Are Block Nets Necessary?: Movement of Stream-Dwelling Salmonids in Response to Three Common Survey Methods

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Abstract.—Fish movement during sampling may negatively bias sample data and population estimates. We evaluated the short-term movements of stream-dwelling salmonids by recapture of marked individuals during day and night snorkeling and backpack electrofishing. Bull trout *Salvelinus confluentus* and rainbow trout *Oncorhynchus mykiss* were captured in sufficient numbers to evaluate instream movements and the influence of stream habitat on movement. Salmonids moved upstream more often than downstream, which suggests that fish fled in response to sampling procedures. Fish movement rates were related to sampling method and stream habitat characteristics. The proportion of bull trout (mean total length, 148 mm) moving upstream from a 50-m reach was 28% for day snorkeling, 25% for night snorkeling, and 18% for single-pass electrofishing. The likelihood of rainbow trout movement upstream during sampling declined as the percentage of rubble substrate increased. Rainbow trout (mean total length, 139 mm) traveled short distances; 67% of mobile rainbow trout traveled 25 m, whereas 59% of mobile bull trout traveled more than 50 m. Our results suggest that fish movement out of sample sites during sampling may negatively bias abundance estimates and positively bias estimates of detection probability. We suggest that block nets are necessary to ensure population closure when estimating population abundance for stream-dwelling salmonids. We further caution that, when fish flee in response to sampling, observations of habitat use may only apply to the proportion of fish that remained stationary and that were observed.

Various sampling approaches are commonly used to assess presence, abundance, and status of stream-dwelling fishes. These surveys are often accomplished with the use of block nets to prevent the movement of individuals into or out of a sample unit (Li and Li 1996), and block nets are believed to be essential for ensuring fish population closure. For example, fish movement can negatively bias sampling data and population estimates (Kendall 1999). The magnitude of bias, however, will depend on the distances fish move and the number of fish moving relative to the length of the reach being sampled. This bias is additional to that

associated with the probability of capture or observation of fish remaining in the sample site. Fish movement out of sampling sites can influence species presence and absence data as well as abundance estimates 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 by physical habitat characteristics, then fish habitat studies and multispecies studies may be confounded. Thus, failure to use block nets may lead to biased data and hence poor management decisions. Block nets, however, are not always feasible to install and maintain, particularly in streams that are larger, that have high water velocities, or that carry debris. Financial (e.g., personnel) or logistical (e.g., stream access) constraints also may preclude use of block nets during surveys.

Even when block nets are used, fish movement

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in response to sampling may confound attempts to assess fish habitat utilization. Underwater observation, for example, is a common technique for assessing relations between stream-dwelling fish and habitat characteristics (Dolloff et al. 1996). In typical studies, one or more underwater observers traverse the sample unit and mark the locations of and habitats used by fish. Previous investigations have assessed fish–habitat relations by recording observations for individuals they judged to be undisturbed, but not for those that exhibited a flight response (Grossman and Freeman 1987; Petty and Grossman 1996). Inferences from these fish habitat studies may only be applicable for fish that actually did not move in response to the observation technique.

Despite the potential influence of fish movement, there currently is little information about the movement of stream-dwelling salmonids during sampling activities. Young and Schmetterling (2004) observed little upstream movement of westslope cutthroat trout *Oncorhynchus clarki lewisi* into fish traps during electrofishing. However, we found no information on previous evaluations of salmonid movement during snorkel sampling. Species- and method-specific information is essential for evaluation of the potential biases caused when block nets are not used, assessment of the validity of habitat utilization observations, and development of methods for adjusting sample data. Therefore, we studied the movement of stream-dwelling salmonids during sampling activities with the following objectives: (1) to measure the distance and direction bull trout *Salvelinus confluentus* and other salmonids move in response to day snorkeling, night snorkeling, and electrofishing surveys, and (2) to estimate the influence of channel features, including stream size, water temperature, channel complexity, and abundance of cover, on movement rates of stream-dwelling salmonids.

Study Area

We evaluated the instream movement of salmonids during sampling in 20 sites within first-through third-order streams located primarily in national forests in Washington State. Bull trout were the focus of our study, so we selected streams within the known range of bull trout and at relatively high elevations (range, 1,976–4,008 m) where bull trout were known to occur. We sampled during June–September (2001–2002), when most sites were at or near base flow.

Methods

Our intent was to examine fish response during sampling under conditions commonly encountered in bull trout streams throughout the region. Consequently, we developed sampling strata based on habitat data from regional streams known to contain bull trout (Peterson and Banish 2002). Each stratum consisted of streams with similar physical and chemical characteristics. For example, one stratum consisted of small (<3.5-m mean wetted width), low-gradient (<3%) streams with high wood density (>0.10 pieces/m²) and high conductivity (>100 μohms). Three-person crews randomly selected 150-m stream sections from within each stratum and installed multiple block nets within and adjacent to each stream section. Upon arriving at a sample site, crews paced a 150-m stream section at least 20 m away from the streambank (to avoid frightening fish) and installed 7-mm square-mesh nets secured to the streambed at the upper and lower boundaries. A second set of block nets was installed approximately 25 m immediately above and below the upstream and downstream block nets (Figure 1). With these four block nets in place, two additional 50-m units were paced off at least 20 m from the streambank within the 150-m section (i.e., at 50- and 100-m intervals) and block nets were installed, for a total of six block nets (Figure 1). Crews attempted to keep sample unit lengths as consistent as possible. However, on a few occasions potential block-net locations were situated in the middle of a pool or in an area where a block net could not effectively isolate a unit (e.g., areas with deeply undercut banks). In these instances, crews placed the block net at the nearest suitable location (e.g., immediately above a pool), which was always less than 5 m from the intended location. Crews also took great care to ensure that all block nets were completely secured to the streambed. To identify the locations where marked fish were observed or captured during sampling, crews placed a total of seven consecutively numbered flags along one stream bank at 25-m intervals beginning at the lowermost block net at the terminus of unit 1 (Figure 1).

Our evaluation of fish movement during sampling required knowledge of the location of individual fish both before sampling and when captured or observed. After block net and flag installation, we captured and differentially marked salmonids (≥70 mm total length [TL]) that were confined within each of the three 50-m-long block-netted units (units 1–3; Figure 1). Salmonids were
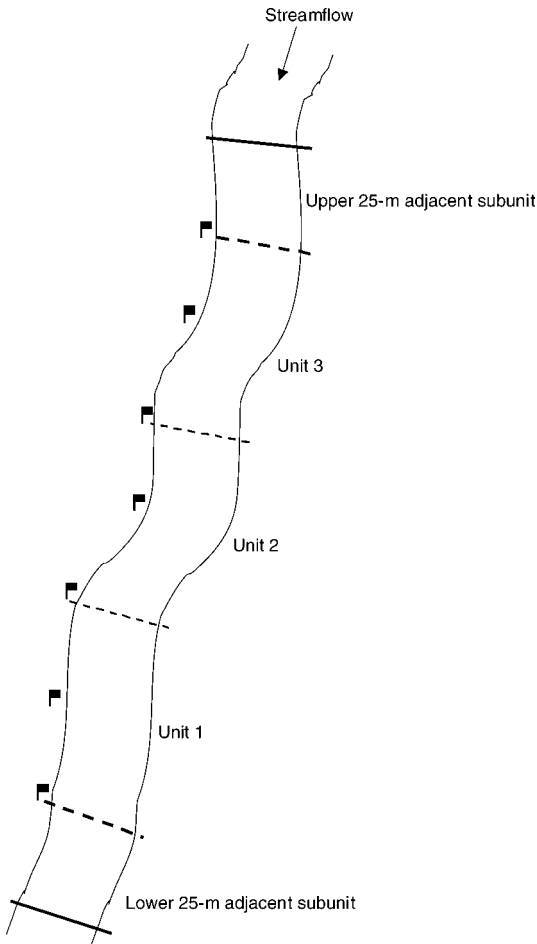
FIGURE 1.—Illustration of 50-m sample units (1–3), 25-m subunits, and adjacent subunit boundaries established to evaluate salmonid movement in Washington streams during 2001 and 2002. Removed block nets (broken lines), retained block nets (solid lines), and flagged locations are also shown. The aquatic camera was located at the uppermost flag during 2001.

captured via continuous-DC electrofishing in one upstream pass and one downstream pass to minimize the potential for injuring fish (Reynolds 1996). Captured fish were placed in live wells (one for each 25-m subunit delineated by the flags), anesthetized with tricaine methanesulfonate, identified, and measured to the nearest 10 mm TL. We differentially marked fish from each 50-m unit by notching or paper punching the dorsal fin, upper caudal fin, or both fins in a manner that was visible to snorkelers. Fish were allowed to recover from the anesthetic and were released into the center of the 25-m subunit from which they were collected. To minimize effects of handling and marking on

fish behavior, we allowed marked fish to recover for a minimum of 24 h prior to initiating our recovery surveys. In previous studies (Thurow et al. 2003; Peterson et al. 2004), we found no detectable effect of marking on the probability of capture or observation of fish that were allowed to recover for at least 24 h.

Evaluation of fish movement during sampling.— For each 150-m stream section, we randomly selected (without replacement) a fish sampling method: day snorkeling, night snorkeling, or electrofishing. At least 24 h after marking (range, 24–32 h), we attempted to minimize disturbance of the fish by slowly and deliberately entering the stream at the point of the lowermost flag (the location of the lower block net at the end of unit 1). We removed the block net, exited the stream, and walked to the next upstream block net along the shoreline at least 20 m from the stream channel. This process was repeated until all four interior block nets were removed (i.e., those separating the units; Figure 1). To maintain a closed population, the outermost block nets were left in place. The two 25-m adjacent subunits bounded by the outermost block nets were intended to provide fish with escape areas outside of the 150-m section that was subjected to the standardized sampling method (Figure 1).

During 2001, we installed an aquatic (Aqua-Vu) camera at the upper end of unit 3 (Figure 1) after removing the block nets to observe fish movement during day and night snorkeling. The camera was equipped with an infrared light that allowed crews to observe fish movement during low-light conditions. However, a halogen dive light with a red cellophane covering was placed adjacent to the underwater camera to aid viewing at night. The camera was placed perpendicular to the stream channel, as close to the streambank as possible, and in water sufficiently deep to entirely submerge the lens. By installing the camera in this manner, we had hoped to view the entire width of the channel. A hidden observer on land monitored the camera at a distance of more than 10 m from the streambank and attempted to identify and count fish moving upstream and downstream for the entire duration of the snorkel surveys. We did not use the Aqua-Vu camera in 2002 due to the practical difficulties discussed below.

After removal of the four interior block nets, we waited 1–2 h before initiating sampling. Other studies have suggested that 15–20 min is sufficient for disturbed warmwater fishes to return after installation of sampling equipment (electrofishing grids, Bain et al. 1985; drop nets, Peterson 1996).

During sampling, we detected fish with the selected method and recorded the locations of marked fish by use of the flags as boundaries (i.e., between flags 2 and 3, etc.). In this manner, we were able to assess the direction and distance fish moved during sampling.

Snorkeling.—We inspected each 150-m stream section and selected the number of snorkelers necessary to survey it in a single pass. Only snorkelers who participated in species identification and size estimation training (Thurow 1994) conducted surveys. Fish were sampled via day snorkeling between 1000 and 1700 hours and via night snorkeling between 2230 and 0230 hours. We used identical sampling techniques during day and night except that night snorkel counts were completed with the aid of an underwater halogen light. Snorkelers began at the lower boundary of the 150-m section, moved slowly upstream, counted the total number of salmonids by species, estimated fish TL to the nearest size-group (70–99, 100–199, and 200–350 mm), recorded marks, and noted the locations of marked fish. The three size-classes were used to facilitate the estimation of capture or observation efficiency based on existing models (Thurow et al. 2003) and because fish larger than 350 mm TL were not encountered during sampling. After counting fish in the 150-m section, crews snorkeled the 25-m adjacent subunits above and below the unit boundaries and recorded all marked fish by size-class and location.

Electrofishing.—We electrofished each 150-m section with continuous DC to reduce the potential for fish injury (Reynolds 1996). Electrofishing was conducted by two-person crews; one person carried the electroshocker and a dip net, and the other carried a dip net and bucket. Electrofishing began at the lower boundary of the 150-m section and proceeded upstream. All salmonids were captured and placed in individual live wells at each flag, corresponding to the location of fish capture (Figure 1). After completing a single upstream sampling pass in the 150-m section, the crew electrofished the adjacent 25-m subunits upstream and downstream from the 150-m section's boundaries. After sampling, fish were anesthetized, identified, and measured for TL to the nearest 10 mm. The species, TLs, and marks of all salmonids were recorded by location of capture.

Physical and chemical data.—Underwater visibility may affect the ability of snorkelers to detect fish and may influence the flight response of fish. Thus, snorkelers measured the underwater visibility of a salmonid silhouette at three locations

adjacent to the sampling section and prior to sampling by use of a Secchi-disk-like approach (Thurow 1994) 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 then measured that distance. Visibility was estimated as the average of three readings.

After sampling, we removed the remaining two outermost block nets and measured unit physical attributes by establishing transects perpendicular to the flow at 10-m intervals (total of 15 transects). To establish transects, we measured the sample section along the center line of the stream beginning at the downstream end of the unit. At each transect, we recorded the type of habitat (e.g., pool, riffle), measured wetted channel width, and estimated mean water depth by averaging readings at one-fourth, one-half, and three-fourths of the channel width. Cross-sectional area was estimated as the product of wetted width and mean depth. Substrate composition was visually estimated in a 1-m-wide band centered across each transect and was categorized as fines (<6 mm), gravel (6–75 mm), cobble (76–150 mm), and rubble (>150 mm). The transect-specific measurements were averaged for each 50-m unit (i.e., five transects per unit).

For each 50-m unit (except during 2001), we counted the pieces of woody debris, which we defined as woody objects at least 3 m long and 10 cm in diameter that were lying within the wetted channel. Wood density was estimated as the total number of wood pieces divided by the wetted surface area of each unit. We estimated the percent cover for each of four cover types (submerged, turbulent, overhead, and undercut). We measured the length of undercut banks and overhead vegetation along each bank and expressed these as percentages of the total bank length (left and right) for each 50-m unit. We visually estimated (to the nearest 10%) the percentage of the reach that contained turbulence and submerged cover. We defined turbulence as abrupt changes in water velocity typically observed at changes in gradient (riffles), near physical obstructions to flow (wood or boulders), and along irregular shorelines. Submerged cover included large boulders, bedrock, and large wood. Wood counts and cover component measurements (described above) were not recorded separately for each 50-m unit during 2001, and hence the 150-m section measurement was assigned to each 50-m unit. Conductivity and tem-

perature were measured in the center of each sample section by use of a calibrated hand-held meter.

Statistical analyses.—For each of our three sampling methods, we used a multinomial logit model to examine the relationships between unit characteristics and the probability that fish either remained in a 50-m unit or moved. Multinomial logit regression is similar to logistic regression in that the probability of a response is modeled as an additive function of explanatory variables, but differs in that the probabilities of more than two categorical responses are estimated (Agresti 1990). We modeled three categorical responses with the number of marked fish that (1) remained in a unit, (2) moved upstream, and (3) moved downstream; the first category was used as the baseline. A marked fish was defined as having moved upstream if it was detected (captured or sighted) in any of the upstream units or in the 25-m adjacent subunit above the 150-m sample section (Figure 1). A marked fish was considered to have moved downstream if it was detected in any of the downstream units or the 25-m adjacent subunit below the 150-m section.

Because capture and observation efficiencies for stream-dwelling salmonids are generally much less than 100% (Riley and Fausch 1992; Rodgers et al. 1992; Riley et al. 1993; Thurow and Schill 1996; Peterson et al. 2004), there was a significant chance that we would fail to detect marked fish, potentially biasing our estimates of fish movement. To account for the probability of a fish being detected ($P[d_i]$) if it remained in the 50-m unit ($i = 1$), moved upstream ($i = 2$), or moved downstream ($i = 3$), we needed to adjust the fish's probability of detection ($P[d_i|m_i]$) with the probability of the fish being in category i ($P[m_i]$). Thus, we jointly modeled fish movement and detection as

$$P(d_i) = P(d_i \mid m_i) \cdot P(m_i),$$

where the probability of movement ($P[m_i]$) was modeled with a multinomial logit model, and $P(d_i|m_i)$ was the estimated capture or observation (sighting) efficiency. Because $P(d_i|m_i)$ was not known exactly, its predicted probability distribution function (PDF) was incorporated by use of a beta PDF. Capture efficiency PDFs were estimated for each 50-m unit and the upstream and downstream adjacent subunits based on unit-specific habitat data and the method-specific capture efficiency models described by Thurow et al. (2003). An appropriate method for jointly modeling the movement and detection of animals with a PDF is

the Markov chain Monte Carlo (MCMC; Fonnesbeck and Conroy 2004) method. Thus, we used MCMC, as implemented in BUGS software version 1.3 (Spiegelhalter et al. 2000), to fit models relating fish movement during sampling to sample unit characteristics. All models were fit based on 100,000 iterations, a 25,000-iteration burn in (i.e., the first 25,000 MCMC iterations were dropped), and diffuse priors. Note that candidate models also included a random effect (Congdon 2001) to account for potential statistical dependence among units within sample sections.

To examine the possible influence of fish location on movement, we used binary indicators (0 or 1) to code for 50-m units 1 and 3, and used unit 2 as the baseline. Similarly, sampling methods were coded as binary indicators for day and night snorkeling, and single-pass electrofishing served as the baseline. To examine the influence of body size on fish movement, we binary coded the the 70–99 and 200–350-mm TL size-classes, and the 100–199 mm TL size-class was used as the baseline. Pearson's product-moment correlations were run on all pairs of predictor variables (i.e., physical and chemical measurements) prior to analyses. To avoid multicollinearity, we selected a subset of six uncorrelated predictor variables ($r^2 < 0.15$) 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 probability of movement ($P[m_i]$) models. The subset of uncorrelated site characteristics (Table 1), 50-m unit location, body size, and sampling method were used to construct the global model containing all of the predictors. From the global model, we then fit all subsets of the global model (including all first-order interactions) and used Akaike's information criterion (AIC; Akaike 1973) corrected for small-sample bias (AIC_c; Hurvich and Tsai 1989) to assess the fit of each candidate model. Because MCMC methods produce a distribution of AIC_c values, we used the mean AIC_c from the 100,000 iterations for all inferences (Fonnesbeck and Conroy 2004). Akaike's information criterion is an entropy-based measure used to compare candidate models describing the same data (Burnham and Anderson 2002); the best-fitting model has 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 is the one with the greatest Akaike weight (range, 0–1).

TABLE 1.—Means, SDs, and ranges of habitat characteristics for sample units used during an evaluation of salmonid movement in Washington streams during 2001 and 2002. 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
Mean depth of adjacent upstream subunit (m)*	0.137	0.049	0.06–0.32
Wood density (pieces/m^2)*	0.034	0.021	0.00–0.09
Percent undercut banks	2.981	5.007	0.14–20.55
Mean water temperature (°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
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

To incorporate model selection uncertainty, we computed model-averaged estimates of the multinomial logit model coefficients ($\tilde{\beta}_j$; 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. 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, which is similar to the general rule of thumb (i.e., 1/8, or 12%) suggested by Royall (1997) for evaluating strength of evidence. 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. Goodness of fit (i.e., MCMC convergence) was assessed for each model in the confidence set by use of the diagnostics detailed by Gelman and Rubin (1992).

Results

We evaluated salmonid movement in 4 sites during 2001 and 16 sites during 2002. Bull trout were the most numerous salmonid encountered; an average of 38 marked bull trout were found per sample site. In several sites, marked individuals of a species were not present in all three units, and thus the site data could not be used in the multinomial logit modeling procedure. After sites with incomplete data were eliminated, the resulting data consisted of 18 sites with marked bull trout, 7 with rainbow trout *O. mykiss*, 4 with brook trout *S. fontinalis*, and 3 with westslope cutthroat trout. Only bull trout and rainbow trout were collected in sufficient numbers to evaluate and model the influence of physical factors on fish movement. Additionally, recapture and resight rates of marked fish were similar to the previous estimates of method-specific efficiencies (Thurow et al. 2003; Peterson et al. 2004) and averaged 15, 40, and 23% for bull trout and 10, 60, and 28% for rainbow trout collected with day snorkeling, night snorkeling, and single-pass electrofishing, respectively.

Our initial model fits that included size-class binary indicators were very poor (MCMC convergence) due to relatively few marked bull trout and rainbow trout 200–350 mm TL (3% of total) and 70–99 mm TL (<10%). We unsuccessfully attempted to remedy the problem by combining the two largest size-classes for each species. Hence, we combined all size-class data and applied the analysis of movement to bull trout and rainbow trout (across size-classes). Correspondingly, we averaged species-specific capture efficiency estimates (from Thurow et al. 2003) across length-classes.

We directly observed salmonid movement with the aquatic camera at three sites during 2001. During all observations, individual fish exhibited presumably normal behavior (e.g., feeding and main-

taining position) when sampling crews were more than 20 m downstream. As crews approached to within 20 m of the camera, we observed abrupt changes in fish behavior and fish movement at all sites. At one sample site, seven bull trout moved upstream and three downstream when the snorkeler approached within 10–15 m of the camera during day snorkeling. We observed four bull trout moving upstream and five downstream as the snorkeler moved within 10 m of the camera during night snorkeling. At the third site, we observed five (unidentified) salmonids moving upstream and two downstream when snorkelers were 15–20 m downstream during night snorkeling. However, we were unable to determine whether individual fish moved upstream and remained there or moved downstream at a later time; fish in the latter scenario would have been counted twice. We also were unable to see bank-to-bank during day and night at any site; hence, fish may have moved without being detected. In addition, we were unable to distinguish marked fish due to poor picture quality and to identify species when individual fish were at the edge of the field of view. We failed to remedy these problems after making several adjustments to the protocol (e.g., repositioning the camera) and did not use the aquatic camera during 2002.

Modeling results suggested that bull trout movement during sampling was influenced by sampling method, channel features, and the presence of the upper block net. Multinomial logit models of bull trout movement from 50-m units indicated that the best-fitting model contained the unit-3 indicator variable and was 3.3 (0.400/0.121) times more likely than the next best-fitting model, which contained the unit-3 and night snorkeling indicator variables (Table 2). Akaike weights indicated that bull trout movement also was influenced by day snorkeling, percent fine substrate, mean maximum water depth, and mean depth of the adjacent upstream subunit (Table 2). Model-averaged estimates indicated that fish movement was lower in unit 3 (i.e., the uppermost unit) than in units 1 and 2 (Table 3), which suggested the possible influence of the upper block net. Upstream movement was more frequent during day snorkeling than during electrofishing, and downstream movement was less frequent during night snorkeling than during electrofishing (Table 3). Estimates of the effects of percent fine substrate, mean maximum water depth, and mean depth of the adjacent upstream subunit, however, were not reliable because the 90% credibility intervals were very wide and contained zero for both the upstream and downstream

TABLE 2.—Akaike's information criterion with small-sample bias adjustment (AIC_c), AIC_c differences (ΔAIC_c), and Akaike weights (w_i) for models describing the movement of bull trout and rainbow trout in response to sampling activities in Washington streams. Akaike weights are interpreted as the relative plausibilities of the candidate models (i).

Species and model	AIC_c	ΔAIC_c	w_i
Bull trout			
Unit 3	293.40	0.00	0.400
Unit 3; night snorkeling	295.79	2.39	0.121
Unit 3; day snorkeling	296.00	2.60	0.109
Unit 3; percent fine substrate	296.81	3.41	0.073
Unit 3; mean maximum depth	297.32	3.92	0.056
Unit 3; mean depth of adjacent upstream subunit	297.93	4.53	0.042
Rainbow trout			
Intercept-only model	83.45	0.00	0.541
Percent rubble substrate	87.82	4.37	0.061

model coefficients (Table 3). Therefore, we used the composite model that contained unit-3, day snorkeling, and night snorkeling variables to estimate bull trout movement (below).

In contrast, rainbow trout movement was influenced primarily by one channel feature. Conditional multinomial logit models of rainbow trout movement in 50-m units indicated that the best-fitting model contained the intercept only (Table 2) and was over eight times more likely than the next best-fitting model, which contained the intercept and percent rubble substrate. Akaike weights indicated little influence on rainbow trout movement by any of the other variables considered (Table 2). Model-averaged estimates indicated that rainbow trout upstream movement was negatively related to percent rubble substrate, which suggested lower movement in units with greater amounts of rubble substrate (Table 3).

For both bull trout and rainbow trout, upstream movement exceeded downstream movement under most conditions (Table 4). The exception was that bull trout exhibited greater downstream movement for electrofishing and day snorkeling than for night snorkeling and less upstream movement during day snorkeling in unit 3. The latter result suggested a block-net effect (bias). There was no substantial difference in salmonid movement rate between units 1 and 2. Sampling method also had a substantial influence on bull trout movement; generally greater movement was observed for the snorkeling methods than for electrofishing (Table 4). Excluding unit 3, we estimated that the probability of bull trout upstream movement in 50-m sample units was 28% for day snorkeling and 25% for

TABLE 3.—Model-averaged results for composite multinomial logit models of bull trout and rainbow trout movements in response to sampling activities in Washington streams. Coefficients should be interpreted relative to remaining in a 50-m unit (the baseline). Importance weights are calculated from the Akaike weights of individual models and are the same for both logit submodels (i.e., upstream and downstream movements).

Model and variable	Mean estimate	Credibility interval		Importance weight
		5%	95%	
Bull trout				
Upstream movement				
Intercept	−1.149	−1.907	−0.391	
Unit 3	−1.543	−2.589	−0.497	0.931
Night snorkeling	0.539	−0.062	1.141	0.182
Day snorkeling	0.747	0.080	1.414	0.177
Percent fine substrate	−0.153	−0.415	0.109	0.120
Mean maximum depth	−1.419	−3.869	1.031	0.119
Mean depth of adjacent upstream subunit	0.115	−2.596	2.826	0.084
Downstream movement				
Intercept	−2.283	−3.470	−1.096	
Unit 3	−0.440	−1.496	0.617	
Night snorkeling	−1.254	−2.414	−0.094	
Day snorkeling	0.624	−0.442	1.691	
Percent fine substrate	−0.077	−0.345	0.192	
Mean maximum depth	−0.019	−2.591	2.552	
Mean depth of adjacent upstream subunit	0.273	−2.469	3.015	
Rainbow trout				
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	

night snorkeling, whereas the probability for single-pass electrofishing was 18% (Table 4). In contrast, we estimated that the probability of rainbow trout upstream movement was as little as 13% and as much as 74% when rubble substrate was absent, whereas the probability was between 9% and 42% when there was 15% rubble substrate (Table 4).

Salmonid movement tended to occur over relatively short distances; 67% of the mobile rainbow trout traveled 25 m and none traveled more than 50 m. Bull trout moved slightly longer distances: 59% of individuals (excluding unit-3 data) moved 50 m or more (Figure 2).

Discussion

Salmonid upstream movement rates were more than 70% greater than downstream rates, which suggests that fish are fleeing during the sampling process. Our models indicated that, on average, 5–29% of bull trout and rainbow trout are displaced upstream during sampling. These estimates are greater than the very low movement rates (<1%) reported for stream-dwelling westslope cutthroat

trout during electrofishing (Young and Schmetterling 2004), but similar to the 15% upstream movement rate reported for warmwater stream fishes (Edwards 2001). The apparent discrepancies in movement rate may have been due to the use of different methods for estimating movement. Westslope cutthroat trout movement was measured from the number of individuals captured in upstream and downstream traps immediately after sampling (Young and Schmetterling 2004), whereas warmwater fish movement was estimated from the number of fish collected in defaunated stream sections immediately upstream of a sample site (Edwards 2001). Similar to our lower two units, warmwater fish escape from sample units in the study by Edwards (2001) was unobstructed (i.e., there were no block nets immediately upstream of sample units). In contrast, westslope cutthroat trout attempting to flee would have encountered fish trap leads that might have caused them to swim downstream rather than into the trap, resulting in lower observed movement rates. This is consistent with the significantly lower upstream movement

TABLE 4.—Mean estimated probability of movement (%) from 50-m sample units and 90% credibility intervals for stream-dwelling bull trout and rainbow trout in response to sampling activities. Estimates are based on model-averaged multinomial logit models (Table 3).

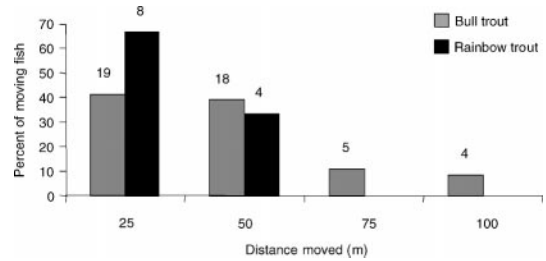| Condition	Mean	Credibility interval	
		5%	95%
Bull trout			
Upstream movement			
Electrofishing, units 1 and 2	17.8	8.5	30.2
Electrofishing, unit 3	4.9	1.2	11.3
Night snorkeling, units 1 and 2	25.4	15.5	36.7
Night snorkeling, unit 3	7.4	2.2	15.9
Day snorkeling, units 1 and 2	28.5	18.6	39.5
Day snorkeling, unit 3	8.6	2.6	17.9
Downstream movement			
Electrofishing, units 1 and 2	10.2	3.7	20.1
Electrofishing, unit 3	7.4	1.9	16.4
Night snorkeling, units 1 and 2	3.5	0.9	7.7
Night snorkeling, unit 3	2.6	0.5	6.6
Day snorkeling, units 1 and 2	16.8	9.3	25.9
Day snorkeling, unit 3	12.6	4.2	25.0
Rainbow trout			
Upstream movement			
Rubble substrate, 0%	41.7	13.4	73.6
Rubble substrate, 15%	23.1	9.3	41.6
Downstream movement			
Rubble substrate, 0%	11.6	2.0	30.1
Rubble substrate, 15%	11.0	3.4	23.3

FIGURE 2.—Distribution of movement distances of marked bull trout and rainbow trout that left 50-m sample units in Washington streams during studies in 2001 and 2002. Bull trout estimates include only fish that left units 1 and 2. Numbers above bars indicate observed individuals that moved in response to sampling activities.

rates we observed for bull trout in the upper unit, which we believe was due to the presence of the upper block net. Of the bull trout that moved, 59% traveled at least 50 m—twice the length of the upper adjacent subunit. Thus, we believe displaced fish probably swam upstream through the upper adjacent subunit, encountered the block net, and swam downstream into the upper 50-m unit before they were detected. The significantly lower movement rates observed for the upstream unit and the discrepancies among estimates from previous studies suggest that future studies of fish movement should attempt to eliminate the influence of artificial obstructions, such as block nets and trap-net leads, on fish movement.

Channel characteristics influenced movement rates of stream-dwelling salmonids during sampling. Rainbow trout movement rates were lower in sample units with larger amounts of rubble substrate. Akaike model weights also suggested that bull trout movement was related to stream depth and substrate; movement rate declined with increasing depth and increasing proportion of large substrate. Large substrate previously has been shown to be important as concealment for both

bull trout (Baxter and McPhail 1997; Thurow 1997; Bonneau and Scarnecchia 1998; Jakober et al. 2000) and rainbow trout (Contor and Griffith 1995; Gregory and Griffith 1996; Meyer and Gregory 2000). We hypothesize that since salmonids conceal to avoid detection and capture, in the absence of cover the fish will move to seek the nearest available cover. The inverse relationship between undercut bank area and electrofishing efficiency (Peterson et al. 2004) is consistent with our hypothesis. Fish movement into undercut banks during sampling appears to lower their detectability. The influence of physical habitat on fish movement further suggests that samples collected without block nets from different habitats are biased by the effect of habitat features.

Salmonid movement differed markedly among sampling methods. In general, snorkeling resulted in the most bull trout movement, whereas electrofishing produced 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., Grossman and Freeman 1987). Our visual observations suggest that fish respond to the presence of snorkelers at a distance of 10–20 m. Therefore, snorkeler detection of fish that are undisturbed (i.e., engaged in normal activity) is unlikely. We also estimate that 28% of bull trout moved upstream during day snorkeling. If fish habitat stud-

ies are conducted via day snorkeling and 28% of fish flee during sampling, 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 on the portion that flees. For example, the influence of habitat on fish movement suggests that observed habitat use might differ in the presence of snorkelers. Further, if fish flee from snorkelers, assume a new position, and are observed, the resulting observations of habitat use may be biased.

Our estimates of salmonid movement suggest that failure to use block nets to maintain closure would likely result in negatively biased abundance estimates of a similar magnitude (e.g., 15% movement = 15% bias). This is bias above and beyond the influence of method-specific capture or observation (sighting) efficiency. For example, bull trout day snorkeling efficiency averages 10% (Thurow et al. 2003), and we estimated that 28% of bull trout moved upstream during day snorkeling. Hence, snorkelers may only be counting 7.2% of bull trout in 50-m sample units. The probability of detecting a species also would be lower when block nets are not used, increasing the chance of missing a species that is present. The influence of fish movement on salmonid detection probability would be particularly acute for day snorkeling due to relatively low snorkeling observation efficiency. Indeed, our estimates of day snorkeling capture efficiency and fish movement suggest that day snorkeling without block nets is among the least efficient methods for detecting stream-dwelling salmonids. 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 the sample size. Therefore, we believe that biologists should consider these factors, in addition to practical considerations like safety, when developing salmonid sampling or monitoring protocols.

Limitations of Our Approach
and Recommendations for Future Evaluations

Two factors limited our ability to assess instream movement patterns of salmonids. First, we had insufficient samples sizes to evaluate movement by different size-classes. Previous studies of fish movement over daily time intervals suggested a range of relations with body size, from no effect

on movement (Dunham et al. 2002) to greater movement by larger-bodied fishes (Nordwall 1999) to stream-specific body-size effects (Gowan and Fausch 1996). Unfortunately, the effect of body size on short-term fish movement during sampling activities has not been evaluated. However, during a pilot study on a section of the Lostine River (mean wetted width, 15 m), Oregon, we observed little to no movement of seven large (>400 mm) radio-tagged bull trout in pools until a snorkeler had detected and was within 5 m of the tagged fish (N. P. Banish, unpublished data). These limited observations suggest that the behavior of large fish during sampling differs from the behavior we measured for smaller fish. Clearly, there is a need for a more thorough study of fish response during sampling.

Second, we assumed that all fish movement within our study sites was in response to our sampling. Hence, we assumed that after removal of the block nets, all marked fish would remain within the units where they were originally captured. Several studies have demonstrated frequent natural movements by stream-dwelling salmonids at daily time intervals (i.e., Gowan et al. 1994; Gowan and Fausch 1996; Young and Schmetterling 2004). It is possible that some of the movements we measured among units were those of undisturbed fish during the 1–2-h period between block-net removal and the initiation of sampling. Additionally, fish may have been disturbed by crews installing and removing block nets. However, the considerably greater upstream movement rates suggest that fish exhibited a directional preference, away from sampling crews. We also directly observed fish fleeing from snorkelers. The significant differences in movement rate among sampling methods also indicate that a large portion of the movement was directly related to sampling activities. Nonetheless, we believe that additional studies are needed to evaluate the effects of stream characteristics, fish species, and body size and to develop more-robust estimates of fish movement. Although the best approach will probably be dependent on a variety of factors, our results should provide some useful guidelines when developing study plans.

Our initial pilot study of radio-tagged fish suggested that use of radio-tagged fish may be valuable for evaluating fish response during sampling, particularly in larger rivers. However, we believe that approach may not be feasible for developing robust models because modeling would require a relatively large number of radio-tagged individuals of various body sizes in streams with different

habitat characteristics. We also found that bull trout in the upper unit exhibited less movement than fish in downstream units; this may be due to the influence of the upper block net on fish behavior. To minimize the influence of artificial obstructions, we recommend that researchers use upstream and downstream escape areas larger than our 25-m adjacent subunits.

Acknowledgments

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