each of the three-blocknetted subunits. Salmonids were captured via electrofishing with unpulsed Direct Current (DC) using one upstream pass and one downstream pass (Figure 2) to reduce the potential for injuring fish. The waveform, voltage, and starting and ending times were recorded and water temperatures measured with a calibrated hand-held thermometer. Captured fish were placed in live wells (one for each subunit), anesthetized, measured, and the species and total lengths recorded to the nearest 10-mm size groups. Crews then notched or paper punched the dorsal, top caudal, or both fins in a manner that was visible to snorkelers and was unique to each subunit. Fishes were allowed to recover from the anesthetic in fresh water and were released into the subunits from which they were collected. To reduce the likelihood of injury, crews terminated the survey and selected another sampling unit when large (>400 mm) bull trout were encountered during the marking.

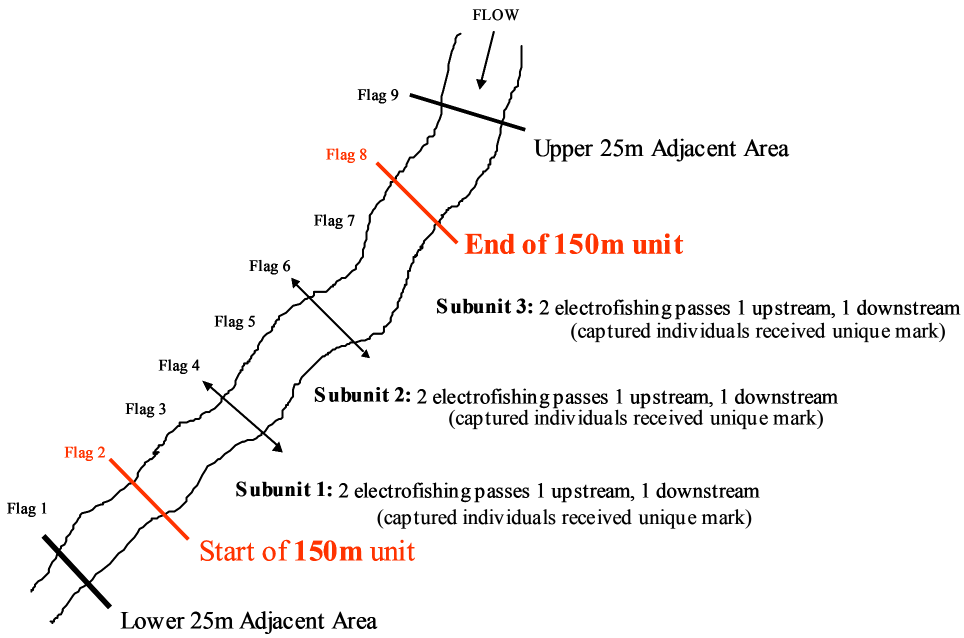

Figure 2. An illustration of the marking phase used during the evaluation of salmonid movement.

2.1.4 Abundance surveys

Crews randomly selected day snorkeling, night snorkeling, or electrofishing as the abundance survey *primary* method prior to leaving for the field. Using a random number generator, potential sampling sites were assigned a uniform (range 0-1) random number. Sites with values ≤ 0.33 were assigned day snorkeling, values ranging from 0.34- 0.66 were night snorkeling, and values > 0.66, electrofishing. Salmonids were first sampled using the primary method in all 3 subunits. If the primary method was snorkeling (e.g., day snorkeling), additional samples were collected via the non-primary snorkeling method (e.g., night snorkeling), and via electrofishing. Note that when electrofishing was selected as the primary method, no snorkeling samples were collected from the study site. This decision was based on reports that fish behavior is affected for approximately 24 hours following electrofishing (Mesa and Schreck 1989) and we believed that effects of a second electrofishing collection in a 24- 30 h period may affect fish for a greater (but unknown) amount, potentially biasing our estimates of fish movement.

At least 24 hours following marking, a crew member slowly and deliberately entered the stream at the location of the lower 150-m section blocknet, removed the blocknet, exited the stream, and walked to the next upstream blocknet along the shoreline at least 20-m from the stream channel. The process was then repeated until all four interior blocknets were removed (i.e., those separating the subunits and at the 150-m unit boundaries; Figure 3). To maintain a closed population, the outermost blocknets were left in place. Following a 1-2 hour settling period, which was greater than the 15-20 minutes required for disturbed warmwater fishes to return following installation of sampling equipment (electrofishing grids, Bain et al. 1985; dropnets, Peterson 1996), crews applied the standard sampling primary method and recorded the location where marked fish were detected using the flags as boundaries (i.e., between flag 2 and 3, etc.). In this manner, crews were able to assess the direction and distance fish moved during sampling.

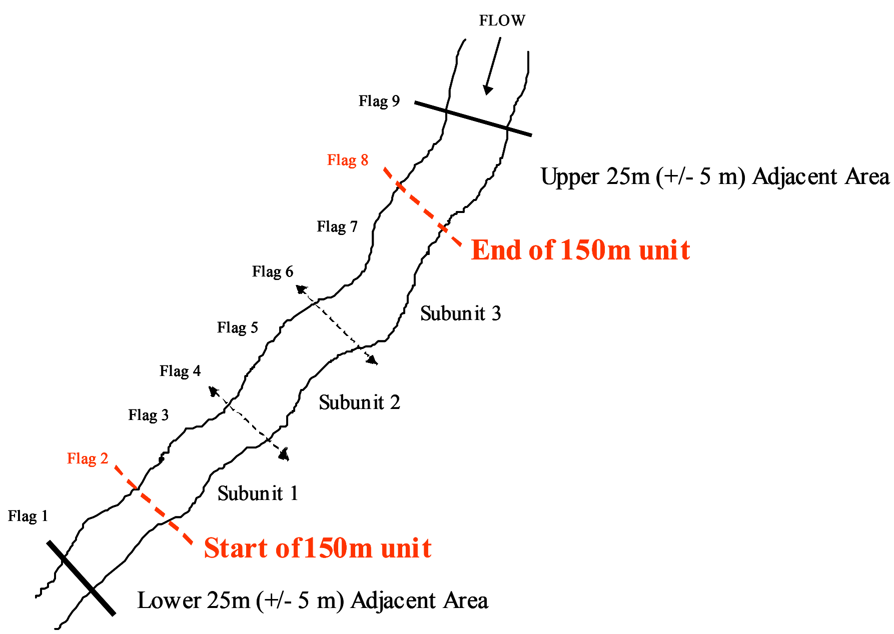

Figure 3. An illustration of blocknet removal (broken lines) for the evaluation of salmonid movement.

Day-Snorkeling.- Crews inspected the sample unit and selected the number of snorkelers necessary to survey the unit in a single pass. Only snorkelers who participated in species identification and size estimation training (Thurow 1994) conducted these surveys. Day snorkeling took place between 1000 and 1700 Pacific Daylight Time (PDT). Snorkelers began at the lower boundary of the 150-m unit and moved slowly upstream (Figure 4). Snorkelers counted the total number of salmonids by species, estimated size classes to the nearest 100-mm size group, recorded marks, and the 25-m area where the mark was observed. After counting fish in the 150-m unit, crews snorkeled the 25-m areas above and below the unit boundaries and recorded all marked fish by size class and location. 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 and measured water temperatures with a calibrated hand-held thermometer.

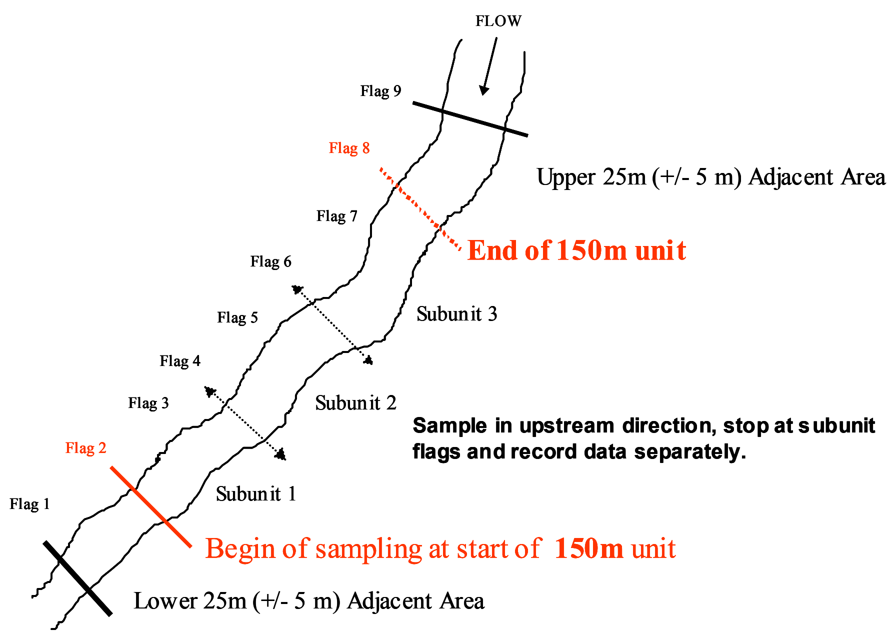

Figure 4. An illustration of sampling the primary gear used for the evaluation of salmonid movement.

Visibility may affect the ability of divers to detect fishes and may influence the flight response of fishes. Thus, 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 reappeared clearly and measured that distance. 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.

Night-Snorkeling.- Nighttime snorkel surveys were completed between 2230 and 0430 PDT using the identical technique described for the daytime survey, but with the aide of a halogen light. Visibility also was measured separately for night snorkeling.

Electrofishing.- Crews electrofished the unit using unpulsed Direct Current (DC) where feasible to reduce the potential for injuring fish. Crews completed five upstream passes and recorded the waveform, voltage, and frequency and starting and ending times and water temperatures. Electrofishing begin at the start of the 150-m unit and proceeded upstream. During each pass, all salmonids were captured and placed in individual live wells corresponding to the pass number and the location that the fish were captured (i.e., 25-m section between flags; Figure 4). Following each pass, crews exited the stream, walked downstream at least 20-m from shore, entered the stream at the lower 150-m unit boundary, and began another upstream electrofishing pass. This process was repeated until all electrofishing passes were completed. Crews were instructed that fish may be increasingly susceptible to handling stress as water temperatures increase above 16 ^{0}C so during warm days, sampling was sometimes conducted in the early morning and late evening to reduce the risk of injury. Fish were anesthetized, total length measured to the nearest 10-mm size group. The species, total lengths, and marks of all salmonids were recorded. Data were recorded by individual pass and location.

After sampling the 150-m unit, crews electrofished the adjacent 25-m area upstream from the uppermost 150-m unit boundary using the same procedure described above until at least 4 consecutive passes were completed. After completing at least 4 passes in the upper 25-m adjacent, crews exited the stream walked downstream at least 20-m from shore, entered the stream at the lower 150-m unit boundary, and sampled the adjacent 25-m areas downstream from the lower most 150-m unit boundary. Marked fish captured in the upper and lower adjacent areas were anesthetized, measured, and the species and total lengths and marks recorded. After all electrofishing was completed, crews removed the blocknets and measured physical habitat characteristics of the unit.

2.1.5 Physical and chemical data

Crews applied the identical habitat measurement protocols detailed in Thurow et al. (2001) with minor modifications: (1) crews measured physical attributes for each subunit (Figure 1) by establishing transects at 10-m intervals for a total of five transects per subunit; (2) temperature and conductivity were measured at the beginning and end of each sampling occasion and averaged; and (3) gradient was only measured using a 1:24,000 USGS topographic map. Additionally, some measurements (identified below) were not recorded separately for each subunit during 2001 sampling.

Conductivity.-- A calibrated conductivity meter and thermometer was used to measure conductivity and temperature, respectively, in each unit at the beginning and end of fish sampling with each method. Mean water temperature and conductivity were estimated by averaging the before and after measurements.

Channel dimensions and substrate.-- 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 10-m intervals in each 50-m subunit. 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 subunit, mean wetted width was estimated by averaging the mean wetted widths (at each transect) and the water surface area (needed for estimation of wood density, below) was calculated by multiplying mean wetted width by the total unit length. Mean wetted cross-sectional area was estimated as the product of mean wetted width and mean depth.

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 subunit 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. Mean depth and mean maximum depth were estimated by averaging transect-specific mean depth and maximum depth estimates, respectively.

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 survey subunit.

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 subunit and divided them by the total length of the survey unit to determine the percentage of pools within the unit. Pool measurements were not recorded separately for each 50-m subunit during 2001 and hence, the total length of pools in the 150-m unit was divided by the total unit length. This 150-m unit value was assigned to each 50-m subunit.

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. Crews also recorded the number of large aggregates (more than four single pieces acting as a single component) and rootwads. Subunit wood density was estimated by dividing the number of wood pieces by the area of the subunit. Wood density was not recorded separately for each 50-m subunit during 2001 and hence, the wood density in the 150-m unit was divided by the total unit length. This 150-m unit value was assigned to each 50-m subunit.

Cover Components.-- Crews measured the total length of each subunit from the lower to the upper blocknet by summing the number of transects and adding the length of the final segment. For the each subunit (except during 2001), 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 subunit 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 subunit surface area to calculate the percentage of 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. Cover components measurements were not recorded separately for each 50-m subunit during 2001 and hence, the 150-m unit measurement was assigned to each 50-m subunit.

Gradient.- Site gradient was estimated from a U.S. Geological Survey 7.5-min (1:24,000) map.

2.2 Statistical Analyses

We examined the relationships between subunit characteristics and the probability that fish remained in the subunit, moved upstream or downstream via a multinomial logit model. A multinomial logit model differs from the more familiar binary logistic regression model in that the probabilities of more than two categorical responses are estimated simultaneously based on several predictors (Agresti 1990). Here we modeled three categorical responses with number of marked fish: (1) remaining in subunit, (2) moving upstream, and (3) moving downstream, using category one (remain in subunit) as the baseline. A marked fish was defined as having moved upstream if it was collected (sighted) in any of the upstream subunits or the 25-m area above the 150-m unit (Figure 1), and downstream if it was collected (sighted) in any of the downstream subunits or the 25-m area below the 150-m unit. To examine the influence of sample unit length on fish movement, separate analyses were conducted (1) by treating each subunit as individual 50-m sample units and (2) by combining mark and recapture data from adjacent 50-m subunit (i.e., subunits 1 and 2, subunits 2 and 3) and analyzing the data as (two) individual 100-m sample units.

Because stream-dwelling salmonid capture or sighting (i.e., snorkeling) efficiencies are generally much less than 100% (Kennedy and Strange 1981; Buttiker 1992; Riley and Fausch 1992; Rodgers et al. 1992; Riley et al. 1993; Thompson and Rahel 1996; Anderson 1995; Thurow and Schill 1996; Thurow et al. 2001; 2003; Peterson et al. 2002), there was a significant chance of not detecting marked fish that did or did not move out of a subunit. To account for the effects of incomplete detectability, we fit a conditional multinomial logit model in which the probability of detecting a fish in a subunit depended upon the joint probability of the marked fish having moved (or remained) and the probability of detecting the fish, given it had moved (or remained). The probability of detecting the fish was modeled as a beta distribution with shape parameters (a, b) estimated using the mean sampling efficiency estimate (q) and dispersion parameter (γ) from the beta-binomial models as: $a = q/\gamma$ and $b = (1-q)/\gamma$. Capture efficiencies and the dispersion parameter were estimated for each subunit and up and downstream areas using habitat data and the capture efficiency models in Thurow et al. (draft report). The conditional multinomial logit model was fit using Markov Chain Monte Carlo methods as implemented in BUGS software, version 1.3 (Spiegelhalter et al. 2000). Note that candidate models also included a random effect (Congdon 2001) to account for potential dependence among subunits within sites.

Prior to model fitting, we evaluated the accuracy of the conditional multinomial logit model via simulation. We conducted simulations using all combinations of three movement probabilities (10%, 15%, and 25%) and three capture efficiency estimates (10%, 15%, and 25%) for a total of nine evaluations. For each simulation, 100 sample units were assigned a number of individuals from a uniform distribution (range 2- 20). For each sample unit, the number of individuals moving upstream and downstream was modeled as a binomial random variate (with parameters N, p), where N = the simulated number of individuals in a site and p = movement probability. The number of individuals detected then was modeled as a binomial random variate, where N = the simulated number of individuals moving up, downstream, or remaining in a site and p = capture efficiency randomly assigned from a beta distribution with shape parameters corresponding to the predetermined mean efficiency (listed above) and a coefficient of variation of 100%. This produced an extra variability to the data that was consistent with the stream sampling process. The generated data then were fit using the conditional multinomial logit model and fish movement was estimated using the fitted model. Error was estimated as the difference between the predicted and actual movement probabilities. This process was repeated 100 times and model bias was estimated as the mean difference across simulation runs. The proportion of known movement probabilities falling within the predicted 90% credibility intervals also is reported.

Categorical predictor variables (e.g., subunit identity) should be coded as binary indicators (dummy variables coded as 0 or 1) before they can be fit with generalized linear models (Agresti 1990). Most statistical software packages automatically recode categorical data during model fitting and baseline categories are usually assigned using some arbitrary rule-set, such as alphabetical order. Rather, we chose to recode the categorical variables prior to analyses based on contrasts we believed relevant. For example, we created dummy coded variables for subunit one and three with subunit two as the baseline for the 50-m sample unit modeling to examine possible influence of the up and downstream blocknets on fish movement. The downstream 100-m subunit also was dummy coded with the upstream subunit as the baseline for the 100-m sample unit modeling. Similarly, sampling methods were dummy coded for day and night snorkeling with single pass electrofishing as the baseline.

A preliminary analysis suggested that fishes were displaced during the sampling with the (randomly selected) primary method and that this would likely bias fish movement estimates for the non-primary sampling methods (i.e., the sampling that was conducted following the primary method). For example, we estimated that fish movement is subunit one and two in response to single pass electrofishing was 33% when electrofishing was not the primary method, whereas it was 17% when electrofishing was the primary method. Similarly, our preliminary analyses also suggested a blocknet effect that would have biased estimates of fish movement in the lower subunits on electrofishing passes 2-5. Therefore, we estimated fish movement in response to day and night snorkeling and single pass electrofishing using only the primary method sampling data. Pearson correlations were run on all pairs of predictor variables (i.e., physical/

chemical measurements) prior to analyses. To avoid multicollinearity, a subset of seven uncorrelated predictor variables ($r^2 < 0.15$) was selected for inclusion in our candidate models.

We used the information-theoretic approach, described by Burnham and Anderson (2002), to evaluate the relative plausibility of the conditional multinomial logit models. The subset of uncorrelated site characteristics (Table 1), subunit location, and sampling method were used to construct the global model containing all of the predictors. From the global model, we then fit all subsets and assessed the fit of each candidate model using Akaike's Information Criteria (AIC; Akaike 1973) corrected for a small sample bias (AIC_c; Hurvich and Tsai 1989). Akaike's Information Criteria is an entropy-based measure used to compare candidate models describing the same data (Burnham and Anderson 2002), with the best fitting model having the lowest AIC_c. The relative plausibility of each candidate model was assessed by calculating Akaike weights (w_i) as described in Burnham and Anderson (2002). The most plausible candidate model has the greatest Akaike weight (range 0 to 1).

To incorporate model-selection uncertainty, we computed model-averaged estimates of the logit model coefficients as described by Burnham and Anderson (2002). Briefly, the estimated coefficients (i.e., model parameters) from each candidate model were weighted by their associated Akaike weights (posterior model probabilities) during model fitting resulting in a composite model. All inferences were based on the composite models. 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 2002). Model-averaged coefficients were only calculated for the predictor variables that occurred in one or more candidate models with weights within 10% of the largest weight. 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 2002).

The precision of each predictor was estimated by computing 90% credibility intervals (Congdon 2001), which are analogous to 90% confidence intervals. Convergence was assessed for each model in the confidence set using the diagnostics proposed by Gelman and Rubin (1992).

Table 1. Means, standard deviation (SD), and ranges of habitat characteristics for streams used during the evaluation of salmonid movement. Predictors with asterisks were used in the candidate models of fish movement.

Variable	Mean	SD	Range
Mean wetted width (m)*	4.919	1.537	2.92 – 7.59
Mean depth (m)	0.139	0.037	0.07 – 0.23
Mean maximum depth (m)*	0.293	0.065	0.17 – 0.42
Map measured gradient (%)	4.124	1.941	1.18 – 8.96
Wood density (no./ m^2)*	0.034	0.021	0.00 – 0.09
Percent undercut banks	2.981	5.007	0.14 - 20.55
Mean water temperature (^{0}C)*	8.816	2.112	5.67 - 12.50
Mean visibility (m)	2.031	0.793	1.10 – 3.88
% Surface turbulence	15.667	4.577	10 - 25
% Submerged cover	27.667	11.782	10- 45
Bull trout abundance (no./unit)*[1]	114.95	146.67	0 - 498
Substrate composition (%)			
Rubble*	33.89	14.54	2 - 55
Cobble	31.32	8.79	12 - 45
Gravel	24.58	12.12	10 - 51
Fines*	10.21	9.54	2 - 34

[1]Abundance estimate was adjusted for capture efficiency.

2.3 Detection probability and sample size estimates

The error associated with our movement estimates could influence bull trout probability of detection estimates when blocknets are not employed. To incorporate the error, we estimated the posterior predictive distribution of the probability of fish remaining in a site (i.e., 1 minus the probability of leaving) using the composite conditional multinomial logit model. This posterior distribution then was used to estimate the parameters of a beta distribution. The probability of detecting bull trout when blocknets are not employed was estimated as the joint distribution of estimated fish abundance (for 50-m and 100-m sample units from Peterson et al. 2002), the probability of fish remaining in a site, and estimated capture efficiency from Thurow et al. (2003) using Markov Chain Monte Carlo methods as implemented in BUGS software, version 1.3 (Spiegelhalter et al. 2000). For comparison, detection probabilities also were estimated for situations in which blocknets are employed (i.e., assuming bull trout can not escape).

Bull trout sample size requirements were estimated using the mean estimated detection probabilities (above) and the desired level of 'power' (1- β) as:

$$n = ln(\beta)/ln(1\text{-}d)$$

where n is the required number of samples, d is the single sample detection probability, and ln is the natural logarithm (Green and Young 1993). We calculated required number of samples for 80%, 90%, and 95% detection values for various combinations of the habitat characteristics that were found to influence capture efficiency (Thurow et al. 2003). To allow for ease of use in the field, the habitat characteristics were separated into two categories based on the mean values observed during the capture efficiency evaluations (Thurow et al. 2003).

3.0 RESULTS

During 2001 and 2002, crews completed salmonid movement evaluations in 4 and 16 streams, respectively. On average, bull trout were the most numerous salmonid encountered with an average of 38 marked individuals per unit (Table 2). In several instances, marked individuals of a species were not present in all 3 subunits and thus, the site data could not be used in the multinomial logit modeling procedure. After eliminating these sites, the resulting data consisted of 18 sites with marked bull trout (Table 2), 4 sites with brook trout (*S. fontinalis*), 3 sites with westslope cutthroat trout (*Oncorhynchus clarki lewisi*) and 7 with rainbow trout (*O. mykiss*). Of these, only bull trout and rainbow trout were collected in sufficient number to evaluate and model the influence of physical factors on fish movement. In addition, preliminary analysis of body size effects on movement indicated very poor model fit (convergence) due to relatively few number (3% of total) of marked large (>199 mm) bull trout and rainbow trout and low proportion (< 10%) of recaptured small (70 - 99 mm) marked individuals. Hence, we combined size class data and focused the analysis of movement to bull trout and rainbow trout (across size classes). Correspondingly, we averaged species-specific sampling efficiency estimates (from Thurow et al. 2003) across body size classes. We also estimated mean up- and downstream movement estimates for brook trout and westslope cutthroat trout.

Table 2. Means, standard deviation (SD), and range of number of marked individuals, by species, and the number of evaluations, by species and primary sampling method.

	Number of marked individuals			Primary sampling method		
Species	Mean	SD	Range	Electrofishing	Day snorkeling	Night snorkeling
Brook trout	1.80	3.61	0 - 13	2	1	1
Bull trout	38.25	39.75	0 - 164	6	5	7
Rainbow trout	19.40	29.83	0 - 89	2	3	2
Westslope cutthroat trout	5.13	13.82	0 - 54	0	1	2

Simulation results indicated that the conditional multinomial logit model was relatively unbiased with mean differences between known and estimated movement of less than 0.5%, on average (Table 3). Conditional multinomial logit models also were relatively accurate with more than 90% of the estimated 90% credibility intervals containing the (true) known probability of movement (Table 3). Therefore, we considered the conditional multinomial logit model adequate for modeling fish movement.

Table 3. Results of 100 simulation runs for 9 combinations of movement and capture probabilities fit with conditional multinomial logit model.

Movement probability (%)	Mean capture efficiency (%)	Mean error	Predictions within 95% confidence intervals
10	10	-0.015	91
	15	-0.001	95
	25	0.003	98
15	10	-0.002	94
	15	0.001	98
	25	-0.001	99
25	10	-0.002	97
	15	0.003	98
	25	-0.001	97

Conditional multinomial logit models of salmonid movement from 50-m sample units indicated that the best fitting model for estimating bull trout movement contained subunit 3 and was 3.3 (0.417/0.126) times more likely as the next best fitting model containing subunit 3 and night snorkeling (Table 4). Akaike weights indicated that there was evidence that bull trout movement also was influenced by day snorkeling, percent fine substrate and mean maximum water depth (Table 4). Model averaged estimates indicated that fish movement was lower in subunit 3 compared to subunits 1 and 2 (Table 5), which suggested the possible influence of the upper blocknet. Upstream movement was greater during day snorkeling and downstream movement lower during night snorkeling (Table 5). Estimates of percent fine substrate and mean maximum water depth, however, were not reliable because the 90% credibility intervals were very wide and contained zero for both the up and downstream coefficients (Table 5). Therefore, we used the composite model containing subunit three, day, and night snorkeling to estimate bull trout movement and evaluate the influence of blocknet use on detection probabilities (below).

Conditional multinomial logit models of bull trout movement from 100-m sample units indicated that the best fitting model contained subunit 1 (i.e., the lower 100-m subunit; Table 4) and was 5.7 times more likely than the next best fitting model that contained subunit 1 and day snorkeling. Akaike weights also indicated that there was evidence bull trout movement in 100-m sample units was influenced by night snorkeling (Table 4). Similar to the 50-m subunit model, model averaged estimates indicated that fish movement was higher in the lower 100-m subunit (i.e., combined 50-m subunits 1 and 2) compared to the upper 100-m subunit (i.e., combined 50-m subunits 2 and 3), again suggesting an upper blocknet influence (Table 5). Similar to movement in 50-m sample units, upstream movement also was greater during day snorkeling (Table 5). Estimates of night snorkeling effects, however, were not reliable because the 90% credibility intervals were relatively wide and contained zero for both the up and downstream coefficients (Table 5). Therefore, we used the composite model containing the upper 100-m subunit and day snorkeling to estimate bull trout movement and evaluate the influence of blocknet use on detection probabilities in 100-m sample units (below).

Conditional multinomial logit models of rainbow trout movement in 50-m sample units indicated that the best fitting model contained the intercept only (Table 4) and was more than 8 times more likely as the next best fitting model containing the intercept and percent rubble substrate. Akaike weights indicated that there was little evidence rainbow trout movement was influenced by any of the other variables considered (Table 4). Model averaged estimates indicated that rainbow trout upstream movement was negatively related to percent rubble substrate, which suggested that movement was lower in subunits with greater amounts of rubble substrate (Table 5).

The best fitting conditional multinomial logit model of rainbow trout movement in 100-m sample units contained the intercept only and was more that 29 times more likely than the next best model. The intercept only model was the only model contained in the confidence set of models. Therefore, we only report average movement by rainbow trout in 100-m sample units.

Table 4. Akaike information criteria with small sample bias adjustment (AIC_c), AICc difference (ΔAIC_c), and Akaike weights (w_i) for confidence set of models relating the movement of bull trout (top) and rainbow trout (bottom) in response to sampling activities. Akaike weights are interpreted as relative plausibility of candidate models (i).

Candidate model	AIC_c	ΔAIC_c	w_i
Bull trout, 50-m sample unit			
Subunit 3	293.40	0.00	0.417
Subunit 3, Night snorkeling	295.79	2.39	0.126
Subunit 3, Day snorkeling	296.00	2.60	0.114
Subunit 3, Percent fine substrate	296.81	3.41	0.076
Subunit 3, Mean maximum depth	297.32	3.92	0.059
Bull trout, 100-m sample unit			
Subunit 1	210.20	0.20	0.664
Subunit 1, Day snorkeling	213.70	3.70	0.115
Subunit 1, Night snorkeling	214.30	4.30	0.085
Rainbow trout, 50-m sample unit			
Intercept only model	83.45	0.00	0.541
Percent rubble substrate	87.82	4.37	0.061

Table 5. Model-averaged results for composite multinomial logit model of bull trout (top) and rainbow trout (bottom) movement in response to sampling activities. Coefficients should be interpreted relative to remaining in a subunit (the baseline). The importance weights are calculated using the Akaike weights from individual models and are the same for both logit submodels (i.e., upstream and downstream movement).

Parameter	Mean estimate	Credibility interval 5%	Credibility interval 95%	Importance weight
Bull trout, 50-m sample unit				
Upstream movement				
Intercept	-1.402	-2.264	-0.540	
Subunit 3	-1.569	-2.582	-0.556	0.928
Night snorkeling	0.475	-0.093	1.043	0.190
Day snorkeling	0.663	0.005	1.320	0.184
Mean maximum depth	-1.478	-3.924	0.908	0.125
Percent fine substrate	-0.016	-0.043	0.011	0.101
Downstream movement				
Intercept	-2.281	-3.291	-1.271	
Subunit 3	-0.421	-1.460	0.618	
Night snorkeling	-1.223	-2.405	-0.041	
Day snorkeling	0.644	-0.404	1.692	
Mean maximum depth	-0.040	-2.531	2.549	
Percent fine substrate	-0.008	-0.035	0.019	
Bull trout, 100-m sample unit				
Upstream movement				
Intercept	-3.915	-5.495	-2.541	
Subunit 1	1.982	0.614	3.488	0.939
Night snorkeling	-0.278	-0.881	0.325	0.186
Day snorkeling	0.568	0.040	1.095	0.208
Downstream movement				
Intercept	-2.746	-4.062	-1.570	
Subunit 1	-0.335	-1.199	0.528	
Night snorkeling	-0.956	-2.423	0.510	
Day snorkeling	0.900	0.050	1.749	
Rainbow trout, 50-m sample unit				
Upstream movement				
Intercept	-0.393	-1.864	1.028	
Percent rubble substrate	-0.060	-0.109	-0.015	0.091
Downstream movement				
Intercept	-2.335	-3.876	-0.844	
Percent rubble substrate	0.005	-0.031	0.040	

Estimates of salmonid movement indicated that upstream movement exceeded downstream movement under most conditions, across species (Tables 6 and 7). One exception was for bull trout that exhibited greater downstream movement for single pass electrofishing and day snorkeling and less upstream movement in 50-m subunit 3 and the upstream 100-m subunit (i.e., the combined 50-m subunits 2 and 3). Again, this suggested a blocknet effect (bias). In contrast, there was no substantial difference in movement at 50-m subunits 1 and 2. Sampling method also had a substantial influence on bull trout movement with generally greater movement for the snorkeling methods (Tables 6 and 7). Excluding subunit 3, we estimate that the probability of bull trout upstream movement in 50-m sample units was 25.4% and 28.5% for night and day snorkeling, respectively, whereas single pass electrofishing was 17.8%. Bull trout movement also was lower in 100-m sample units compared to 50-m units, especially for night snorkeling. Excluding the upper 100-m subunit, the probability of bull trout upstream movement was 12.1% for both single pass electrofishing and night snorkeling and 21.1% for day snorkeling (Table 7).

Rainbow trout movement in 50-m samples units was influenced by the amount of rubble substrate (Table 6). We estimate that the probability of rainbow trout upstream movement was as little as 13.4% and as much as 73.6% when there was no rubble substrate, whereas it was between 9.3% and 41.6% when there was 15% rubble substrate. In contrast, estimates of rainbow trout movement in 100-m sample units suggested that it was lower than 50-m units (Table 7). We caution, however, that the 100-m sample unit estimates were highly imprecise as evidenced by the very wide credibility intervals (Table 7).

Table 6. Mean estimated probability of movement (expressed as a percentage) from 50-m sample units and 90% credibility intervals for stream-dwelling salmonids in response to sampling activities, by species. Bull trout and rainbow trout estimates are based on model-averaged multinomial logit models.

Condition [a]	Mean	Credibility interval 5%	95%
Bull trout			
Upstream			
1 pass EF, SU1 & SU2	17.8	8.5	30.2
1 pass EF, SU3	4.9	1.2	11.3
Night snorkel, SU1 & SU2	25.4	15.5	36.7
Night snorkel, SU3	7.4	2.2	15.9
Day snorkel, SU1 & SU2	28.5	18.6	39.5
Day snorkel, SU3	8.6	2.6	17.9
Downstream			
1 pass EF, SU1 SU2	10.2	3.7	20.1
1 pass EF, SU3	7.4	1.9	16.4
Night snorkel, SU1 & SU2	3.5	0.9	7.7
Night snorkel, SU3	2.6	0.5	6.6
Day snorkel, SU1 & SU2	16.8	9.3	25.9
Day snorkel, SU3	12.6	4.2	25.0
Rainbow trout			
Upstream			
Rubble substrate, 0%	41.7	13.4	73.6
Rubble substrate, 15%	23.1	9.3	41.6
Downstream			
Rubble substrate, 0%	11.6	2.0	30.1
Rubble substrate, 15%	11.0	3.4	23.3
Brook trout			
Upstream	28.6	5.9	63.8
Downstream	17.4	1.8	48.1
Westslope cutthroat trout			
Upstream	12.8	3.7	26.2
Downstream	9.7	2.1	21.8

[a] EF = electrofishing, SU = subunit

Table 7. Mean estimated probability of movement (expressed as a percentage) from 100-m sample units and 90% credibility intervals for stream-dwelling salmonids in response to sampling activities, by species. Bull trout estimates are based on model-averaged multinomial logit model.

Condition [a]	Mean	Credibility interval 5%	95%
Bull trout			
Upstream			
1 pass EF or night snorkel, SU1	12.1	5.4	18.8
1 pass EF or night snorkel, SU2	2.1	1.4	2.9
Day snorkel, SU1	21.1	11.2	31.0
Day snorkel, SU2	4.3	2.9	5.7
Downstream			
1 pass EF or night snorkel, SU1	3.5	2.0	4.9
1 pass EF or night snorkel, SU2	4.7	2.6	6.8
Day snorkel, SU1	11.0	6.0	16.0
Day snorkel, SU2	14.8	8.1	21.6
Rainbow trout			
Upstream	5.3	1.2	13.0
Downstream	8.5	2.7	18.6

[a] EF = electrofishing, SU = subunit

When salmonids did move, they tended to move relatively short distances. For instance, 67% of the rainbow trout that moved traveled 25-m and none traveled more than 50-m. Bull trout appeared to move slightly greater distances with 17.6% of individuals moving 75-m or more (Figure 5).

The conditional multinomial logit model suggested that bull trout downstream movement was similar in 50-m subunits one and two. Assuming that bull trout abundances in adjacent stream areas are similar, we believe that downstream movement out of a subunit may be compensated by the downstream movement into a subunit from some upstream area for both 50-m and 100-m subunits. Therefore, we considered only upstream movement (as estimated by the conditional multinomial logit model, Tables 6 and 7) when estimating bull trout detection probabilities and sample size requirements.

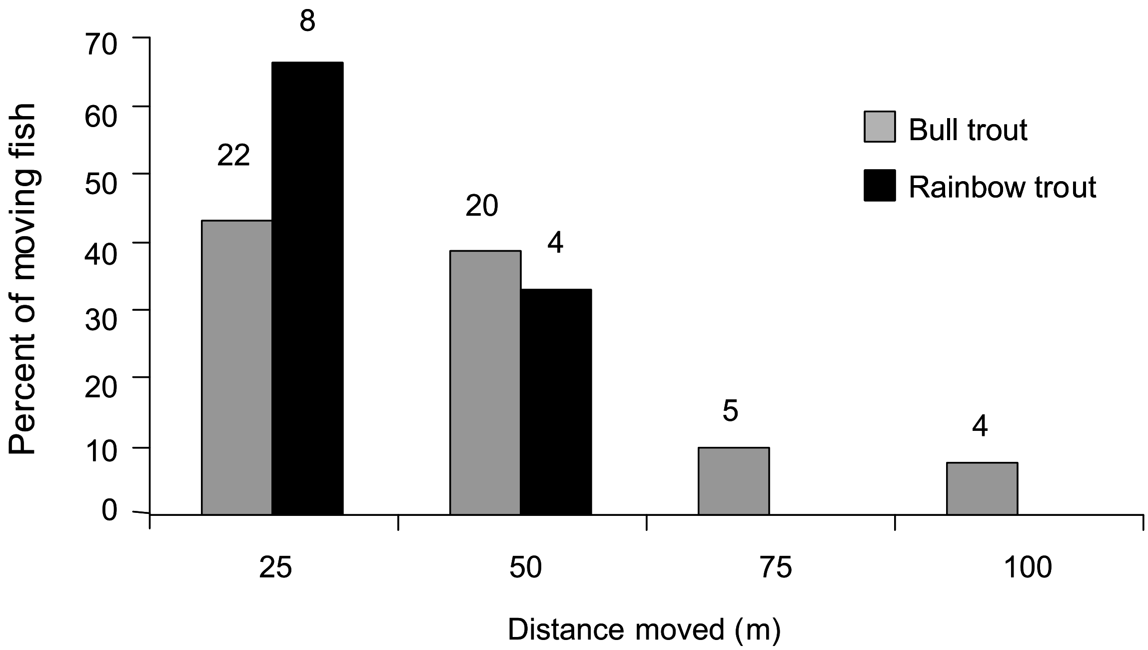

Figure 5. Distribution of distances moved by marked bull trout and rainbow trout leaving subunits. Numbers above bars are numbers of observed number individuals moving in response to sampling activities.

Bull trout movement decreased detection probabilities in 50-m sample units (on average) 11.4% across sampling methods, whereas detection probabilities in 100-m sample units decreased 5.8% (Tables 8, 9, and 10). These, in turn, increased required sample sizes (i.e., number of samples) for 80%, 90%, and 95% power, on average, 13.4% and 6.5% for 50-m and 100-m sample units, respectively. The greatest increase in sample sizes was for day snorkeling in 50-m sample units with an increase of 12, 17, and 22 samples for 80%, 90%, and 95% power, respectively (Table 8). The smallest increase in sample sizes was for night snorkeling in 100-m sample units with an increase of 1 sample for 80%, 90%, and 95% power (Table 9).

Table 8. Mean estimated bull trout single sample detection probabilities (averaged across fish body sizes) and required sample sizes for 80%, 90%, and 95% detection probabilities for single pass day snorkeling with and without blocknets, by habitat groups[1]. Detection probabilities estimated assuming distribution of densities for 50-m and 100-m sample units in Peterson et al. (2002).

			With blocknets					Without blocknets				
Water temperature	Mean depth	Undercut banks	Mean capture efficiency	Single sample detection	80%	90%	95%	Mean capture efficiency	Single sample detection	80%	90%	95%
50-m sample units												
> 9.25 ^{0}C	>0.17 m	> 1.6 %	0.062	0.021	75	107	140	0.044	0.018	91	130	169
		≤ 1.6 %	0.166	0.051	31	44	57	0.119	0.044	36	52	67
	≤0.17 m	> 1.6 %	0.080	0.027	58	83	108	0.057	0.023	70	100	130
		≤ 1.6 %	0.207	0.061	25	36	47	0.148	0.053	30	42	55
≤ 9.25 ^{0}C	>0.17 m	> 1.6 %	0.041	0.014	112	161	209	0.029	0.012	137	196	255
		≤ 1.6 %	0.114	0.038	42	60	78	0.081	0.032	50	71	93
	≤0.17 m	> 1.6 %	0.054	0.019	84	121	157	0.039	0.016	102	147	191
		≤ 1.6 %	0.147	0.047	33	47	62	0.105	0.040	39	56	73
100-m sample units												
> 9.25 ^{0}C	>0.17 m	> 1.6 %	0.062	0.027	59	85	110	0.049	0.024	67	96	125
		≤ 1.6 %	0.166	0.063	25	35	46	0.131	0.057	27	39	51
	≤0.17 m	> 1.6 %	0.080	0.033	47	68	88	0.063	0.030	53	76	99
		≤ 1.6 %	0.207	0.075	21	30	38	0.163	0.068	23	32	42
≤ 9.25 ^{0}C	>0.17 m	> 1.6 %	0.041	0.018	89	127	165	0.032	0.016	100	144	187
		≤ 1.6 %	0.114	0.046	34	49	63	0.090	0.042	38	54	71
	≤0.17 m	> 1.6 %	0.054	0.024	67	96	125	0.043	0.021	76	109	142
		≤ 1.6 %	0.147	0.058	27	39	50	0.116	0.052	30	43	56

[1]Habitat group cutoff values were based on the mean values observed in Thurow et al. (2003).

Table 9. Mean estimated bull trout single sample detection probabilities (averaged across fish body sizes) and required sample sizes for 80%, 90%, and 95% detection probabilities for single pass night snorkeling with and without blocknets, by habitat groups[1]. Detection probabilities estimated assuming distribution of densities for 50-m and 100-m sample units in Peterson et al. (2002).

	With blocknets					Without blocknets				
Undercut banks	Mean capture efficiency	Single sample detection	80%	90%	95%	Mean capture efficiency	Single sample detection	80%	90%	95%
50-m sample units										
>1.6%	0.258	0.075	21	30	39	0.192	0.067	23	33	43
<1.6%	0.222	0.066	24	34	44	0.166	0.058	27	38	50
100-m sample units										
>1.6%	0.258	0.088	17	25	32	0.226	0.086	18	26	33
<1.6%	0.222	0.079	19	28	36	0.195	0.077	20	29	37

[1]Habitat group cutoff values were based on the mean values observed in Thurow et al. (2003).

Table 10. Mean estimated bull trout single sample detection probabilities (averaged across fish body sizes) and required sample sizes for 80%, 90%, and 95% detection probabilities for single pass electrofishing with and without blocknets, by habitat groups[1]. Detection probabilities estimated assuming distribution of densities for 50-m and 100-m sample units in Peterson et al. (2002).

			With blocknets					Without blocknets				
Stream mean wetted cross-sectional area	Conductivity	Undercut banks	Mean capture efficiency	Single sample detection	80%	90%	95%	Mean capture efficiency	Single sample detection	80%	90%	95%
50-m sample units												
> 1.00 m^2	>53 μohms	> 1.6 %	0.127	0.043	36	52	68	0.104	0.040	40	57	74
		≤ 1.6 %	0.203	0.063	25	35	46	0.167	0.059	26	38	49
	≤53 μohms	> 1.6 %	0.087	0.030	52	75	97	0.071	0.028	57	82	106
		≤ 1.6 %	0.140	0.048	33	47	61	0.115	0.044	36	51	66
≤ 1.00 m^2	>53 μohms	> 1.6 %	0.170	0.055	29	41	53	0.139	0.051	31	44	57
		≤ 1.6 %	0.264	0.078	20	29	37	0.217	0.073	21	30	39
	≤53 μohms	> 1.6 %	0.118	0.041	39	55	72	0.097	0.038	42	60	78
		≤ 1.6 %	0.186	0.060	26	37	48	0.153	0.056	28	40	52
100-m sample units												
> 1.00 m^2	>53 μohms	> 1.6 %	0.127	0.051	31	44	57	0.112	0.049	32	46	60
		≤ 1.6 %	0.203	0.075	21	30	39	0.179	0.072	21	31	40
	≤53 μohms	> 1.6 %	0.087	0.037	42	61	79	0.076	0.036	44	64	83
		≤ 1.6 %	0.140	0.056	28	40	52	0.123	0.054	29	42	54
≤ 1.00 m^2	>53 μohms	> 1.6 %	0.170	0.065	24	34	44	0.149	0.063	25	35	46
		≤ 1.6 %	0.264	0.089	17	25	32	0.232	0.087	18	25	33
	≤53 μohms	> 1.6 %	0.118	0.048	33	47	61	0.104	0.046	34	49	63
		≤ 1.6 %	0.186	0.070	22	32	41	0.164	0.068	23	33	43

[1]Habitat group cutoff values were based on the mean values observed in Thurow et al. (2003).

4.0 DISCUSSION

Salmonid movements were primarily upstream, which suggests that species may be attempting to flee during the sampling process. Nordwall (1999) discovered that an estimated 25% of brown trout *Salmo trutta* moved upstream into fish traps within 3 days after electrofishing a 200-m unit downstream of the fish traps. In contrast, Dunham et al. (2002) found no increase in stream-dwelling brook trout movement in response to electrofishing in two sample reaches. Our results indicated that, on average, more than 17% of bull trout and rainbow trout leave unblocked units during sampling. This is similar to the 15% movement rate reported for warmwater fish species during electrofishing (Edwards 2001), but is lower than the 41-77% movement rate reported for reef fishes in response to divers (Stanley and Wilson 1995). Failure to use blocknets or adjust data for fish movement would likely result in biased low salmonid abundance estimates of a similar magnitude (e.g., 15% movement = 15% bias). We also estimate that detection probabilities are lower when blocknets are not used, increasing the chances of missing a species when it is present. Increasing sample sizes, however, can minimize the effect of lowered detection probabilities.

Physical habitat characteristics influenced stream-dwelling salmonid movement during sampling. Rainbow trout movement was lower in sample units with greater amounts of rubble substrate. The Akaike weights also suggested that bull trout movement was related to stream depth and substrate. We hypothesize that fish are using protective cover to avoid detection and capture and in the absence of cover, such as rubble substrate, fishes move to the nearest available protective cover. The negative effect of undercut banks on electrofishing and day snorkeling efficiency (Thurow et al. 2003) is consistent with our hypothesis. For example, fishes may have moved into undercut banks in response to sampling, lowering the ability to capture or detect them. The influence of physical habitat on fish movement also suggests that samples collected without blocknets from different habitats are likely biased by factors influencing fish movement.

Salmonid movement differed markedly among sampling methods. In general, snorkeling methods resulted in the greatest bull trout movement, whereas electrofishing the least. We believe that this may be due in part to the greater amount of disturbance during snorkeling activities as snorkelers crawl over obstructions and shallow areas and peer into crevices. Snorkelers swimming through a fish's environment also may be perceived as a greater threat than individuals wading in the stream during electrofishing. The substantial response of salmonids to snorkeling activity also brings into question the validity of studies that rely on snorkeling to evaluate fish behavior (e.g., Petty and Grossman 1996). We estimate that 28% of bull trout moved in response to day snorkeling. If fish-habitat studies are conducted via day snorkeling and 28% of fish flee in response, then observers are potentially missing fish and habitat associations for more than a quarter of the fish within sample units. This leads us to believe that fish-habitat observations can only be based on the portion of the population directly observed, not those that flee. For example, the influence of habitat on fish movement suggests that observed habitat use might differ in the presence of snorkelers.

Fish movement rate also appeared to be related to sample unit size. In general, movement rates were higher in the 50-m subunits compared to the 100-m subunits. Our data also suggest that fishes were moving relatively short distances, generally less than 50-m. We believe that fish may have moved until encountering appropriate cover, such as rubble substrate. Larger reaches presumably, contain larger amounts of appropriate cover increasing the chances that a fleeing individual will remain in the sample unit. Thus, the influence of fish movement may be minimized, in part, by sampling longer reaches. However, the optimal sample unit length may depend on the types and amounts of habitats. Further, we caution that the data collected by a protocol that includes very large (long) sample units would be less powerful in interpreting species-habitat relationships (Bayley and Peterson 2001).

The decreased probability of detection as a result of salmonid movement during day snorkeling is compounded by low capture efficiency during the day (Thurow et al. 2003). Indeed, our estimates of capture efficiency and fish movement suggest that day snorkeling without blocknets is among the least efficient methods for sampling stream dwelling salmonids. For example, under the best of circumstances (relatively warm, shallow stream, with amounts of low undercut banks), we estimate that 33, 50-m samples are required to detect bull trout with an 80% probability. In contrast, we estimate that only 21 samples need to be collected via night snorkeling. Abundance data would be similarly influenced because sample variance is negatively related to fish capture efficiency (lower efficiency = higher variance; Peterson and Rabeni 1995) and high variance (for a given sample design) can only be overcome by increasing sample size. Therefore, we believe that biologists should consider these factors, in addition to practical considerations such as safety, when developing salmonid sampling or monitoring protocols.

Low numbers of marked large (>199 mm) and a low proportion of recaptured small (70-99 mm) salmonids precluded us from investigating body size effects on fish movement. Hence, our results are only applicable to stream-dwelling salmonids $\leq$400 mm. As such, we caution that our findings may not reflect instream movement of larger salmonids. However, Nordwall (1999) revealed the size of brown trout caught in traps after electrofishing increased, suggesting larger fish moved more in response to sampling than did small fish. This contrasts work conducted by Dunham et al. (2002) that found no difference in size of fish moving out of electrofished areas versus control areas. More research in this area will be needed to determine size-related movement patterns in response to sampling.

Recommendations and future directions

Because it is unlikely that all streams reaches within a watershed will have the same habitat characteristics, our estimates of sample size requirements are intend to be used during the planning stages as detailed in Peterson et al. (2002). Briefly, biologists should attempt to characterize the streams in their watersheds. For example, previous surveys may suggest that streams in a potential study area are, on average, cold, shallow and with low amounts of undercut banks. Given these average habitat characteristics, an expected number of samples can be determined using the sample size requirements. Thus, the tabled values allow for a quick assessment of personnel needs and a comparison of the efficacy of the 3 sampling techniques. Actual detection probabilities then can be estimated using the tabled single sample unit probabilities based on habitat classes (as detailed in Peterson et al. 2002) or alternatively, using, measured habitat characteristics to estimate sampling efficiencies and detection probabilities directly. The latter approach also allows for the use of different abundance estimates (e.g., threshold densities) and statistical distributions, provided that they are biologically justifiable.

We had originally intended to estimate fish movement using all of the sampling data (i.e., the primary and non primary method samples). However, our preliminary analysis suggested that some of the fishes displaced during primary method sampling did not return to their original subunits, inflating (biasing) estimates of movement for the non primary methods. Sampling with the non primary methods also increased the amount of time required to collect data at a given sample unit, sometimes by two or more days. Given the potential biases and effort required to collect the non primary samples, we recommend that future evaluations only collect a primary method sample. This also will allow crews to conduct a greater number of evaluations over the course of a sampling season.

We included the upper and lower 25-m adjacent areas (i.e., the areas adjacent to the 150-m sample unit) to allow fishes to escape the upper and lower 50-m subunits and minimize the effect of blocknets on fish movement. Nonetheless, we found that fishes in the upper subunit exhibited less movement than fishes in downstream subunits. We believe that this may be the result of displaced fishes swimming upstream through the 25-m section, encountering the blocknet, and swimming downstream into the upper 50-m subunit where they were detected by crews. This is, in part, consistent with some of our observations of fish response to electrofishing in warmwater streams in the Midwest. For example during multiple occasions, stream fishes in the Missouri Ozarks, mostly black basses and sunfish (*Centrarchidae*) and suckers (*Catastomidae*), were observed fleeing ahead of sampling crews, encountering upstream blocknets, and swimming downstream where they were collected via electrofishing (J. Peterson, *personal observation*). However, the distance traveled downstream (after encountering the blocknet) was generally 25-m or less. The presumably, greater distance traveled by salmonids(> 25-m) may have been the results of the generally slower pace of crews in Washington in 2002 or alternatively, the greater reaction distance or swimming speed of salmonids. Regardless of the mechanism, the observed blocknet effect suggests that the size of our 25-m adjacent areas was inadequate for minimizing the effect of blocknets. Therefore, we suggest that future evaluations consider using longer, perhaps 50-m, upper and lower adjacent areas to ensure that estimates of movement are unaffected by blocknets.

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6.0 LITERATURE CITED

Agresti, A. 1990. Categorical data analysis. Wiley, New York.

Akaike, H. 1973. Information theory and an extension of the maximum likelihood Principle. *Pages* 267-281 *In* Second International Symposium on Information Theory. B. N. Petrov and F. Csaki, *editors*. Akademiai Kiado, Budapest, Hungary.

Bain, M. B., J. T. Finn, and H. E. Booke. 1985. A quantitative method for sampling riverine microhabitats by electrofishing. North American Journal of Fisheries Management 5:489-493.

Bayley, P. B. and J. T. Peterson. 2001. An approach to estimate probability of presence and richness of fish species. Transactions of the American Fisheries Society 130: 620-633.

Burnham, K. P., and D. R. Anderson. 2002. Model selection and inference: an information-theoretic approach. Springer-Verlag, New York.

Buttiker, B. 1992. Electrofishing results corrected by selectivity functions in stock size estimates of brown trout (*Salmo trutta* L.) in brooks. Journal of Fish Biology 41:673-684.

Congdon, P. 2001. Bayesian statistical analysis. Wiley, New York.

Dolloff, A., J. Kershner, and R. Thurow. 1996. Underwater observation. Pages 533-554 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2^{nd} edition. American Fisheries Society, Bethesda, Maryland.

Dunham, K. A., J. Stone, and J. R. Moring. 2002. Does electric fishing influence movements of fishes in streams? Experiments with brook trout, *Salvelinus fontinalis*. Fisheries Management and Ecology 9:249-251.

Edwards, M. R. 2001. Comparison of two electrofishing methods for surveying fish assemblages in warmwater streams in central Tennessee. MS Thesis, Tennessee Technological University, Cookeville, Tennessee.

Gelman, A. and D. B. Rubin. 1992. Inference from iterative simulation using multiple sequences. Statistical Science 7:457-511.

Green, R. H. and R. C. Young. 1993. Sampling to detect rare species. Ecological Applications 3:351-356.

Hurvich, C. M. and C. Tsai. 1989. Regression and time series model selection in small samples. Biometrika 76:297-307.

Kendall, W. L. 1999. Robustness of closed capture-recapture methods to violations of the closure assumption. Ecology 80:2517-2525.

Kennedy, G. J. and C. D. Strange. 1981. Efficiency of electrofishing for salmonids in relation to river width. Fisheries Management 12:55-60.

Li, H. W. and J. L. Li. 1996. Fish community composition. *Pages* 391- 406 *in* R. Hauer and G. A. Lamberti, editors. Methods in stream ecology. Academic Press, San Diego, CA.

Mesa, M. G. and C. B. Schreck. 1989. Electrofishing mark-recapture and depletion methodologies evoke behavioral and physiological changes in cutthroat trout. Transactions of the American Fisheries Society 118:644-658.

Nordwall, F. 1999. Movements of brown trout in a small stream: effects of electrofishing and consequences for population estimates. North American Journal of Fisheries Management 19:462-469.

Peterson, J. T. 1996. The evaluation of a hydraulic unit based habitat classification system. PhD Dissertation, University of Missouri, Columbia, Missouri.

Peterson, J. T. and N. P. Banish. 2002. The evaluation of sampling conditions across the bull trout range in Washington State. Final Report to U. S. Fish and Wildlife Service, Aquatic Resources Division, Lacey, WA.

Peterson, J., Dunham, J., Howell, P., Thurow, R., and S. Bonar. 2002. Protocol for determining bull trout presence. Western Division of the American Fisheries Society. Available from: http://www.fisheries.org/wd/committee/bull_trout/bull_trout_committee.htm (accessed June 10, 2003).

Peterson, J.T. and C. F. Rabeni. 1995. Optimizing sampling effort for sampling warmwater stream fish communities. North American Journal of Fisheries Management 15:528-541.

Platts, W.S., W.F. Megahan, and G.W. Minshall. 1983. Methods for evaluating stream, riparian, and biotic conditions. General Technical Report INT-138. U.S.

Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Petty, J.T. and G. D. Grossman. 1996. Patch selection by mottled sculpin (Pisces: *Cottidae*) in a southern Appalachian stream. Freshwater Biology 35:261-276.

Riley, S.C. and K.D. Fausch. 1992. Underestimation of trout population size by maximum-likelihood removal estimates in small streams. North American Journal of Fisheries Management 12:768-776.

Riley, S. R. Haedrich and R. Gibson. 1993. Negative bias in removal estimates of Atlantic salmon parr relative to stream size. Journal of Freshwater Ecology 8: 97-101.

Rodgers, J. D., M. F. Solazzi, S. L. Johnson and M. A. Buckman. 1992. Comparison of three techniques to estimate juvenile coho salmon populations in small streams. North American Journal of Fisheries Management 12:79-86.

Spiegelhalter, D., A. Thomas, and N. Best. 2000. Win BUGS, version 1.3. available online at < http://www.mrc-bsu.cam.ac.uk/bugs/winbugs/contents.shtml>.

Stanley, D. R. and C. A. Wilson. 1995. Effect of scuba-divers on fish density and target strength estimates from stationary dual-beam hydroacoustics. Transactions of the American Fisheries Society 124:946-949.

Thompson, W. L. 2003. Hankin and Reeves' approach to estimating fish abundance in small streams: limitations and alternatives. Transactions of the American Fisheries Society 132:69-75.

Thompson, W. L., and D. C. Lee. 2000. Modeling relationships between landscape-level attributes and snorkel counts of Chinook salmon and steelhead parr in Idaho. Canadian Journal of Fisheries and Aquatic Sciences 57:1834-1842.

Thompson, P. D. and F. J. Rahel. 1996. Evaluation of depletion-removal electrofishing of brook trout in small rocky mountain streams. North American Journal of Fisheries Management 16:332-339.

Thurow, R. F. 1994. Underwater methods for study of salmonids in the Intermountain West. U. S. Department of Agriculture, Forest Service, Intermountain Research Station. General Technical Report INT-GTR-307. Ogden, Utah.

Thurow, R. F., J. T. Peterson, and J. W. Guzevich. 2001. Development of Bull Trout Sampling Protocols. Final Report to U.S. Fish and Wildlife Service, Aquatic Resources Division, Lacey, Washington.

Thurow, R. F., J. T. Peterson, C. A. Larsen, and J. W. Guzevich. 2003. Development of Bull Trout Sampling Protocols. Final Report to U.S. Fish and Wildlife Service, Aquatic Resources Division, Lacey, WA.

Thurow, R. F. and D. J. Schill. 1996. Comparison of day snorkeling, night snorkeling, and electrofishing to estimate bull trout abundance and size structure in a second-order Idaho stream. North American Journal of Fisheries Management 16: 314-323.

Wolman, G.M. 1954. A method of sampling coarse river-bed material. Transactions, American Geophysical Union 35(6):951-956.

Appendix A. The names, sampling end dates, and locations of sample units used to evaluate salmonid movement in Washington State streams during 2001 and 2002. Latitude and longitude are given in degrees (^{o}), minutes ('), and seconds (") format.

River basin	Stream name	Survey unit	Date	Latitude	Longitude
Methow River	Early Winters Creek	1	8/28/2001	48° 34' 94"N	120° 37' 35"W
NF Nooksack	Canyon Creek	1	7/24/2001	48° 56' 93"N	121° 49' 04"W
Bumping River	Deep Creek	1	7/30/2001	46° 47' 33"N	121° 19' 27"W
SF Nooksack	Bell Creek	1	8/9/2001	48° 41' 50"N	121° 52' 52"W
American	Kettle Creek	1	8/28/2002	46° 56' 28"N	121° 19' 34"W
American	Kettle Creek	2	8/29/2002	46° 56' 22"N	121° 19' 33"W
Bumping	Copper Creek	1	8/21/2002	46° 48' 49"N	121° 18' 24"W
Mill	Low Creek	1	7/31/2002	45° 59' 33"N	118° 02' 03"W
Mill	NF Mill	1	8/7/2002	46° 01' 19"N	117° 59' 42"W
Tieton River	Indian Creek	1	7/16/2001	46° 39' 44"N	121° 17' 04"W
Tieton	Indian Creek	1	8/20/2002	46° 40' 28"N	121° 17' 71"W
Tieton	Indian Creek	2	8/22/2002	46° 39' 34"N	121° 17' 80"W
Tucannon	Meadow Creek	1	7/24/2002	46° 09' 39"N	117° 43' 42"W
Ahtanum	NF Ahtanum	1	7/25/2002	46° 31' 84"N	121° 09' 57"W
Touchet	NF Touchet	1	8/6/2002	46° 06' 59"N	117° 50' 07"W
Twisp	EF Buttermilk	1	8/14/2002	48° 19' 19"N	120° 17' 55"W
Twisp	Reynolds Creek	1	9/4/2002	48° 24' 19"N	120° 28' 41"W
Twisp	NF Twisp	1	9/5/2002	48° 27' 41"N	120° 34' 39"W
Chiwawa	Minnow Creek	1	7/10/2002	47° 54' 50"N	120° 43' 09"W
Entiat	Tillicum Creek	1	7/15/2002	47° 43' 75"N	120° 25' 93"W