Salmo River Tributary Fertilization Study:

Baseline Monitoring Results (2001-2002) and Implications for the Experimental Design

Scott Decker[1]

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BC Hydro

Burnaby, BC

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[1] Apt. 303-533 2nd Ave, Kamloops, B.C., V2C 2K3, decker_scott@hotmail.com

EXECUTIVE SUMMARY

As compensation for the installation of a fourth unit at the 7 Mile Generating station, BC Hydro agreed to fund an experimental stream fertilization project. To test the effect of stream fertilization on the production of juvenile bull trout and other fish species in Salmo River tributaries, a six year before-after-control experiment (3 baseleine and 3 treatment years) was initiated in two tributaries; Sheep Creek and the South Salmo River. During 2001and2002, two years of baseline abundance data were collected for juvenile fish, benthic macroinvertebrates, periphyton biomass and water chemistry. Results indicate that phosphorus and nitrogen were at or below detection limits, and periphyton biomass was also very low (0.9 to 2.5 μg/cm^2 chlorophyll *a*), suggesting both streams are nutrient limited. Estimates of mean invertebrate density (900-3,400 total organisms/m^2) and salmonid biomass (1.6-2.8 g/m^2) also appeared low compared to values reported for other systems. Both study tributaries appear to be good candidates for a fertilization trial; For logistical reasons, Sheep Creek is likely the best choice as the treatment stream for the experiment. Use of calibrated single-pass electrofishing as a rapid assessment method to estimate fish numbers resulted in a 250% increase in sampling efficiency compared to conventional three-pass electrofishing and provided relatively precise population estimates despite high spatial heterogeneity in abundance (95% CI: ±14%-51% and ±17%-27% for fish density and biomass, respectively). Precision of the estimates of macroinvertebrate density and biomass in 2001 and 2002 was comparable to that obtained for juvenile fish populations (±16%-±19% and ±21%-±35%, respectively). The relatively good precision of the abundance estimates for juvenile fish and macroinvertebrates, coupled with limited evidence that fish populations in the study tributaries may be fairly stable –(mean bull trout and rainbow trout densities differed by less than 10% in 2001 and 2002) - suggest that a 6 year study should have a relatively high probability (> 0.8) of detecting a response in fish production to fertilization provided the increase exceeds about 35% of pre-treatment levels. It should be emphasized that conclusions from two years of monitoring are preliminary, and statistical power should be revaluated in 2003/2004 prior to fertilization.

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1.0 INTRODUCTION

1.1 Project Background

BC Hydro operates the Seven Mile Generating station on the Pend d'Oreille River in southeastern British Columbia, and completed the installation of a fourth turbine at the facility. To ensure that there is no net loss of the productive capacity of Seven Mile and Waneta reservoirs (and their associated watersheds) as a result of the addition of this fourth turbine, BC Hydro (BCH) entered into a Fisheries Act authorization (FAA) with Fisheries and Oceans Canada (DFO) and the BC Ministry of Water, Land and Air Protection (MWLAP) in 1996. The FAA requirement was in response to several issues, including the potential for increased entrainment of bull trout (*Salvelinus confluentus*) and rainbow trout (*Oncorhynchus mykiss*) through the powerplant with the addition of the fourth turbine, and the potential loss of fish habitat in the Pend d'Oreille River downstream of the dam. The FAA also reflects a possible conservation concerns for bull trout (*Salvelinus confluentus*) in the Salmo River, the only major tributary in the Canadian portion of the Pend d'Oreille watershed supporting a bull trout population. In addition to potential entrainment losses, bull trout carrying capacity in the Pend d'Oreille watershed has likely been reduced (relative to historical levels) through restricted migration and the extirpation of anadromous salmonid populations and the loss of lotic habitats

The primary focus of the FAA was to increase bull trout production in the Salmo River and its tributaries (see RL&L 1995), with increased rainbow trout production as a secondary objective. After conducting several studies of the bull trout population in the Salmo River (Baxter et al. 1998; Baxter 1999, 2001a, 2001b, 2001c) and reviewing a number of compensation options (Baxter 1999), the Seven Mile Technical Working Group (7MTWG) was formed with representatives from BCH, DFO, MWLAP, and First Nations. The group was responsible for implementing the FAA, and, based on several fisheries studies undertaken from 1997 until 2001, 7MTWG decided that stream fertilization would be conducted in the South Salmo River - a major bull trout spawning and rearing tributary of the Salmo River. It was decided that this tributary represented the best option for enhancing bull trout production in the watershed as a whole. A detailed review of the potential limiting factors to bull trout production in the Salmo River and the rationale used by the 7MTWG in selecting stream fertilization as a compensation option are discussed in Baxter (1999, 2001a) and are beyond the scope of this report.

1.2 Stream Fertilization

Stream fertilization has received considerable attention in British Columbia as a methodology to increase fish production in oligotrophic streams and lakes (Johnston et al. 1990; Ashley and Slaney 1997). Similar to most temperate steams (vanNieuwenhuyse and Jones 1996), primary production in B.C. streams is usually limited by either phosphorus (P) or nitrogen (N). Although the effect of stream fertilization on overall production of lotic fish is not always readily apparent (e.g., Deegan et al. 1997), several studies have found positive results. For example, on the Keogh River on northern Vancouver Island, the addition of inorganic nitrogen and phosphorous over several years resulted in an increase in the number of steelhead smolt outmigrants and adult returns compared to pre-treatment levels (Slaney and Ward 1993). Stream fertilization assumes ‘bottom-up’ control to fish production (Deegan et al. 1997), whereby removing nutrient limitations will increase primary production, which will support a higher biomass of benthic invertebrates, and ultimately lead to faster growth rates for fish. Increased growth rates may increase fish production through increased overwinter survival for juvenile fish (Hartman et al. 1996) or reduced length of freshwater residency for anadromous fish (Slaney and Ward 1993). Alternatively, increased food abundance may allow stream rearing salmonids to decrease the size of the feeding territories they defend, which could allow increased standing stocks in fertilized streams (Keeley and McPhail 1998).

Phosphorus (P) and nitrogen (N) can be added to streams in either a liquid or solid form, with the solid form (slow release pellets) being the easiest to apply and monitor (see Sterling and Ashley 2003). The pellets, which are added to riffle areas of a stream immediately following the spring freshet, are designed to dissolve in a uniform manner over 4-5 months during the summer-early fall growing season. Constant nutrient concentrations throughout a stream can be achieved through careful distribution of pellets and by matching pellet application rates to the seasonal discharge pattern of the stream (Sterling and Ashley 2003).

1.3 Stream fertilization in the Salmo River watershed

From previous radio telemetry work, it would appear that in the Salmo River, adult bull trout reside most of the year in the mainstem, embarking on spawning migrations to the colder tributaries (upper Salmo, Clearwater, , Sheep, South Salmo, Stagleap; Figure 1) in summer-early fall and then returning to the mainstem immediately after the completion of spawning (Baxter 2001c). Radio telemetry data collected to date suggests that very little movement occurs between the Salmo River and Seven Mile Reservoir (Baxter 2001c). Observations of individual bull trout spawning in different tributaries in consecutive years (J. Baxter, B.C. Hydro, pers. comm.), suggests that bull trout in the Salmo River likely constitute a single spawning stock. Based on spawner surveys conducted in the tributaries, the present adult bull trout population in the Salmo River watershed is probably less than 200 individuals (J. Baxter, B.C. Hydro, pers. comm.). The use of tributaries by adult rainbow trout in the Salmo River is less clear. A recent radio telemetry study suggested that most adults spawned in mainstem habitats rather than in the tributaries (Hagen and Baxter 2003).

Based on life history information, the potential benefit of adding nutrients to one of the major rearing tributaries would be to increase juvenile carrying capacity of that tributary, thereby increasing juvenile survival and recruitment to the adult population in the Salmo River mainstem, or, in the case of rainbow trout, increasing recruitment to the resident tributary population and possibly the mainstem population. It is imperative to understand that the stream fertilization approach assumes that adult populations in the Salmo River are currently limited by juvenile recruitment. While juvenile survival and abundance has been shown to affect overall population in some of the studies mentioned above, there is no way of knowing whether this will be the case in the Salmo River watershed. The question of what factors limit fish production in streams has been the focus of an enormous amount of research over the past several decades, with increasing evidence that limiting factors often vary depending on the stream and the species of interest. With this in mind, the 7MTWGhas agreed to take an adaptive approach to compensation in the system by initially conducting stream fertilization as a controlled experiment rather than simply as a management action. Other potential limiting factors to bull trout abundance in the Salmo River may include overharvest and juvenile habitat degradation, but are beyond the scope of this report.

1.4 Objectives

To determine the potential benefit of nutrient addition on the production of juvenile bull trout and other fish species in Salmo River tributaries, a multi-year before-after-control (BACI) experiment was initiated in 2001. Two tributaries were selected (one control and one treatment), and a monitoring program was implemented to assess juvenile fish abundance as well as productivity at the lower trophic levels upon which fish production depends (benthic invertebrate composition and abundance, periphyton accrual and water chemistry).

The major objective for the study in 2001 and 2002 was to collect two years of baseline data. This data describes the age-structure, abundance and distribution of juvenile fish populations in the study tributaries and to address three critical issues concerning the stream fertilization experiment:

1. Are the chosen study tributaries suitable candidates for nutrient enrichment?
2. Will the experimental design and field methods used in the study provide sufficiently accurate and precise estimates of productivity at each trophic level for the purposes of the experiment?
3. If there is to be a reasonably high statistical probability of detecting a treatment effect, how long will the experiment likely need to be conducted and

how large will the response to nutrient enrichment at each trophic level need to be (i.e., what is the expected power of the experimental design?)

2.0 METHODS

2.1 Study Area

The Salmo River rises from the Selkirk Mountains 12 km southeast of Nelson, B.C. (Figure 1). The river progresses in a southerly direction for approximately 60 km from its origin to the confluence with the Pend d'Oreille River (Seven Mile Reservoir). The system is a 5th order stream, and has a total drainage basin area of roughly 1,230 km^2. Elevation in the basin ranges from 564 meters at its confluence to 2,343 meters at the height of land. Within this elevation range, the system lies within two biogeoclimatic zones: the Englemann Spruce-Subalpine Fire (ESSF) zone in headwater reaches, and the Interior Cedar-Hemlock (ICH) zone within lower elevations valleys (Braumandl and Curran 1992). The Salmo River has a total of eight 2nd and 3rd order tributaries (including Apex Creek, Clearwater Creek, Hall Creek, Barrett Creek, Ymir Creek, Porcupine Creek, Erie Creek, and Hidden Creek) and two 4th order tributaries (Sheep Creek and the South Salmo River) (Figure 1).

The 7MTWG selected Sheep Creek and the South Salmo River to represent bull trout spawning rearing tributaries in the Salmo River watershed because they are the two largest tributaries that supported bull trout and because they are the closest major tributaries upstream of the seven Mile reservoir (the choice of which stream to assign as the control and which to assign as the treatment is addressed in Section 4.1). Sheep Creek and the South Salmo River comprise 11% and 15%, respectively, of the total watershed area of the Salmo River. Spring freshet in Salmo River tributaries normally peaks in late May, with the highest flows occurring each year between April and July. Channel gradient per km, estimated from 1:50,000 topographic maps, ranges from 2% to 6% in Sheep Creek, and from 2% to 4% in the South Salmo River.

Adult bull trout enter Sheep Creek and the South Salmo River in summer-early fall and spawn mainly in the upper portions of the accessible length of each stream (Baxter and Nellestijn 2000; Baxter 2001c). At present, adult bull trout are able to access the lower 12.2 km of Sheep Creek; further upstream movement is prevented by a large debris jam (Figure 2). In the South Salmo River, a series of steep cascades 16.5 km upstream from the mouth (5 km above Stagleap Creek; Figure 3) prevent further access. Bull trout are also known to spawn and rear in Stagleap Creek, which has an accessible length of 2.0 km.

In addition to bull trout and rainbow trout, the two study tributaries also support populations of slimy sculpin (*Cottis cognatis*) and longnose dace (*Rhinichthys cataractae)*. Introduced eastern brook trout (*Salvelinus fontinalis*), native west-slope cutthroat (*Oncorhynchus clarki*), suckers (*catostomus spp.*), and mountain whitefish (*Prosopium williamsoni*) have been infrequently observed in these streams as well (J. Baxter, BC Hydro, pers. comm.).

2.2 Study design

To examine the effect of nutrient addition on juvenile fish production in one of the two study tributaries, the 7MTWG had agreed to a BACI experimental study to be conducted for a minimum of three years prior to during fertilization. The BACI design is considered to be one of the best approaches to monitoring large-scale ecological manipulations (Smith et al. 1993; Mellina and Hinch 1995). With respect to the stream fertilization study, a BACI design increases the likelihood of detecting the effects of nutrient addition when fish production is also affected by temporal variation in other factors such as recruitment, seasonal discharge and water temperature that may occur over the same time period.

Sheep Creek and the South Salmo River will be monitored during each year of the BACI study: the stream selected for treatment will be fertilized each year of the treatment period, and the other stream will be left as an unfertilized control. Each stream will therefore constitute an experimental unit. This is preferable to using upstream and downstream reaches within one or both streams as separate treatment and control units because of the risk of non-independence of experimental units (Mellina and Hinch 1995). For example, treatment effect for a pair of experimental units in the same stream is not independent if substantial fish movement occurs between non-fertilized upstream and fertilized downstream reaches. For a more detailed discussion of the major experimental design and sampling issues relevant to the fertilization study and a rationale as to how these issues were addressed in the design of the study and the field and data analysis methods used, refer to Decker et al. (2002).

2.3 Juvenile fish sampling

2.3.1 Stratification and site selection

To quantify average fish size, density and standing stock for each species and age class in the study tributaries, in August 2001 and 2002, I conducted juvenile population surveys in the major rearing portions of the two study tributaries. For Sheep Creek, this included the entire 12.2 km section from the Salmo River confluence to the migration barrier (Figure 2). The study portion of the South Salmo River extended from the Salmo River confluence to approximately 1 km upstream of Stagleap Creek (Figure 3). Bull trout and rainbow trout are likely distributed at least 6.0 km upstream of the Stagleap Creek confluence, but I excluded the uppermost portion of the accessible length of the South Salmo River because of a lack of road access and the fact that it lies mostly within the state of Washington.

In each stream, I stratified fish population sampling based on a downstream (reach 1) and an upstream reach (reach 2) (Figures 2 and 3), as I expected bull trout densities to be higher in the upper portions of these streams based on the distribution of adult redds observed during earlier studies (Baxter 1999, 2001a, 2001b). To improve the precision of the standing stock estimates for bull trout, I also assigned a somewhat higher sampling intensity to the upper reaches of both streams. Sampling was not stratified by habitat type as suggested by some researchers (e.g., Hankin and Reeves 1988; Johnston and Slaney 1996) because an initial reconnaissance suggested that in both streams, habitat was relatively homogenous, consisting mostly of riffles and cascades, and also because previous juvenile fish sampling data did not indicate consistent differences in fish density between habitat types in these streams. I chose to use an alternative to stratification recommended by Hankin (1984) and Decker et al. (1999), whereby sampling effort is distributed among habitat types in proportion to the abundance of each type (see Table 1). For example, if pools represented 10% of total wetted area in a reach, 10% of the total number of sampling sites would be located in pools.

Within a particular reach, the location of each sample site was randomly determined based on a systematic sampling design (Cochran 1977). The sampling interval was determined by dividing the total length of the reach by the number of sites to be sampled. If the sampling interval occurred at a stream section where access was impractical (i.e., the stream was > 500 m from the nearest road access point), the sampling site was located at the nearest upstream or downstream location where access was reasonable. The habitat type sampled at each selected interval was based on a random assignment of the allocated number of sites for each habitat type. At each interval, the sample site was selected as the nearest habitat unit of the appropriate type. Because individual habitat units often exceeded 20 m in length, a sample site generally included only a portion of a selected habitat unit. However, because the study tributaries were relatively high in gradient and contained large bed material, well-defined areas could be sampled within a habitat unit type. Each site spanned the full width of the stream channel and was 10-20 m in length.

To facilitate the relocation of sample sites during future years, each site was photographed with the stop nets in place, its upstream and downstream boundaries were marked with flagging tape, and its location was recorded with a handheld global positioning system (GPS) unit. Physical attributes recorded at each site included site length, site wetted width, estimated available cover by type, maximum depth, and the approximate diameter of a substrate piece at the 90^{th} percentile of the size distribution (D^{90}).

2.3.2 Habitat Survey

Prior to fish population sampling in 2001, field crews surveyed the total wetted area of each stream and the proportion of this area represented by each habitat type. Each member of the survey crew, working independently, traveled downstream within a stream section and classified all habitat units as cascades, riffles, runs, or pools based on criteria established by Johnston and Slaney (1996). Side-channels and braids were rarely encountered due to the relatively high gradient and confined nature of the streams. When encountered, these habitats were measured separately from mainstem habitats and classified using the same habitat unit criteria. Poorly defined habitat units that were less than 1.5 times as long as their wetted width were included as part of the length of the adjacent unit upstream. Surveyors mapped habitat units by recording cumulative distance (to the nearest metre) at the downstream and upstream end of each unit using a hip chain. At each habitat unit, 2-6 visual estimates of wetted width were also made (nearest 0.5 m). Visual estimates of wetted width were calibrated based on measurements of width (nearest 0.1 m using a spring-loaded logger's tape) for a sub-sample of the visual estimates (Hankin and Reeves 1988). Each surveyor's visual estimates of width were calibrated by regressing the measured widths against these data, and then factoring the remainder of the visual estimates by the regression coefficients. The wetted area of each habitat unit was estimated as the product of the average of the calibrated width estimates and the difference between the cumulative upstream and downstream hip-chain distances.

2.3.3 Fish population sampling and calibration

Because it is very labour intensive, conventional three- or four-pass electrofishing is generally not a cost effective means of sampling juvenile fish populations. It has been shown that, for a given cost, the precision of standing stock estimates can be improved by substituting a relatively fast method of population sampling in a high proportion of sample sites (Hankin and Reeves 1988). However, the faster method must be calibrated with a more accurate method at a sub-sample of sites where both methods are applied. Diver counts have been shown to be an effective "rapid assessment" method of estimating fish abundance in several studies (e.g., Hankin and Reeves 1988; Thurow and Schill 1996; Hagen et al. 2002). However, because the majority of their wetted area consisted of shallow, turbulent riffles; the study tributaries were unsuitable for conducting underwater surveys (Heggenes et al. 1990; Hillman et al. 1992). Instead, I used single-pass electrofishing (Lobon-Cervia and Utrilla 1993; Jones and Stockwell 1995; Decker et al. 1999) to estimate fish abundance; single-pass catches were calibrated by conducting three-pass electrofishing at a sub-sample of the sites in 2001.

Three-pass electrofishing data were used to compute maximum likelihood (ML) removal estimates of fish abundance (Warren 1994) at each calibration site. Removal estimates were regressed against the single-pass electrofishing catches, and the slope coefficients for these regressions were factored with the single-pass totals to produce 'calibrated' estimates for all sites (Jones and Stockwell 1995). The calibration sites were randomly chosen from the total number of sites sampled, with roughly equal numbers of calibration sites distributed to each stream. I assumed the ML estimates to represent 'true' fish abundance at the calibration sites. To assess the reliability of the ML estimates, I estimated mean capture probability for three-pass electrofishing at each calibration site (see Appendix 1 for the algorithm used to estimate capture probability).

The regression models were computed without constants to allow an abundance estimate of zero for sites where no fish were captured during single-pass electrofishing. For bull trout and rainbow trout, ANCOVA was used to determine if the same regression model could be used to calibrate single-pass electrofishing counts for more than one age class. For each species, I pooled calibration data for age classes if the interaction term (single-pass electrofishing count × age class) was non-significant, and the regression slopes for the age classes were similar ($P < 0.05$ for age class effect). Separate models were used to calibrate abundance data for age classes when regression slopes differed.

To assure that the regressions coefficients developed in 2001 would be reliable for calibrating single-pass electrofishing totals in 2002, several steps were taken: 1) the two electrofishing crews consisted of three people on all occasions and a standardized methodology was used at each site (see below); 2) the electroshockers were operated by the same two crew leaders during both years of the study, with each crew sampling the same sites in both years; and 3) an attempt was made to conduct the 2002 survey at similar flows and temperatures as in 2001. Stream temperatures during the electrofishing survey were measured with hand thermometers. At the beginning of the electrofishing survey, discharge was estimated near the mouth of each stream using a Marsh-McBirney current meter and velocity-area methodology.

Prior to electrofishing, each selected sample site was fully enclosed with stop nets. Exceptions to this were sites where the upstream end could be delineated by a well defined rapid or boulder 'step', and an upstream stop net was deemed unnecessary. At all sites, electrofishing was initiated at the downstream net, and consisted of a thorough surprise/ambush search in an upstream direction to the top of the site, followed by a systematic downstream sweep. To standardize electrofishing effort, each crew always consisted of three people: one person equipped with a Smithroot Model 12 backpack electrofisher, another person equipped with a long-handled dip net (25 cm diameter round, rigid net) and a bucket for storing captured fish, and the third person equipped with a short, two-handed dip net (40 cm × 20 cm square net). To avoid having stunned fish being swept downstream by the fast currents encountered at many sites, the third person positioned himself/herself directly downstream of the anode, holding his/her net flush against the stream bottom. All fish captured during electrofishing were anaesthetized, identified as to species, measured, weighed, and released back into the site following the completion of sampling.

2.3.4 Length-at-age

The ability to accurately discriminate fish age based on sampling data allows for computation of size and abundance statistics and annual survival rates for each age class (see Section 2.3.6). To estimate the age of juvenile bull trout and rainbow trout, I used frequency histograms of fish fork length in combination with scale age data. Scale samples were collected for a portion (≈ 30%) of the juvenile bull trout and rainbow trout captured from each reach. Scales were taken from the sides of fish approximately 2-4 scale rows above the lateral line and between the back of the dorsal fin and the insertion of the anal fin. Scales were "read" using a microfiche reader. The best scale for each individual was aged and then photographed with a digital camera so that images could be saved for future reference. For other species, I did not attempt to estimate age; size and abundance statistics for other species were based on pooled age classes.

2.3.5 Whole-stream fish populations

I used the calibrated single-pass totals from the electrofishing sites to compute separate population statistics for each species/age class (bull trout, rainbow trout) or species (sculpin, longnose dace) for each stream. To address the problem of non-normally distributed data I computed estimates of mean fish density (fish/100 m^2), biomass (g/100 m^2) and total standing stock using a non-parametric bootstrap procedure (Efron and Tibshirani 1993). Mean fish density and standing stock were estimated from the median values of the 4000 iterations (i.e., 50% percentile taken from the cumulative distribution of the bootstrap estimates), and the 95% confidence intervals for these estimates were computed as the 2.5% and 97.5% percentiles, respectively, of the cumulative distribution (Haddon 2001). Appendix 1 describes the algorithms used in the bootstrap procedures. To account for the additional error in fish density and standing stock estimates resulting from measured error associated with the use of calibrated single-pass electrofishing (Hankin and Reeves 1988), the standard errors for the slope coefficients in the calibration regressions were used to represent measurement error in the bootstrap computations (see Appendix 1). To describe the precision of fish density and standing stock estimates, throughout the report percent relative error was used which can be defined as the average confidence interval as a proportion of the mean, expressed as a percentage (e.g., ± 30%; Krebs 1999).

2.3.6 Annual survival estimates

For bull trout and rainbow trout, I estimated annual survival for each age class (S) based on the difference in the standing stock of a cohort between consecutive years (Ricker 1975, pp. 29-30):

$$S = P_{t+1} / P_t$$

where P_t and P_{t+1} are the total stream standing stocks for a particular age class cohort in year t and year t+1. It is important to note that while S is a measure of the decline in the abundance of a cohort from year *t* to year *t*+1, it is not an explicit measure of survival because it does not distinguish mortality from emigration. For example, a 50% decline in a bull trout cohort in Sheep Creek from age-2 to age-3 would likely reflect both mortality and emigration to the Salmo River mainstem. Survival estimates presented in the report should therefore be considered as the proportion of a cohort remaining in a study tributary from one year to the next assuming negligible immigration.

2.4 Macroinvertebrate abundance

Monthly sampling of macroinvertebrates in 2001 (Aug, Sept, Nov) suggested that benthic standing crops in the two study tributaries were at or near peak abundance in September (Decker et al. 2002). Therefore, in 2002 sampling was limited to August and September, with only the September samples being analysed in the lab. For the purposes of the fertilization experiment, variability in the September samples from 2001 and 2002 was examined to assess whether the sampling design for invertebrates is likely to provide a reliable index of abundance during the baseline and treatment periods.

For each study tributary, macroinvertebrate sampling consisted of five replicate surber samples (mesh size 220 μm, area 0.16 m^2) collected at each of three sites (lower, middle, upper). Sampling sites were spaced at roughly equal distances along the length of each stream. To minimize the spatial heterogeneity of the sampled substrates, at each site, all samples were collected from one contiguous section of riffle and an attempt was made to only sample micro-sites that had a depth of between 20-40 cm deep, and a current velocity of between 0.2-0.4 cm/s. Samples were collected by placing the surber sampler onto the substrate to establish a sampling grid, and then randomly selecting and scrubbing by hand (inside the mesh bag of the surber sampler), 10 stones from within the grid. Samples were then rinsed from the surber sampler and preserved in 70% ethanol.

To correct for differences in the surface area of the stones among samples, I estimated the total surface area presented by the stones in each sample (Minshall and Minshall 1977). To do this, each stone from a sample was first measured for maximum circumference (nearest mm). Surface area (m^2) for each stone in a sample was estimated based on a regression relationship between surface area and circumference, and these estimates were summed to compute surface area for the sample. The regression was developed by measuring both circumference and surface area for a subsample of stones representing the range of stone sizes that occurred at the sample sites (see Calow 1972).

Prior to sorting and identification, macroinvertebrate samples were washed and sorted from sediments and detritus using a dissecting microscope (10-40× magnification). Individual organisms were then identified to family and total counts were made. To provide an index of total invertebrate biomass, dry weight was measured for each sample. Dry weights were obtained by placing each sample in a drying oven for 72 hours and then weighing the sample (nearest 0.0001 g). Sample weights were corrected for the presence of inorganic material by placing the dried samples in a 500°C muffle furnace overnight, and then subtracting the remaining weight from the original weight. In the results, the abundance and biomass of macroinvertebrates in each stream are expressed as average densities (i.e., numbers and grams, respectively, per m^2 of surface area presented by the stones). To address non-normality in the data, means and 95% confidence intervals were computed using a non-parametric bootstrap procedure similar to that described above for juvenile fish.

2.5 Periphyton biomass

Relative levels of periphyton biomass were used (estimated using a chlorophyll *a* accrual approach) as an index of the autotrophic productive capacity of the two study tributaries. Chlorophyll *a* is considered a reliable index of periphyton growth and biomass (Perrin et al. 1987), and of relative productivity among aquatic systems (Hynes 1970). In Sheep Creek, chlorophyll *a* accrual was monitored at one site located at the longitudinal midpoint of the study area. In the South Salmo River, two sites were established, one in each reach. Chlorophyll *a* accrual was measured using artificial substrate (e.g. styrofoam sheets) following Perrin et al. (1987). Styrofoam core samples were collected weekly, one from each of three artificial substrates at each site. Sampling occurred during three, six week periods in 2001: June 25-July 26, July 26-September 6 and September 6-October 19; and during two periods in 2002: July 14-August 24 and August 24-October 6. Periphyton cores were immediately wrapped in aluminum foil and frozen to prevent further chlorophyll *a* accrual. Density of chlorophyll *a* (mg/m^2) on each styrofoam core was measured using acetone extraction and spectrophotogammetry (Strickland and Parson 1972).

2.6 Water quality

2.6.1 Water temperature and discharge

Temperature can influence fish growth in a number of ways, but its effects on spring emergence timing and metabolism are probably the most important (Hynes 1970) and can lead to considerable differences in fish size and total biomass at the end of the growing season. Daily temperature records for the Salmo River mainstem indicate that mean monthly temperatures in summer can vary among years by as much as 7°C (J. Baxter, BC Hydro, unpublished data). This is a potential confounding factor for a study of the effect of stream fertilization on fish size. However, it may be possible to incorporate inter-annual differences in temperature by estimating the number of degree days (i.e., days when mean temperature exceeds 6°C) that occur during each year of the study, and expressing growth as the ratio of end-of-growing-season fish size or biomass to the number of degree days. To facilitate temperature data collection, in June 2001, automated thermographs were installed near the mouth of Sheep Creek and the South Salmo River to provide continuous temperature monitoring. Unfortunately, the temperature loggers were lost during high flows. New thermographs were installed in October 2002. Temperature data was also collected for the Salmo River mainstem during limited periods in 2001 and 2002, and for the Salmo River and the two study tributaries in several previous years (J. Baxter, BC Hydro, unpublished data). For periods when temperature data were available for both the Salmo River mainstem and the tributaries, computed regressions of mainstem temperatures against temperatures in each tributary. These regression equations were used to estimate temperatures in the two study tributaries for periods during the 2001 and 2002 when temperature data were collected in the Salmo River, but not in the tributaries.

Inter-annual variation in discharge regime may also affect fish growth and abundance, and therefore should also be considered as part of the stream fertilization study. The Water Survey of Canada (WSC) collects discharge data for the Salmo River mainstem (WSC hydrometric station 08NE074), but not for the tributaries. However, in case where discharge data is collected for the mainstem river of a watershed, discharge in the tributaries can be estimated based on the proportion of the total watershed area they represent. Mean monthly flows in Sheep Creek and the South Salmo River were estimated by factoring discharge estimates for the Salmo River by the percent watershed area of each stream (11% and 15%, respectively).

2.6.2 Water chemistry

To assess water quality and nutrient abundance, a water sample was collected monthly from three sites in each study tributary (spaced at roughly equal distances) from July to September 2001. Samples were analyzed for pH, conductivity, alkalinity, dissolved inorganic nitrogen ($NO_3 + NO_2$ or DIN), soluble reactive phosphorus (SRP), total metals, and ions. The portion of each sample analyzed for concentrations of DIN and SRP was stabilized with sulphuric acid during collection. Samples used to measure pH and total alkalinity were obtained by filling 1 L sample bottles directly from the stream after several rinses with water. All samples were immediately placed in coolers with freezer packs and transported to the lab within 24 hours. The handling and analysis of the samples were conducted by a commercial lab (ALS Labs, Burnaby, B.C.) according to standard methods (APHA 1985). Protocols for metal sampling followed Cavanagh et al. (1994). Total metal samples were obtained by filling 1 L sample bottles three-quarters full with stream water, and then adding nitric acid.

3.0 RESULTS

3.1 Juvenile Fish Populations

3.1.1 Habitat Survey

Habitat surveys for Sheep Creek and the South Salmo River were completed on July 31 and August 1 of 2001, at estimated flows of 0.71 cms and 1.23 cms, respectively. For Sheep Creek, stream lengths for reaches 1 and 2 were estimated at 5.9 and 6.3 km, respectively for a total length of 12.2 km (Table 1). For the South Salmo River, stream lengths for reaches 1 and 2 were estimated at 7.6 km and 5.7 km, respectively for a total length of 13.3 km (Table 1). In all cases, visual estimates of wetted width made by the surveying crew were excellent predictors of actual width (r^2 = 0.87-0.91, n = 33-44; Table 2). In reaches 1 and 2 of Sheep Creek, wetted widths averaged 10.3 m and 9.2 m respectively, in reaches 1 and 2 of the South Salmo River, widths were 12.7 m and 9.6 m, respectively. Total wetted areas for the study portions of the two streams at the time of the surveys were 117,068 m^2 and 150,056 m^2, respectively (Table 1). In each stream, riffles and cascades together represented 80-90% of total habitat area, with the percentage of cascades being higher in the upstream reach (reach 2) where gradient, estimated from topographic maps, was 4% to 6% compared to 2% to 3% in the downstream reach (reach 2). The percentages of pools and runs were roughly similar between reaches in each stream.

3.1.2 Electrofishing Survey

During August 2-10, 2001, and August 19-23, 2002, I sampled fish abundance at 25 sites in Sheep Creek and at 27 sites in the South Salmo River (Table 1; Figures 2 and 3). Combined area of the sample sites represented 2.5% and 2.1%, respectively of the total wetted area of the study portions of the two streams (Table 1). Observed mortality averaged less than 1% for all species. Sample sites ranged in size from 75 m^2 to 164 m^2. Estimated discharge (velocity-area method) was similar during the 2001 and 2002 electrofishing surveys for the South Salmo River, but for Sheep Creek, discharge was nearly double during the 2002 survey compared to 2001 (see above). This apparent difference may have been the result of a biased high estimate of discharge in Sheep Creek in 2002. An estimate of 1.1 m^3/s for Sheep Creek in 2002 appeared high considering that discharge was similar during the survey periods for both the South Salmo River (see above) and the Salmo River mainstem (6.4 m^3/s and 6.3 m^3/s in 2001 and 2002, respectively). Moreover, predicted discharge for Sheep Creek (based on the stream representing 11% of the Salmo River watershed area) was 0.7 m^3/s for both 2001 and 2002; this closely matches the 2001 estimate obtained using the velocity-area method (0.6 m^3/s), but is considerably lower than the 2002 estimate of 1.1 m^3/s. Water temperatures were similar during the 2001 and 2002 electrofishing surveys for both the South Salmo River and Sheep Creek (see below).

	Discharge (m^3/s)		Temperature (°C)	
Stream	2001	2002	2001	2002
Sheep Creek	0.6	1.1	9-13	9-12
South Salmo R.	1.0	1.2	10-16	9-14

3.1.3 Length-at-age

During 2001 and 2002, readable scale samples were obtained for a total of 76 bull trout and 40 rainbow trout in Sheep Creek, and for 62 bull trout and 38 rainbow trout in the South Salmo River. Bull trout that were sampled for scales from the two sample streams ranged from 51 mm to 187 mm in fork length, and from 0+ to 3+ in age, while rainbow trout that were sampled for scales ranged from 54 mm to 224 mm in fork length and 0+ to 4+ in age (Appendix 2).

Prior to estimating length categories for each age class of bull trout and rainbow trout, length and scale data for 2001 and 2002 were pooled because there was little evidence of differences in length-at-age between years. For bull trout in both study tributaries, length-frequency histograms suggested length categories for each age class were in excellent agreement with the scale age data (see Figure 4 for an example of the graphical analyses used for the South Salmo River). For rainbow trout in the South Salmo River, the length-frequency histograms suggested length categories were within 10 mm of those based on the scale age data (Figure 4). Length categories for age classes of rainbow trout in Sheep Creek were estimated based solely on the length-frequency histograms because the scale age data appeared to be unreliable. The apparent late emergence and modest growth of rainbow trout in Sheep Creek during their first year (mean lengths for age 0+ and 1+ fish were 27-33 mm and 81-86 mm, respectively), resulted in very few scale annuli during the first year of growth. This led to a high likelihood of age being underestimated by one year. Although the length-frequency histograms for Sheep Creek rainbow trout could not be cross-validated by scale age data, they did suggest a clear division between age classes similar to that observed for rainbow trout in the South Salmo River (see Figure 4). Table 3 summarizes the fork length categories that were used to estimate the age of bull trout and rainbow trout captured in the two study tributaries.

3.1.4 Calibration of single-pass electrofishing

With the exception of 0+ rainbow trout fry, single-pass electrofishing catches were excellent predictors of three-pass ML abundance estimates derived from three-pass electrofishing (r^2 = 0.76-0.95; Table 4 and Figure 5). For bull trout, I developed regression models to calibrate the single-pass electrofishing data (three-pass ML estimates regressed on single-pass electrofishing catches) based on pooled data for the 1+, 2+ and 3+ age classes because an ANCOVA indicated similar regression slopes and non-significant interaction between single-pass electrofishing catch and these age classes ($P > 0.05$ for all cases). A separate calibration model was developed for bull trout fry because the regression slope for fry was steeper compared to that for parr ($P > 0.05$; Figure 5).

For rainbow trout, separate calibration models were developed for age 1+ parr, and older parr (age 2+ to 4+), based on differences in regression slopes (ANCOVA, $P < 0.05$ for all cases; Figure 5). A Y-intercept variable was included in the regression model for age 1+ rainbow trout, as this improved the fit to the data considerably (Figure 5). For age 1+ rainbow trout parr, site 4 in Sheep Creek was considered an outlier (studentized residual = 7.02; Figure 5) and excluded from the calibration regression. Estimated capture probability for age 1+ parr during the three-pass removal electrofishing at site 4 was atypically poor compared to the average for all 16 calibration sites (0.44 versus 0.73).

I did not calibrate catch data or compute abundance estimates for age 0+ rainbow trout fry because the field crews considered the catch data to be unreliable for these fish. At the time of the electrofishing surveys in the two streams, most rainbow trout fry were less than 30 mm in fork length, and as a result, capture efficiency was reduced due the difficulty of spotting these small fry after they had been stunned and the tendency for fry to pass through the lower stop net. For longnose dace, the calibration model developed for sculpin was used to calibrate the single-pass electrofishing data (Table 4) as too few dace were captured at the calibration sites to develop a reliable regression.

3.1.5 Fish size and abundance

Overall, for each study tributary, mean fish size (fork length and weight) was highly similar in 2001 and 2002 (Table 5). Bull trout fry and rainbow trout fry and 1+ parr in Sheep Creek may have been marginally larger in 2002 than in 2001, but in other cases, apparent between-year size differences were associated with small sample sizes and relatively large standard errors. Bull trout and rainbow trout were generally larger in the South Salmo River compared to Sheep Creek, but size differences were not great. Mean length and weight estimates for rainbow trout fry may have been biased high as a result of lower capture efficiency for smaller individuals in this age class (see Section 3.1.4).

For both study tributaries, estimated mean densities differed by less than 10% in 2001 and 2002 for bull trout fry, bull trout parr (ages 1+ to 3+ pooled), and rainbow trout parr (ages 1+ to 4+ pooled) (Figure 6). The exception to this was in the South Salmo River where bull trout parr density in 2002 was 40% less than that in 2001. When parr age-classes were examined separately for bull trout and rainbow trout, differences in fish density and biomass between years were generally less than 30%, with biomass estimates being somewhat more consistent between years than density estimates (Table 6). Total salmonid biomass (all age classes of bull trout and rainbow trout pooled) and total fish biomass (all species pooled) were also quite similar between years in each stream, varying by less than 20% and 10%, respectively (Figure 7). Abundance of non-salmonid species was more variable between years. In Sheep Creek, densities of sculpin and longnose dace were about 2-fold higher in 2002 compared to 2001 (Figure 6). In the South Salmo River, sculpin density was also somewhat higher in 2002, but longnose dace density was similar between years.

Table 6 summarizes mean density, biomass, standing stock and 95% confidence intervals by age class for each species. Precision of the stream-wide density estimates (95% CI) ranged from ±22% to ±46% for bull trout fry, from ±22% to ±51% for bull trout parr, and from ±14% to ±20% for rainbow trout parr (Figure 6). Abundance estimates for sculpin and longnose dace were less precise compared to those for salmonids (±26% to ±128%; Table 6).

In 2001 and 2002, densities of bull trout fry and parr in Sheep Creek were roughly double those in the South Salmo River, whereas rainbow trout and longnose dace density were similar for the two streams (Figure 6). Sculpin were the most abundant fish per area in the South Salmo River, and the least abundant in Sheep Creek. Overall, salmonid biomass was about 40% greater in Sheep Creek (Figure 7). Higher sculpin density in the South Salmo River resulted in similar estimates of total fish biomass for the two streams (Figure 7).

3.1.6 Fish distribution

In Sheep Creek, there was no apparent trend in the longitudinal distribution of bull trout fry, but parr densities increased in an upstream direction (Figure 8). In the South Salmo River, both fry and parr density increased in an upstream direction, with parr being entirely absent from the majority of sites in the lower reach. Compared to bull trout, rainbow trout parr were distributed relatively uniformly in each stream (Figure 8). Sculpin appeared to be limited to the lower two km of Sheep Creek, as were longnose dace in 2001 (Figure 8). In 2002, dace were present in the lower 5 km of the stream. In the South Salmo River in both years, sculpin were abundant at most sites, while dace were limited to the lower reach. See Appendix 3 for fish density data by species and age class for all sample sites in 2001 and 2002.

3.1.7 Annual survival estimates

For bull trout, the annual survival rate (proportion of a cohort remaining in a study tributary from August 2001 to August 2002) was lower for older age classes compared to 0+ fry in Sheep Creek, but was similar among age classes in the South Salmo River (see below). For rainbow trout, survival was highest for 2+ parr and lowest for 1+ parr in both streams. Overall, survival estimates were somewhat higher in Sheep Creek compared to the South Salmo River.

	Bull trout			Rainbow trout		
Stream	age-0+	age-1+	age-2+	age-1+	age-2+	age-3+
Sheep Creek	43%	26%	22%	44%	75%	30%
South Salmo River	23%	25%	20%	27%	76%	18%

3.2 Benthic macroinvertebrates

In 2002 estimates of mean invertebrate density (numbers/m^2 of stone surface for all families pooled) in Sheep Creek and the South Salmo River were 3.7- and 2.3-fold greater, respectively, compared to 2001 (Figure 9a). The trend of greater invertebrate density in 2002 compared to 2001 was consistent for all three sample sites in each stream. Greater invertebrate abundance in 2002 was largely the result of the high number of early instars in the 2002 samples. However, because of the small size of the early instars (< 5 mm) differences in mean biomass between the two years were much less; biomass was 30% and 45% higher in 2002 for Sheep Creek and the South Salmo River, respectively (Figure 9b). Estimates of mean invertebrate density (95% CI: ±16% to ±19%; Figure 9a) and biomass (±21% to ±35%; Figure 9b) in each stream were relatively precise, with density estimates being the more precise of the two.

The benthic samples were numerically dominated by typical stream taxa (chironomids, mayflies, stoneflies, and caddis flies; Figure 9c), and the trend of greater invertebrate density in 2002 compared to 2001 was consistent for all four of these taxa. During both years, the proportional abundance of these taxa was fairly similar for the two streams. One notable exception was in Sheep Creek, where in 2002, stoneflies occurred in higher proportion, and chironomids, in lower proportion, compared to 2001. The most abundant invertebrate families in both streams were Baetidae, Epherellidae and Heptageniidae (Ephemeroptera) and Tanytarsini, Orthocladiinae and Diamesinae (chironomids). For both streams, the maximum number of invertebrate families observed (all samples pooled) was similar between years (Figure 9d), suggesting similar diversity at the family level.

3.3 Periphyton Accrual

Sample means for peak chlorophyll *a* accrual on artificial substrate ranged 0.9 to 2.5 $\mu g/cm^2$ among years and study tributaries (Figure 10). For both streams, peak chlorophyll *a* accrual was similar between 2001 and 2002 during the summer (Aug-Sept) and fall (Sept-Oct) sampling periods. The one exception was the fall sampling period in Sheep Creek where peak chlorophyll *a* was double in 2002 compared to 2001 (2.1 versus 1.0 $\mu g/cm^2$). Both streams experienced greater peak chlorophyll *a* in fall compared to summer. I did not attempt to quantify the rate of chlorophyll *a* accrual, but it appeared to be higher in 2002 in both streams (Figure 10). Algae samples appeared to be composed primarily of diatoms, with no substantial periphyton mats or filamentous algae observed at the sampling sites.

3.4 Water Quality

Using previously collected thermograph data (1998-2000), I found a highly significant logarithmic relationship between temperatures in the Salmo River mainstem and the two study tributaries (Sheep Creek: $y = 4.7963\text{Ln}(x) - 3.5259$, $r^2 = 0.94$; South Salmo River: $y = 4.7089\text{Ln}(x) - 3.7806$, $r^2 = 0.92$). Using these regressions, estimates of mean monthly temperatures for the two study tributaries were computed (Table 7). Incomplete temperature data for the Salmo River mainstem meant that estimates for the study tributaries for various months in 2001 and 2002 could not be computed, and this prevented a meaningful comparison of temperature between years. However, mean montly temperatures appeared to be similar between the two streams.

Based on the percent drainage area of the Salmo River watershed represented by each study tributary, predicted mean monthly flows (1950-2002) for Sheep Creek and the South Salmo River ranged from 0.8-13.3 m^3/s and from 1.2-18.2 m^3/s, respectively (Table 8). During most months in 2001, flows in the study were likely well below the 50-year average. In 2002, mean monthly flows were, on average, double that in 2001, and were comparable to the long-term average.

During July and August 2001, concentrations of soluble reactive phosphorus (SRP) in the study tributaries were below the detection limit (1 μg/L) (Table 9), but low concentrations were detected in September (5 and 2 μg/L in Sheep Creek and South Salmo River, respectively). Low concentrations of dissolved inorganic nitrogen (DIN) were detected in Sheep Creek in July and September, but not in August (Table 9). Concentrations of DIN in the South Salmo River were always below the detection limit (5 μg/L). During July-September, total alkalinity ranged from 22-39 mg/L $CaCO_3$ in Sheep Creek and from 54-80 mg/L $CaCO_3$ in the South Salmo River (Table 9). Conductivity ranged from 49-88 μs/cm in Sheep Creek and from 101-175 μs/cm in the South Salmo River (Table 9). The pH and hardness levels for Sheep Creek (7.7-8.0 and

23-39, respectively) and the South Salmo River (8.0-8.2 and 48-80, respectively) indicated that water in both streams was slightly basic and 'soft'. During the three sampling periods, all potentially harmful trace metals tested for were either below detection limits, or if detectable (aluminium, barium, magnesium, uranium, zinc), were at least an order of magnitude below the B.C water quality criteria for drinking water and freshwater aquatic life (MWLAP 2001; see Appendix 4 for provincial water quality criteria and a list of the trace metals tested for and the detection limits for these metals, see Appendix 5 for raw water quality data).

4.0 DISCUSSION

4.1 Fish age, abundance and distribution: implications for the experiment

In both streams, the majority (93%-94%) of the standing stock of bull trout parr (by numbers) consisted of age 1+ and 2+ fish (Table 6), with mean lengths for the two age classes ranging from 104-106 mm and from 140-147 mm, respectively (Table 5). During two years of sampling, a total of only eight 3+ (161-185 mm) and one 4+ (213 mm) bull trout were captured. These results suggest that the vast majority of bull trout in the study tributaries migrate to the Salmo River mainstem prior to their fourth summer at a length of less than 150 mm. Furthermore, estimates of annual survival rate (which accounted for both mortality and emigration) for individual bull trout cohorts suggested that emigrants in 2002 likely consisted of both two and three summer fish (i.e., 1+ and 2+ fish enumerated in the August survey). Unlike survival estimates for rainbow trout which were considerably higher for 2+ parr than 1+ parr (75%-76% versus 27%-44%; see Section 3.1.7), survival for older bull trout parr (20%-26%) was similar to or lower than that for 0+ fish (23%-43%), which is unlikely in the absence of emigration because mortality is expected to be lower for older fish (Ricker 1975). A mix of two- and three-summer emigrants from the study tributaries, ranging in size from 100-150 mm, closely mirrors smolt-trapping results for anadromous Dolly Varden (*Salvelinus malma*) in the Keogh River (Smith and Slaney 1980).

Compared to 1+ and 2+ bull trout, 1+ and 2+ rainbow trout represented a smaller proportion of the overall parr standing stock in the study tributaries (73%-84%). During the 2001 and 2002 surveys I captured 166 3+ and 4+ rainbow, ranging in length from 151-215 mm. Higher survival for 2+ compared to 1+ rainbow resulted in similar standing stocks of 2+ and 3+ parr (Table 6), suggesting that rainbow trout populations in these streams may be largely resident, at least in the upper reaches, a conclusion supported by a recent radio telemetry study of adult rainbow trout in the Salmo River mainstem (Hagen and Baxter 2003).

Rainbow trout populations were distributed relatively evenly in both study tributaries (Figure 8). In contrast, bull trout were concentrated in the upper reaches, particularly in the South Salmo River (Figure 8). This is a common observation for juvenile bull trout in rearing tributaries of both the Salmo River (Baxter et al. 1998) and the Wigwam River in the east Kootenays (Westslope Fisheries 2002), and may reflect the tendency of adults to spawn in headwater areas, or the preference of juveniles for higher gradient reaches with abundant cobble and boulder cover. In Sheep Creek, with the exception of the lowermost 2-5 km, bull trout and rainbow trout compromised 100% of fish biomass (Figure 8), whereas in the South Salmo River, sculpin were abundant throughout both reaches and represented about 40% of the total fish biomass (Table 6).

Overall, bull trout densities were higher in Sheep Creek than in the South Salmo River, while rainbow trout densities were relatively similar for the two streams (Figure 6). During 2001 and 2002, estimated salmonid biomass was about 30% greater in Sheep Creek than in the South Salmo River (Figure 7). Conversely, because of the large population of sculpin in the South Salmo River, total fish biomass there was about 20% greater than that in Sheep Creek. Lower salmonid biomass in the two study tributaries in 2002 compared to 2001 can be attributed to lower abundance of older salmonid parr (1+ and 2+ bull trout; 3+ and 4+ rainbow trout) in 2002 (Table 6). Total fish biomass varied little between years because reduced salmonid parr abundance was offset by higher longnose dace abundance in Sheep Creek and by higher sculpin abundance in the South Salmo River in 2002 compared to 2001.

4.2 Suitability of Salmo River tributaries for stream fertilization

Mean biomass of juvenile salmonids in the study tributaries ranged from 1.6-2.8 g/m^2. For comparison, Mullan et al. (1992) compiled a list of mean juvenile salmonid biomass estimates from electrofishing surveys in 122 streams in Idaho, Oregon Washington and B.C. The average biomass for this dataset was 3.5 g/m^2 (range: 0.9-12.7 g/m2, CV: 0.57) which was 60% higher than average of the 2001 and 2002 values for the study tributaries (2.2 g/m2). This would suggest that the study tributaries are at the lower end of the productivity scale for Pacific Northwest streams. However, in making this comparison, it should be noted that the Pacific Northwest dataset includes mostly streams with anadromous populations and does not include any streams where bull trout were one of the dominant species representing biomass. As an alternative comparison, bull trout parr densities (all ages pooled) in the study tributaries in 2001-2002 and in 1997 (Baxter et al. 1998) were plotted and compared to bull trout parr densities reported for other streams in the Cascade and Rocky Mountain regions (Baxter et al. 1998). This comparison suggested that bull trout productivity in Sheep Creek may be about average for streams in these regions, whereas productivity in the South Salmo River may be below average (Figure 11).

To meet the required compensation program attached to the Seven Mile Unit FAA, the 7MTWG agreed to a stream fertilization trial in the South Salmo River, accompanied by a monitoring program, with monitoring also to occur in Sheep Creek to provide a control. However, for the purposes of the fertilization experiment it may be better to fertilize Sheep Creek, while leaving the South Salmo River as the unfertilized control. One advantage to this is that the entire portion of Sheep Creek used by bull trout is accessible by road and has been included in the study area, whereas for the South Salmo River, road access and the study area ends 6 km and 4 km from the upstream barrier, respectively (Figures 2 and 3). Access to the upper South Salmo River is also made difficult by the fact that the stream extends beyond the Canadian border into the United States. Lack of road access would increase the cost of fertilizer application in the South Salmo River compared to Sheep Creek, as would the greater amount of fertilizer that would be needed given the greater length and higher discharge of the former stream. More importantly, because the South Salmo River extends into the United States, it would be necessary to leave the upper portion of the stream untreated. Because the primary objective is to enhance bull trout production, another disadvantage of fertilizing the South Salmo River is that bull trout are largely absent from the lower reach, whereas in Sheep Creek, bull trout is distributed throughout. Moreover, a large proportion (≈ 40%) of the fish biomass in the South Salmo River consists of non-salmonids which were not identified for enhancement in the FAA. Fertilizing the South Salmo River is less desirable from an experimental point of view because of the likelihood of fish movement between treated (South Salmo River downstream of the U.S. border) and untreated reaches (i.e., upper South Salmo River and Stagleap Creek), and because of the lower likelihood of detecting a treatment response for bull trout which exhibit a very patchy distribution in the stream.

The issue of whether possible metal contamination from earlier mining activity would confound study results for Sheep Creek was brought up at an earlier 7MTWG meeting on November 5, 2002. However, this is not likely to pose a confounding factor to the study or the use of Sheep Creek as the treatment stream; in both study tributaries, all potentially harmful trace metals that were tested for were either below detection limits, or if detectable (aluminium, barium, magnesium, uranium, zinc), were at least an order of magnitude below the B.C water quality criteria for drinking water and freshwater aquatic life.

Comparing macroinvertebrate abundance in the study tributaries to that in other systems is made difficult by the inherent complexity of stream benthos sampling (Minshall and Minshall 1977). Nevertheless, similar sampling methodology to that used in this study was employed to monitor macroinvertebrate colonization of a re-wetted reach in the Bridge River, a regulated stream with considerably higher levels of nitrogen and phosphorus compared to the study tributaries (Decker and Higgins in prep.). After a 30-day colonization period, invertebrate density (all taxa pooled) in the Bridge River averaged about 11,000 organisms/m^2 which was about 4.5 times higher than densities observed in the Salmo study tributaries (900-3,400 organisms/m^2; Figure 9). This limited evidence suggests that macroinvertebrate production in the study tributaries may also be relatively low.

Standing crops of periphyton biomass in the study tributaries were very low (0.9 to 2.5 $\mu g/cm^2$ measured as chlorophyll *a* accrual), and would likely increase by several times following nutrient addition. In phosphorous-limited streams with peak periphyton biomass of less than 10 $\mu g/cm^2$, dramatic increases in periphyton standing crop have been observed in response to fertilization (2 to 20-fold increases in peak chlorophyll *a*; Peterson et al. 1985; Johnston et al. 1990; Paul et al. 1996; Toth et al. 1996).

Pre-treatment monitoring of water chemistry and productivity at the major trophic levels (juvenile fish, macroinvertebrates, periphyton) in Sheep Creek and the South Salmo River in 2001-2002 indicates that based on productivity, either stream would be a suitable candidate for stream fertilization. At low flow levels during the summer growing period, SRP and DIN were generally at or below detection limits, suggesting that Sheep Creek and the South Salmo River are both strongly nutrient-limited. SRP was detected in both streams in September (2-5 μg/L; Table 9), but concentrations were well within a range thought to limit the productivity of algae and macroinvertebrates in streams (< 10 μg/L; Bothwell 1989; Quamme and Slaney 2003). Concentrations of DIN, when high enough to be detected, also did not exceed a range thought to limit algae and macroinvertebrates (< 20 μg/L; Perrin 1989).

While phosphorus is the nutrient most often limiting autotrophic production in streams (vanNieuwenhuyse and Jones 1996), nitrogen can also be limiting depending on the N:P ratio, autotrophic production is thought to be limiting by nitrogen at N:P values less than five (by weight), by phosphorus, at values greater than 12, and by both nutrients at values in between (OECD 1982). It was not possible to calculate N:P ratios from the water chemistry data because concentrations of both nutrients were often below detection limits. However, given the low abundance of nitrogen in the study tributaries, both nutrients would likely be applied as part of the fertilization experiment.

Total alkalinity levels in Sheep Creek (22-39 mg/L $CaCO_3$) and the South Salmo River (54-80 mg/L $CaCO_3$) suggest that these streams have buffering capacity typical of streams in B.C. and in the Kootenay region. A survey of B.C. streams found that alkalinity levels ranged from 2-272 mg/L $CaCO_3$, with a median value of 34 mg/L $CaCO_3$ (n = 91, data from Appendix 2 of Ptolemy et al. 1991). Kootenay Region streams had a somewhat higher median level of 57 mg/L $CaCO_3$ (n = 14, range 10-126 mg/L).

4.3 Suitability of the experimental design and field methods

Results from 2001 support the use of calibrated single-pass electrofishing as an accurate method of estimating juvenile fish abundance for the purposes of the fertilization experiment. Data from the calibration sites indicated that single-pass electrofishing totals were excellent predictors of three-pass removal estimates of fish abundance (r^2 = 0.76-0.95; Figure 5) in all cases except for age 0+ rainbow trout. Similar to this study, Jones and Stockwell (1995) reported a strong correlation between single-pass electrofishing catches and removal estimates for rainbow trout in Ontario streams (r^2 = 0.76-0.86). Comparable relationships between single-pass electrofishing catches and multiple removal estimates have also been obtained for Atlantic salmon (*Salmo salar*) (Crozier and Kennedy 1994) and brown trout (*S. trutta*) (Lobon-Cervia and Utrilla 1993).

In 2002, the two survey crews were able to sample 50 sites in five days, using single-pass electrofishing. This represented a 250% increase in sampling efficiency compared to conventional three-pass electrofishing. The greater sampling intensity achieved using this 'rapid assessment' approach (Jones and Stockwell 1995) likely resulted in higher precision for the population estimates. Despite high spatial heterogeneity in fish abundance (Figure 8), estimates of bull trout and rainbow trout density (95% CI: ±14%-51%; Figure 6), and salmonid and total fish biomass (±17%-27%; Figure 7) were quite precise. Robson and Regier (1964) recommend standards for precision of ±50%, ±25% and ±10%, respectively, for preliminary surveys, management monitoring and research levels of population assessment. While achieving a precision level of ±10% for juvenile stream populations is probably not realistic, attaining precision levels of ±25% with the present sampling method appears likely, at least for composite measures of fish productivity (e.g., total salmonid biomass).

For the purpose of calibrating the single-pass electrofishing data, I assumed the three-pass ML removal estimates to represent 'true' fish abundance at the calibration sites (see Appendix 1). This assumption was supported by consistently high estimates of capture probability for salmonids during three-pass electrofishing (0.62-0.88; Table 4). Not surprisingly, capture probability was lower for sculpin (0.50), which, along with longnose dace, are more difficult to capture by electrofishing due to their lack of a swim bladder and their tendency to remain within the substrate. Calibrated single-pass estimates for sculpin and dace are likely less reliable than those for salmonids. As well, I was unable to reliably estimate mean size and abundance of 0+ rainbow trout fry because in August these fish were still too small (<30 mm) to be effectively captured by electrofishing. However, because the monitoring program provides reliable data for the four older age classes of rainbow trout in the study tributaries, it will be possible to assess the effect of stream fertilization on rainbow trout despite a lack of data for fry.

While the high capture probabilities reported in this study suggest that 'good' estimates of juvenile abundance were obtained, Bohlin and Cowx (1990) point out that declines in capture rates may not be detectable from capture probability estimates based on electrofishing catches alone (as was done in this study). In fact, the three-pass ML estimates obtained in 2001 probably underestimate the actual number of fish that were present at the calibration sites since it has been shown that even for 'good' estimates of juvenile salmonid abundance, negative bias can be on the order of 15-25% (Peterson and Cedarholm 1984; Bohlin and Cowx 1990; Riley and Fausch 1992; Rodgers et al. 1992). Other researchers have reported difficulty in electrofishing for bull trout and other salmonids in streams with similar characteristics to the study tributaries (i.e., large substrate, low conductivity; Bonneau et al. 1995 and references within). Regardless, the purpose of monitoring fish populations in this study is to detect a change in abundance in response to stream fertilization, thus determining the true number of fish present during the baseline and treatment periods is not important, providing the electrofishing data represents a reliable index of true abundance. In my experience, this assumption is reasonable so long as the electrofishing surveys continue to be conducted using standardized methodology developed in 2001 and timed to standardize stream flows and water temperatures among years.

For the purpose of providing an index of macroinvertebrates abundance, the field and lab methods used to sample benthos also appeared to be effective. Considering the notorious degree of spatial heterogeneity typical in stream invertebrate communities (Resh 1979), and the modest number of replicate samples that were collected in each study tributary (15), the precision of the estimates of invertebrate density (95% CI: ±15%-19%; Figure 9a), and biomass (±21%-35%; Figure 9b) was surprisingly good. I was able to minimized heterogeneity in the invertebrate samples by sampling habitats with similar substrate composition, depth and velocity, and by correcting for differences in the surface area presented by the stones in each sample.

Most stream fertilization studies in B.C. have addressed high spatial heterogeneity in stream substrate composition by relying on invertebrate colonization of gravel-filled baskets as an index of invertebrate abundance rather than directly sampling the stream substrate, and there is evidence to suggest that this method can provide a reasonably good measure of abundance and biomass of the predominant taxa (e.g., Mason et al. 1973). However, other studies have shown that artificial colonization baskets or trays failed to provide a suitable measure of the relative abundance of invertebrates on the stream bed (Minshall and Minshall 1977). The advantage of the methodology used here is that *in situ* samples of the invertebrate community of the study tributaries were obtained, and at a level of precision that matched or exceeded that reported in other studies that relied on colonization of artificial substrates (e.g., Johnston et al. 1990; Paul et al. 1996).

4.4 Response to stream fertilization and statistical power

At this preliminary stage in the fertilization experiment, it is essential to consider the likely probability of detecting an effect of nutrient addition on juvenile fish production given the sampling design and the intent to collect three years of baseline and three years of treatment data. Unfortunately, conducting a prospective power analysis using the data collected in 2001 and 2002 would have little meaning because with a BACI study, power is dependent upon three sources of error: spatial (i.e., variation in fish density among sites within a year), temporal (i.e., variation across years) and unexplained (i.e, measurement error + site-year interaction effects + unexplained error). Two years data is likely sufficient to estimate spatial error, but not temporal error or site-year interaction effects, both of which can have a large effect on power (Underwood 1993). To examine what level of power might be expected for the fertilization experiment as it is planned, I instead referred to study by Higgins et al. (in prep.) that looked at the effect of the above mentioned error components on the power to detect a juvenile salmonid response to flow manipulation in the Bridge River, BC. In their study, five years of pre-treatment data allowed for estimates of all three error sources. The results of their analysis are likely highly applicable to this study because 1) the Bridge River flow experiment utilized a similar multi-year before-after comparison to evaluate the treatment; 2) a similar number of sites in the Bridge River were sampled (20) using similar methods (electrofishing); and 3) levels of spatial variation in fish abundance observed in the Bridge River were comparable to those observed in Salmo tributaries.

To provide a more relevant power analysis for this study, I modified the parameters in the bootstrap simulation model used by Higgins et al. (in prep.) in their analysis. I based my simulations on 25 sites sampled over six years (3 baseline and 3 treatment), with components of variation typical of Bridge River data (total variance = 20% spatial error, 20% temporal error and 60% unexplained error). A two sample one-tailed test ($\alpha = 0.2$) was used to detect a significant positive increase in mean density during the treatment period (Cohen 1988). Table 10 summarizes statistical power for three levels of total variance (CV%) in fish density across sites and years at four treatment *effect sizes* (% increase in average density during treatment period). Higgins et al. (in prep.) found that in the Bridge River, total variance rarely exceeded a CV value of 50% (shaded column in the table) despite typical one order of magnitude variation in fish density among sites within years and several-fold variation in density among years. Between 2001 and 2002, salmonid densities and biomass in Sheep Creek and the South Salmo River differed by only 10-15% (Figures 6 and 7), which suggests that fish production may be more temporally stable than that in the Bridge River, thus, a total variance of 50% is likely a reasonable estimate to apply here. If a total variance of CV 50% is applied, the statistical power for the fertilization experiment would be acceptably high (> 0.8; Cohen 1988) at effect sizes of about 35% and higher. However, this is only a preliminary conclusion and statistical power should be revaluated in year 3 before fertilization occurs. Considering that some researchers have suggested that potential increases in juvenile fish biomass of 100% or more can be expected following stream fertilization (various papers in Stockner 2003 and Slaney and Zaldokas 1997), to conclude that fertilization had a biologically meaningful effect on juvenile fish production in the Salmo River watershed, I would suggest that a minimum response in fish numbers or biomass of 35% is reasonable.

5.0 REFERENCES

Ashley, K.I. And P.A. Slaney. 1997. Accelerating recovery of stream, river and pond productivity by low-level nutrient replacement. In P.A. Slaney and D. Zaldokas, eds. Fish Habitat Rehabilitation Procedures. Watershed Restoration Technical Circular No. 9. Produced by British Columbia Watershed Restoration Program, Ministry of Environment, Lands and Parks and Ministry of Forests.

Baxter, J.S. 1999. Bull trout studies in the Salmo River watershed: 1998 and 1999. Report to BC Hydro, Castlegar, B.C. Report by Baxter Environmental, Nelson, B.C.

Baxter, J.S. 2001a. Bull trout studies in the Salmo River watershed: 2000. Report to BC Hydro, Castlegar, B.C. Report by Baxter Environmental, Nelson, B.C.

Baxter, J.S. 2001b. Bull trout studies in the Salmo River watershed: 2001. Report to BC Hydro, Castlegar, B.C. Report by Baxter Environmental, Nelson, B.C.

Baxter, J.S. 2001c. Aspects of the biology of bull trout (Salvelinus confluentus) in the Salmo River watershed as identified through radio telemetry (2000 and 2001 data) and a watershed management plan for the species. Report to Columbia-Kootenay Fisheries Renewal Partnership, Cranbrook, B.C, and BC Hydro, Burnaby and Castlegar, B.C. Report by Baxter Environmental, Nelson, B.C.

Baxter, J.S., and G. Nellestijn. 2000. Aspects of the biology of bull trout in the Salmo River watershed as identified through radio telemetry. Report to Columbia-Kootenay Fisheries Renewal Partnership, Cranbrook, B.C. Report by Baxter Environmental, Nelson, B.C.

Baxter, J.S., Coughlin, W.D., Pennington, B.M., and G.G. Oliver. 1998. Synoptic bioreconnaissance of bull trout distribution and abundance in the Salmo River watershed. Report to BC Hydro, Environmental Department, Castlegar, B.C. Report by Interior Reforestation Co. Ltd., Cranbrook, B.C. xii + 119 pp + 7 appendices.

Bohlin, T. and I.G. Cowx. 1990. Implications of unequal probability of capture by electric fishing on the estimation of population size. In Cowx, I.G. [ed.] Developments in Electric Fishing. Fishing News Books.

Bonneau, J.L., R.F. Thurow, and D.L. Scarnecchia. 1995. Capture, marking and enumeration of juvenile bull trout and cutthroat trout in small, low conductivity streams. N. Amer. J. Fish. Manage. 15: 563-568.

Bothwell, M.L. 1989. Phosphorus-limited growth dynamics of lotic periphytic diatom communities: area biomass and cellular growth rate responses. Can. J. Fish. Aquat. Sci. 46:1293-1301.

Braumandl, T.F. and M.P. Curran [eds.]. 1992. A field guide for site identification and interpretation for the Nelson Forest Region. British Columbia, Ministry of Forests, Land Management handbook No. 20.

Calow, P. 1972. A method for determining the surface area of stones to enable quantitative density estimates of littoral stone-dwelling organisms to be made. Hydrobiologia 40(1):37-50.

Cavanagh, N., R.N. Nordin, L.G. Swain and L.W. Pommen. 1994. Ambient Fresh Water and Effluent Sampling Manual (Field Test Edition). Water Quality Branch, Environmental Protection, Environment, Victoria, .

Cochran, W.G. 1977 Sampling techniques. Wiley, New York.

Cohen, J. 1988. Statistical Power Analysis for the Behavioral Sciences (2nd ed.). Lawrence Erlbaum Associates, Hillsdale, New Jersey.

Crozier, W.W. and G.J.A. Kennedy. 1994. Application of semi-quantitative electrofishing to juvenile salmonid stock surveys. J. Fish Biol. 45:159-164.

Decker, A.S., J.M. Bratty, S. Riley, and J. Korman. 1999. Estimating coho salmon and cutthroat trout standing stock in a small stream: a comparison of sampling designs. Can. Tech. Rep. Fish. Aquat. Sci. 2084.

Decker, A.S., and P.S. Higgins. (In prep.) The recolonization of a re-wetted stream reach by juvenile salmonids.

Deegan, L.A., B.J. Peterson, H. Golden, C.C. McIvor, and M.C. Miller. 1997. Effects of fish density and river fertilization on algae standing stocks, invertebrate communities, and fish production in an arctic river. Can. J. Fish. Aquat. Sci. 54:269-283.

Efron, B. and R.J. Tibshirani. 1993. An introduction to the bootstrap. Chapman and Hall, London.

Haddon, M. 2001. Modelling and Quantitative Methods in Fisheries. Chapman and Hall/CRC, Florida.

Hagen, J., and J.S. Baxter. 2003. Conservation status of the mainstem Salmo River rainbow trout population. Prepared for Columbia-Kootenay Fisheries Renewal Partnership/Columbia Basin Trust and six other agencies or groups. March 31, 2003. Nelson, B.C. 52 p.

Hagen, J., A.S. Decker, and R. Bison. 2002. Estimation of steelhead parr standing stock in the Thompson River system using an innovative rapid assessment method. Unpublished report prepared for MLWAP, Kamloops Region, Kamloops, B.C. 35p.

Hankin, D.G. 1984. Multistage sampling designs in fisheries research: applications in small streams. Can. J. Fish. Aquat. Sci. 41: 1575-1591.

Hankin, D.G. and G.H. Reeves. 1988. Estimating total fish abundance and total habitat area in small streams based on visual estimation methods. Can. J. Fish. Aquat. Sci. 45: 834-844.

Hartman, G.F., J.C. Scrivener, and M.J. Miles. 1996. Impacts of logging in Carnation Creek, a high energy coastal stream in British Columbia, and their implication for restoring fish habitat. Can. J. Fish. Aquat. Sci., 1996. 53(Supp. 1):237-251.

Heggenes, J., A. Brabrand, and S.J. Saltveit. 1990. Comparison of three methods for studies of stream habitat use by young brown trout and Atlantic salmon. Trans. Amer. Fish. Soc. 119:101-111.

Higgins, P.S., J. Korman, and M.J. Bradford. (In prep.) Evaluating the reliability of standing crop abundance time series data for detecting responses of salmonid populations to stream habitat alteration: a components of variance approach. Unpublished MS, B.C. Hydro, Burnaby B.C.

Hillman, T.W., J.W. Mullan, and J.S. Griffith. 1992. Accuracy of underwater counts of juvenile chinook salmon, coho salmon, and steelhead. N. Amer. J. Fish. Manage. 12:598-603.

Hynes, H. B. N. 1970. The Ecology of Running Waters. Toronto, University of Toronto Press.

Johnston, N. T., and P. A. Slaney. 1996. Fish Habitat Assessment Procedures. April, 1996. Ministry of Environment, Lands and Parks, Vancouver, B.C.

Johnston, N.T., C.J. Perrin, P.A. Slaney, and B.R. Ward. 1990. Increased juvenile salmonid growth by whole-river fertilization. Can. J. Fish. Aquat. Sci. 47: 862-872.

Jones, M.L. and J.D. Stockwell. 1995. A rapid assessment procedure for the enumeration of salmonine populations in streams. N. Amer. J. Fish. Man. 15: 551-562.

Keeley, E. R. and J. D. McPhail. 1998. Food abundance, intruder pressure and body size as determinants of territory size in juvenile steelhead trout. Behaviour 135:65-82.

Krebs, C.J. 1999. Ecological Methodology. Benjamin/Cummings, Menlo Park. 620 pp.

Lobon-Cervia, J. and C.G. Utrilla. 1993. A simple model to determine stream trout (Salmo trutta L.) densities based on one removal with electrofishing. Fisheries Research 15: 369-378.

Mason, W.T., Jr., G.I. Weber, P.A. Lewis, and E.C. Julian. 1973. Factors affecting the performance of basket and multiplate macroinvertebrate samplers. Freshwat. Biol. 3:1-30.

Mellina, E., and S.G. Hinch. 1995. Overview of large-scale ecological experimental designs and recommendations for the British Columbia Watershed Restoration Program. Ministry of Environment, Lands and Parks, and Ministry of Forests, Vancouver.

Minshall, G. W. and J. N. Minshall. 1977. Microdistribution of benthic invertebrates in a Rocky Mountain (U.S.A.) stream. Hydrobiologia 55:231-249.

Mullan, J.W., and four co-authors. 1992. Production and habitat of mid-Columbia River tributary streams. U.S. Fish Wild. Serv. Monograph 1 1992.

MWLAP. 2001. http://wlapwww.gov.bc.ca/wat/wq/BCguidelines/approved.html

OECD (Organization for economic co-operation and development). 1982. Eutrophication of waters: monitoring, assessment and control. OECD Publications, Paris.

Paul, A. J., and four coauthors. 1996. Development of a premier northern fishery: Mesilinka River, the first year of fertilization (1994), B.C. Ministry of Environment, Lands and Parks.

Perrin, C.J. 1989. Pilot fertilization of the Nechako River II: Nitrogen-limited periphyton production and water quality studies during treatment of the upper river. Nechako Fisheries Conservation Program. Limnotek Res. And Dev. Inc. Contract Proj. 2041-14: 66 p.

Perrin, C.J., M.L. Bothwell, and P.A. Slaney. 1987. Experimental enrichment of a coastal stream in British Columbia: effects of organic and inorganic nutrient addition on autotrophic periphyton production. Can. J. Fish. Aquat. Sci. 44:1247-1256.

Peterson, B. J. and ten coauthors. 1985. Transformation of a tundra river from heterotrophy to autotrophy by addition of phosphorous. Science 229:1383-1385.

Peterson, N.P. and C.J. Cederholm. 1984. A comparison of the removal and mark-recapture methods of population estimation for juvenile coho salmon in a small stream. N. Amer. J. Fish. Manage. 4: 99-102.

Ptolemy, R.A., D.C. Sebastian, and C.D. Tredger. 1991. Maximum Salmonid Densities in Fluvial Habitats. Fisheries Management Report (Draft). Ministry of Environment, Lands and Parks, and Ministry of Forests, Victoria.

Quamme, D.L. and P.A. Slaney. 2003. Examination of nutrient-limited community dynamics of benthic insects using mesocosms. Pages 163-176 in J. Stockner [ed.] Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society Symposium No. 34, Bethesda, Maryland.

R.L.&L. Environmental Services Ltd. 1995. Seven Mile Unit 4 Study: fish and aquatic investigations, September 1994 to June 1995 - study results and impact discussion. R.L.&L. Report No. 434-95D: 161p. Unpublished report prepared for BC Hydro.

Resh, V. H. 1979. Sampling variability and life history features: basic considerations in the design of aquatic insect studies. Journal of the Fisheries Research Board of Canada 36:290-311.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board. Can. Bull. 191.

Riley, S.C. and K.D. Fausch. 1992. Underestimation of trout population size by maximum likelihood removal estimates in small streams. N. Amer. J. Fish. Man. 12: 768-776.

Robson, D.S., and H.A. Regier. 1964. Sample size in Petersen mark-recapture experiments. Trans. Am. Fish. Soc. 93: 215-226.

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. N. Amer. J. Fish. Manage. 12: 79-86.

Slaney, P. A., and B. R. Ward. 1993. Experimental fertilization of nutrient deficient streams in British Columbia. Pages 128-141 in e. S. A. G. Shooner, ed. Le developpement du Saumon atlantique au Quebec: connaitre les regles du jeu pour reussir. Colloque international de la Federation quebecoise por le saumon atlantique., Quebec.

Slaney, P.A., and D. Zaldokas. 1997. Fish Habitat Rehabilitation Procedures. Watershed Restoration Technical Circular No. 9. British Columbia Watershed Restoration Program, Ministry of Environment, Lands and Parks and Ministry of Forests.

Smith, E. P., D. R. Orvos, and J. C. Jr. 1993. Impact assessment using the before-after-control-impact (BACI) model: concerns and comments. Can. J. Fish. Aquat. Sci. 50:627-637.

Smith, H. A. and P. A. Slaney. 1980. Age, growth, survival and habitat of anadromous Dolly Varden (*Salvelinus malma*) in the Keogh River, British Columbia. Vancouver, Ministry of Environment, Lands and Parks.

Sterling, M.S., and K.I. Ashley. 2003. Evaluations of slow-release fertilizer for rehabilitating oligotrophic streams. Pages 237-243 in J. G. Stockner [ed.] Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society Symposium No. 34, Bethesda, Maryland.

Strickland, J.D.H. and T.R. Parsons. 1972. A practical handbook of seawater analysis. Bulletin of the Fisheries Research Board of Canada 67.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. N. Amer. J. Fish. Manage. 16: 314-323.

Stockner, J. G. editor. 2003. Nutrients in salmonid ecosystems: sustaining production and biodiversity. American Fisheries Society Symposium No. 34, Bethesda, Maryland.

Toth, B., and five coauthors. 1996. Development of a premier river fishery: Big Silver Creek fertilization experiment, year two (1995) of low-level inorganic nutrient addition, B.C. Ministry of Environment, Lands and Parks.

Underwood, A.J. 1993. The mechanics of spatially replicated sampling programs to detect environmental impacts in a variable world. Aust. J. Ecol. 18: 99-116.

Van Nieuwenhuyse, E.E., and J.R. Jones. 1996. Phosphorus-chlorophyll relationship in temperate streams and its variation with stream catchment area. Can. J. Fish. Aquat. Sci. 53:99-105.

Warren, W.G. 1994. Removal estimates of Atlantic salmon parr: maximum likelihood and Bayesian methods. Department of Fisheries and Oceans, St. John's, Nfld. ICES C.M.1994/D:8.

Westslope Fisheries. 2002. Wigwam River juvenile bull trout and fish habitat monitoring program: 2001 data report. Report to Bonneville Power Administration.

Table 1. Habitat survey results and the allocation of fish population sampling effort among habitat types and reaches in Sheep Creek and the South Salmo River during 2001 and 2002 .

			Habitat survey			Fish population sampling		
Stream	Reach	Habitat type	Total length (m)	Total area (m^2)	% of reach area	Number of sites sampled	Mean site area (m^2)	% of total area sampled
Sheep	1 (lower)	riffle	4,540	48,784	77%	7	129	
		pool	356	3,420	6%	1	113	
		cascade	226	2,224	4%	0	-	
		run	754	6,519	13%	1	123	
		total	5,876	60,946	100%	9	-	1.9%
	2 (upper)	riffle	3,528	33,462	56%	7	141	
		pool	229	1,514	4%	1	125	
		cascade	1,932	15,846	31%	6	105	
		run	627	5,300	10%	1	87	
		total	6,316	56,122	100%	15	-	3.3%
Grand total			12,192	117,068		24	-	2.5%
South Salmo	1 (lower)	riffle	5,861	71,169	77%	8	137	
		pool	362	3,591	5%	0	-	
		cascade	725	6,970	10%	2	116	
		run	663	7,464	9%	1	131	
		total	7,611	89,194	100%	11	-	1.6%
	2 (upper)	riffle	3,912	44,040	68%	11	115	
		pool	162	1,269	3%	0	-	
		cascade	1,151	11,013	20%	3	90	
		run	488	4,541	9%	2	96	
		total	5,713	60,863	100%	16	-	2.8%
Grand total			13,324	150,056		27	-	2.1%

Table 2. Summary of the regressions of measurements of wetted stream widths on visual estimates of wetted width that were made by three different surveyors during habitat surveys conducted in Sheep Creek and the South Salmo River in 2001.

Surveyor	*N*	Intercept	Slope coeffic.	Std. error estimate	r^2	*P*
1	44	0.19	1.00	1.09	0.87	<0.0001
2	34	0.30	0.89	0.52	0.97	<0.0001
3	33	0.47	0.95	1.15	0.91	<0.0001

Table 3. Maximum fork lengths (mm) used to estimate length-at-age for bull trout and rainbow trout in Sheep Creek and the South Salmo River during 2001-2002. These values are based on both visual analysis of length frequency histograms for all fish captured and scale data collected for a portion (see Figures 4 and 5).

		N	*N*	Age-class length cutoff			
Stream	Reach	age	length	0+/1+	1+/2+	2+/3+	3+/4+
			Bull trout				
Sheep	1	27	98	75	125	160	-
	2	49	302	75	120	160	-
S. Salmo	1	23	42	75	120	160	-
	2	39	157	75	120	160	-
			Rainbow trout				
Sheep	1	-	250	60	110	145	190
	2	-	260	50	100	145	180
S. Salmo	1	-	279	65	115	160	215
	2	-	195	55	110	160	205

Table 4. Summary of the estimates for electrofishing capture probability (averaged among passes), and the regressions of three-pass maximum likelihood estimates of fish abundance (three-pass electrofishing) on single-pass electrofishing total catches for calibration sites in Sheep Creek and the South Salmo River in 2001.

Species age class	Age class	*N*	Cap. prob.	Y-intcpt.	Slope coeff.	SE slope	SEE	r^2	*P*
Bull trout	0	16	0.62	-	1.75	0.12	2.89	0.87	<0.001
Bull trout	1-3	16	0.82	-	1.37	0.09	1.30	0.81	<0.002
Rainbow trout	1	15	0.73	1.57	0.94	0.70	1.02	0.76	<0.003
Rainbow trout	2-4	16	0.88	-	1.17	0.03	0.67	0.95	<0.004
Sculpin spp. [1]	All	13	0.50	-	2.25	0.24	11.43	0.82	<0.005

Table 5. Mean fork lengths and weights by age class for bull trout, rainbow trout, slimy sculpin and longnose dace in Sheep Creek and the South Salmo River in 2001 and 2002. Values in brackets are standard deviations.

		Length (mm)					Weight (g)				
Stream	Year	0+	1+	2+	3+	4+	0+	1+	2+	3+	4+
Bull trout											
Sheep	2001	48 (4.7)	104 (10.7)	142 (5.8)	177 (8.2)		1.3 (1.8)	11.3 (3.7)	27.7 (5.8)	50.5 (7.1)	
	2002	52 (5.2)	104 (10.4)	140 (5.7)	181 (23.2)		1.4 (0.5)	11.2 (3.5)	25.5 (3.4)	57.2 (25.3)	
S. Salmo	2001	53 (6.7)	106 (9.7)	142 (8.7)	165 (8.6)		1.6 (0.5)	12.6 (3.2)	29.2 (5.8)	41.2 (13.2)	
	2002	54 (5.5)	106 (12.6)	147 (8.8)	Too few obs.		1.8 (1.4)	11.2 (3.8)	31.0 (7.0)	Too few obs.	
Rainbow trout											
Sheep	2001	27 (7.4)	81 (12.2)	124 (7.0)	169 (10.5)	203 (9.7)	0.3 (0.5)	6.6 (3.1)	21 (4.1)	54.3 (10.0)	93.4 (17.3)
	2002	33 (7.4)	86 (10.9)	126 (8.6)	165 (12.5)	207 (17.0)	0.3 (0.2)	8.2 (5.4)	23 (10.2)	52.3 (14.2)	100.9 (25.0)
S. Salmo	2001	31 (8.7)	87 (12.4)	127 (9.7)	166 (13.7)	209 (20.8)	0.5 (0.4)	8.1 (3.5)	24 (6.5)	51.8 (15.3)	96.0 (14.3)
	2002	29 (7.6)	89 (11.6)	130 (9.9)	164 (13.2)	201 (10.6)	0.3 (0.4)	8.3 (3.2)	23 (6.0)	46 (14.3)	83.0 (13.5)
Sculpin spp.											
Sheep	2001	78 (7.5)	All ages pooled				6.0 (1.4)	All ages pooled			
	2002	66 (15.3)					7.8 (8.0)				
S. Salmo	2001	69 (18.0)					4.6 (3.4)				
	2002	64 (18.3)					4.3 (4.2)				
Dace											
Sheep	2001	98 (10.5)	All ages pooled				11.0 (4.1)	All ages pooled			
	2002	105 (14.0)					16.5 (5.1)				
S. Salmo	2001	104 (17)					12.8 (6.8)				
	2002	96 (18.6)					10.0 (5.9)				

[1] The regression model for sculpin was also used to calibrate the single-pass electrofishing data for longnose dace.

Table 6. Estimated fish densities, biomass, and standing stocks with 95% confidence intervals (± CI%) for Sheep Creek and the South Salmo River in 2001 and 2002.

		Density (fish/100m^2)		Biomass (g/100m^2)		Standing Stock			
						2001		2002	
Species	Age	2001	2002	2001	2002	Estimate	± CI	Estimate	± CI
Sheep Creek									
Bull trout	0+	6.0	5.3	7.8	7.4	6,981	46%	6,222	33%
	1+	2.0	2.6	22.8	28.8	2,359	37%	3,026	32%
	2+	1.0	0.5	26.4	13.3	1,117	42%	610	83%
	3+	0.3	0.2	14.0	11.9	324	85%	243	105%
Rainbow trout	1+	4.3	3.7	28.0	30.5	4,988	36%	4,363	30%
	2+	1.6	1.9	34.1	43.8	1,873	26%	2,214	23%
	3+	1.4	1.2	78.5	62.8	1,691	34%	1,407	33%
	4+	0.7	0.4	67.5	43.9	846	61%	509	69%
Sculpin	All	0.4	0.9	2.2	7.1	437	128%	1,075	105%
Dace	All	1.6	3.6	17.1	58.5	1,815	110%	4,163	63%
Total salmonids		17.2	15.9	278.9	242.4	20,178		18,594	
Total all fish		19.2	20.4	298.2	308.0	22,431		23,832	
South Salmo River									
Bull trout	0+	2.8	2.6	4.4	4.7	4,241	37%	3,914	41%
	1+	1.2	0.6	15.7	7.1	1,866	29%	957	45%
	2+	0.3	0.3	10.2	9.7	525	66%	471	88%
	3+	0.1	0.1	3.9	3.2	142	121%	106	153%
Rainbow trout	1+	4.6	5.9	36.9	48.4	6,839	22%	8,785	23%
	2+	1.4	1.2	32.9	28.9	2,090	34%	1,850	39%
	3+	1.4	1.1	73.5	48.6	2,129	58%	1,585	35%
	4+	0.2	0.3	22.7	20.9	355	80%	378	74%
Sculpin	All	29.8	40.4	137.1	171.9	44,781	26%	60,564	27%
Dace	All	2.6	2.6	33.7	26.5	3,944	84%	3,970	58%
Total salmonids		12.1	12.0	200.2	171.5	18,187		18,045	
Total all fish		44.6	55.0	371.0	369.9	66,912		82,578	

Table 7. Estimates of mean monthly growing season temperatures (°C) in Sheep Creek and the South Salmo River in 2001 and 2002. Estimates are based on regressions of tributary temperatures on temperatures in the Salmo River mainstem in previous years (1998-2000). Missing data reflect incomplete temperature monitoring in the Salmo River during the study period.

	Sheep Creek		South Salmo R.	
Month	2001	2002	2001	2002
April		3.6		3.2
May		4.3		3.9
June		5.6		5.2
July	8.8		8.3	
August	9.3		8.8	
September	8.5		8.0	
October	6.0	4.9	5.6	4.3
November	3.2	2.6	2.8	1.9

Table 8. Estimates of mean monthly discharge (m^3/s) in Sheep Creek and the South Salmo River in 2001 and 2002. Estimates were derived by factoring discharge estimates for the Salmo River mainstem by the percent watershed area of each study tributary.

	Sheep Creek			South Salmo R.		
Month	2001	2002	1950-2002	2001	2002	1950-2002
January	0.4	2.0	0.9	0.6	2.7	1.3
February	0.3	1.4	1.0	0.5	1.9	1.4
March	0.6	1.5	1.7	0.9	2.1	2.3
April	2.1	5.6	5.5	2.9	7.7	7.5
May	9.1	12.8	13.3	12.5	17.5	18.2
June	4.4	13.6	10.8	6.0	18.5	14.7
July	1.3	3.5	3.3	1.7	4.7	4.5
August	0.6	0.8	1.1	0.8	1.1	1.4
September	0.4	0.5	0.8	0.5	0.7	1.2
October	0.5	0.4	1.0	0.6	0.6	1.4
November	1.9	0.6	1.4	2.5	0.8	1.9
December	1.1	0.9	1.2	1.5	1.2	1.6

Table 9. Mean concentrations of dissolved inorganic nitrogen (DIN), soluble reactive phosphorus (SRP) and other water quality parameters for Sheep Creek and the South Salmo River during July-September 2001 (N = 3 for sampling period in each stream).

Stream	Date	*N*	DIN (μg/L)	SRP (μg/L)	Total alk. (mg/L ($CaCO_3$)	Conduc-tivity (μS/cm)	PH	Hard-ness
Sheep	4-Jul	3	8	< 1	23	49	7.7	23
	3-Aug	3	< 5	< 1	31	73	8.0	32
	10-Sep	3	6	5	39	88	7.9	39
S. Salmo	4-Jul	3	< 5	< 1	54	101	8.0	48
	3-Aug	3	< 5	< 1	65	136	8.2	65
	10-Sep	3	< 5	2	80	175	8.0	80

Table 10. Predicted statistical power to detect a response to nutrient addition by bull trout or rainbow trout in a Salmo River tributary stream for three levels of total variance (spatial + temporal variance expressed as %CV) in fish density across sites and years, and for six treatment effect sizes (i.e., % increase in fish density during stream fertilization treatment).

Effect size	Total variation in fish density (CV)		
(% increase)	50%	100%	150%
10%	0.37	0.32	0.27
25%	0.68	0.47	0.42
30%	0.73	0.53	0.46
40%	0.86	0.66	0.56
50%	0.98	0.73	0.61
100%	1.00	0.95	0.87

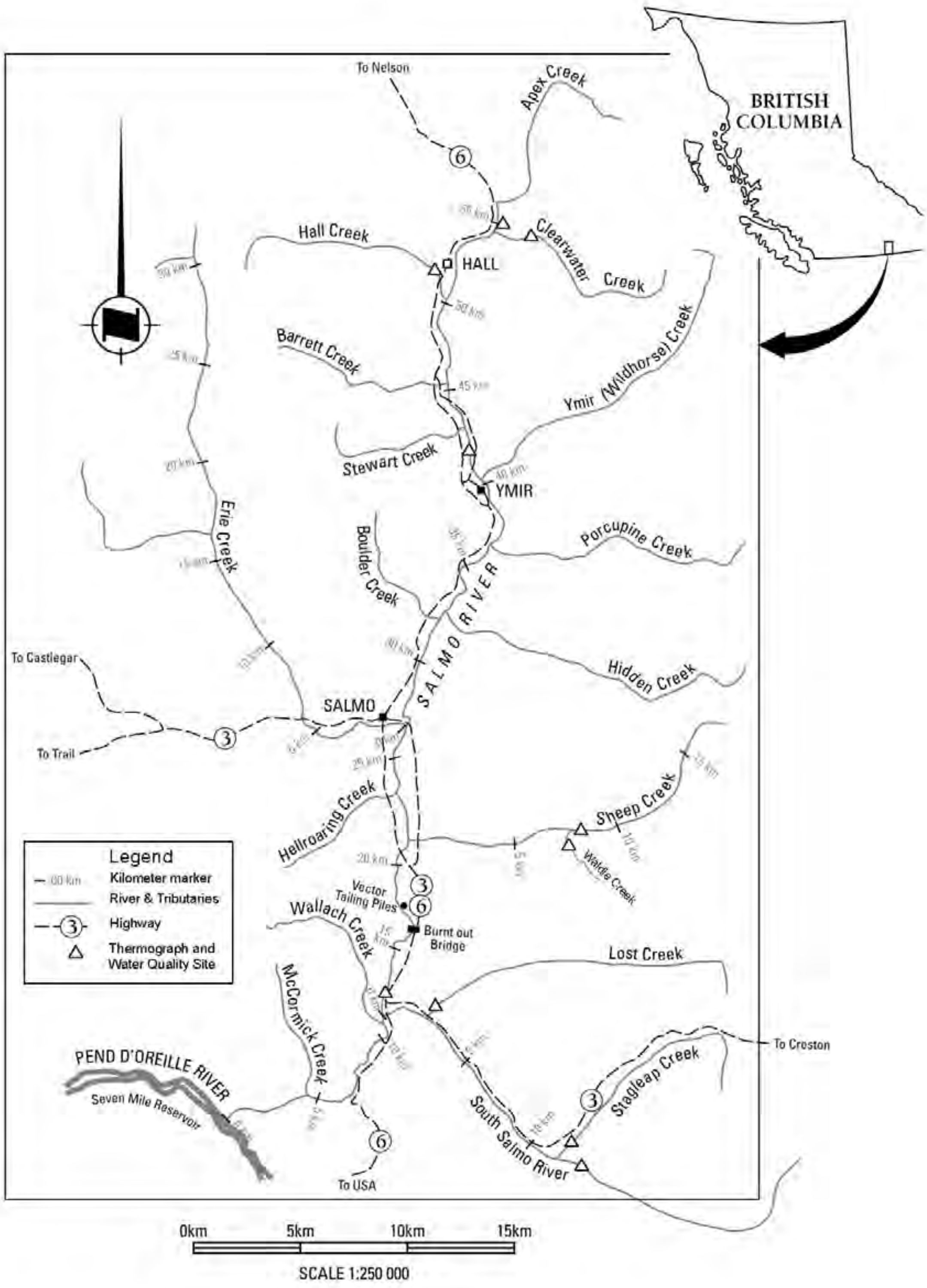
BRITISH COLUMBIA
To Nelson
Apex Creek
Hall Creek
HALL
Clearwater Creek
Barrett Creek
Stewart Creek
Ymir (Wildhorse) Creek
YMIR
Erie Creek
Boulder Creek
Porcupine Creek
SALMO RIVER
Hidden Creek
To Castlegar
SALMO
To Trail
Hellroaring Creek
Sheep Creek
Waldie Creek
Legend
Kilometer marker
River & Tributaries
Highway
Thermograph and Water Quality Site
Vector Tailing Piles
Burnt out Bridge
Wallach Creek
Lost Creek
McCormick Creek
PEND D'OREILLE RIVER
Seven Mile Reservoir
To Creston
Stagleap Creek
South Salmo River
To USA
0km
5km
10km
15km
SCALE 1:250 000

Figure 1. Map of the Salmo River watershed study area.

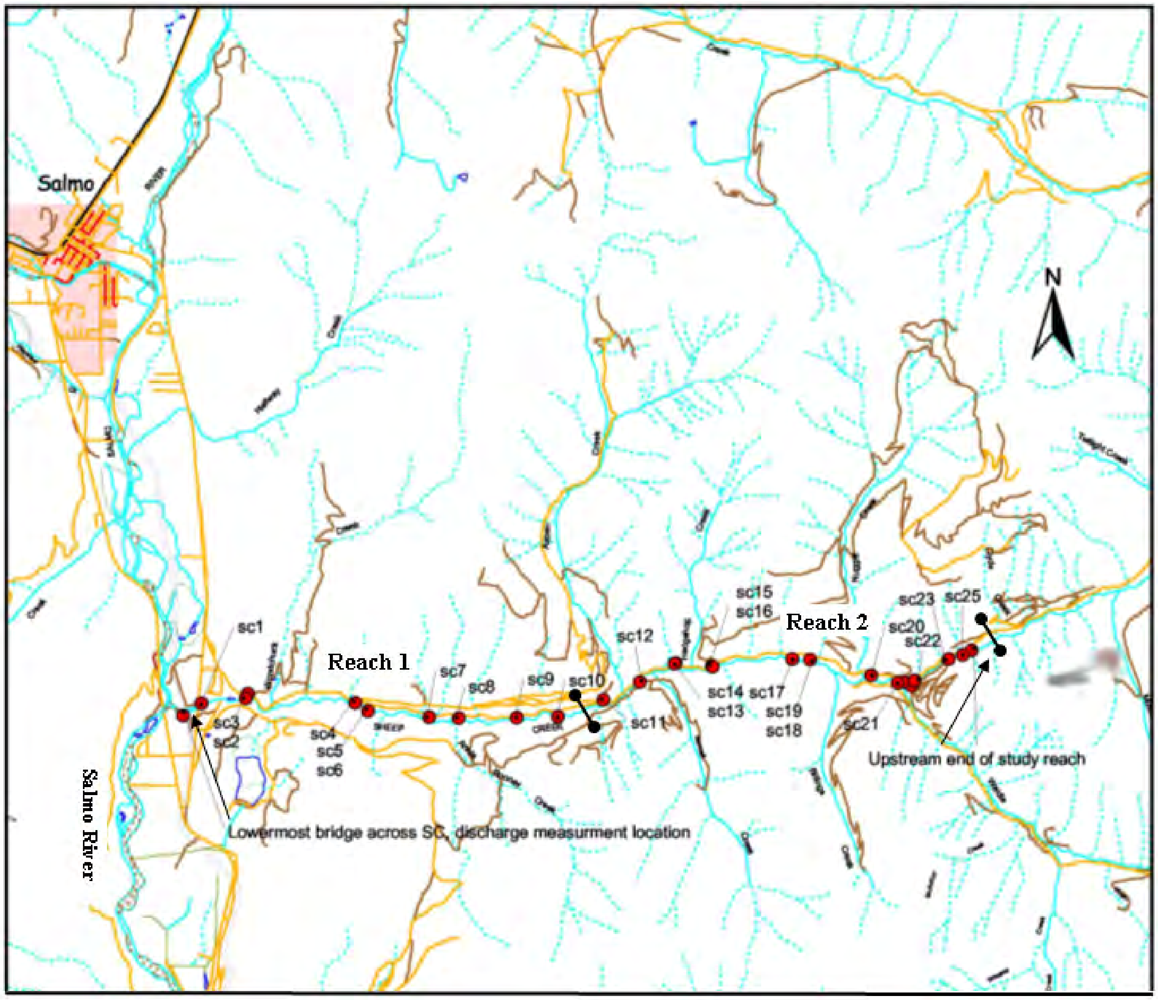

Figure 2. Map of the study area in Sheep Creek showing reach breaks (dumb bells) and fish sampling sites (dotted circles).

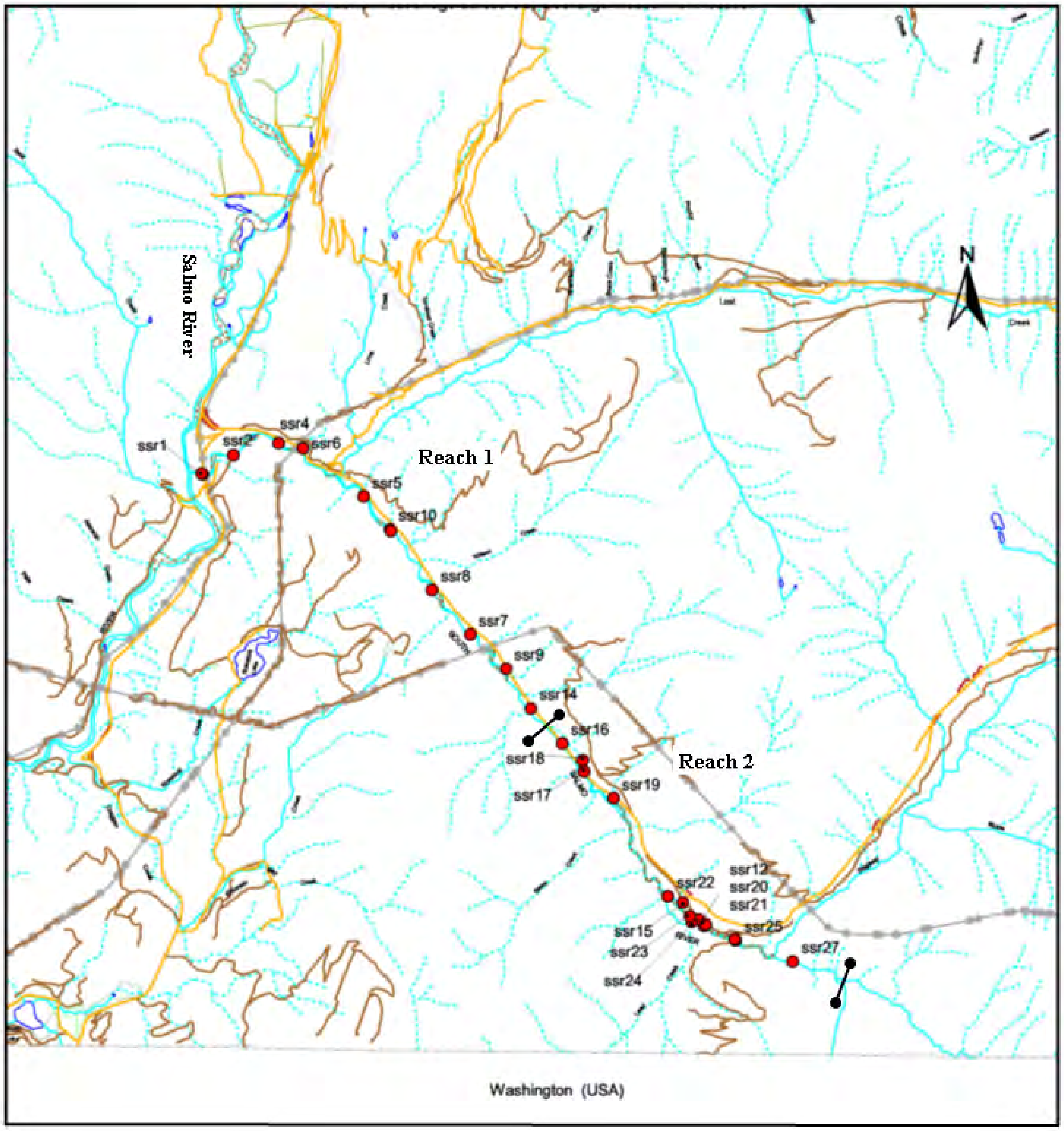

Figure 3. Map of the study area in the South Salmo River showing reach breaks (dumb bells) and fish sampling sites (dotted circles).

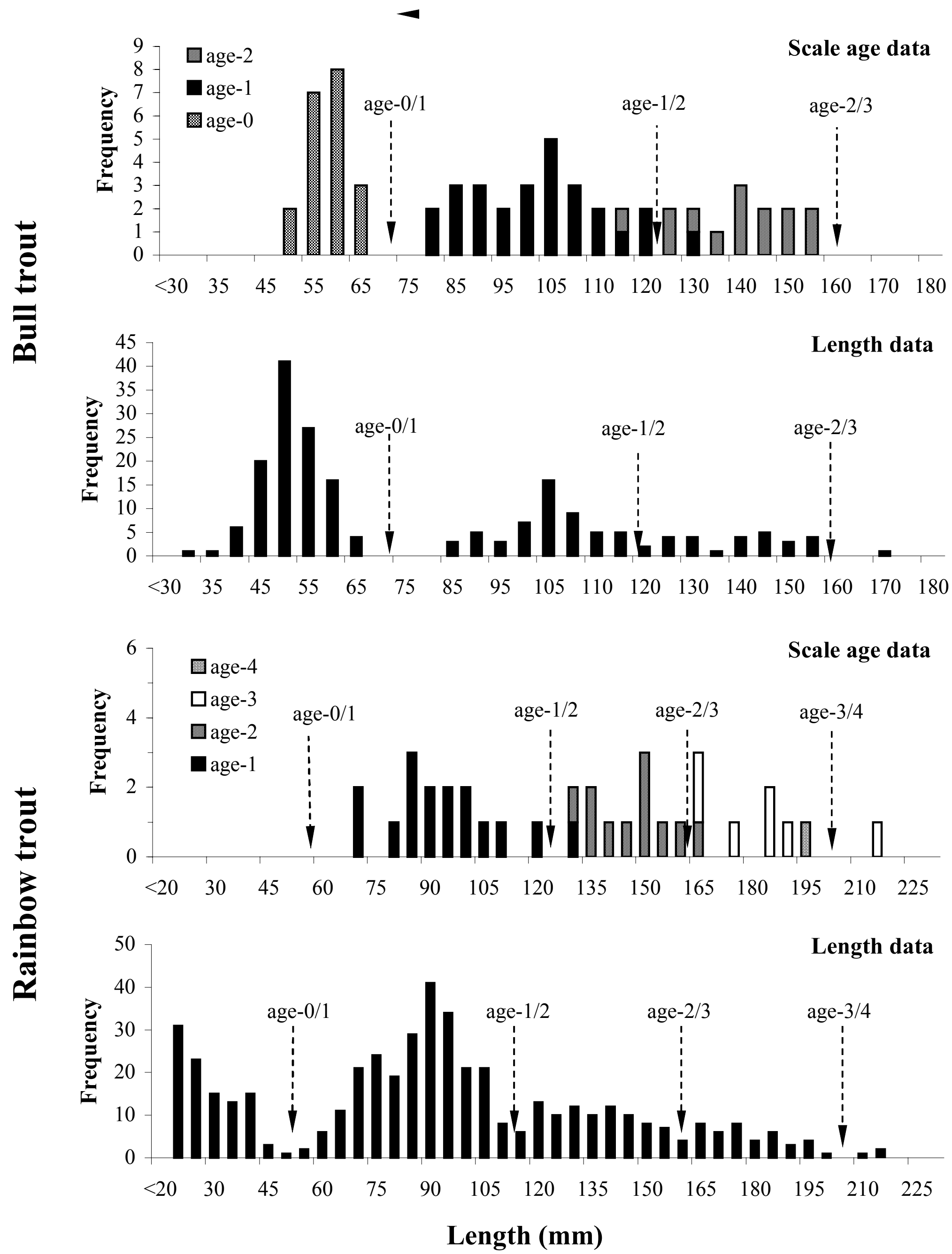

Figure 4. Comparison of estimated length-at-age categories for bull trout and rainbow trout in the South Salmo River in 2001 and 2002 using two methods: scale age data (upper graphs) and histograms of fork length frequencies (lower graphs). The dotted arrows indicate estimated length ‘cut-offs’ for each age class.

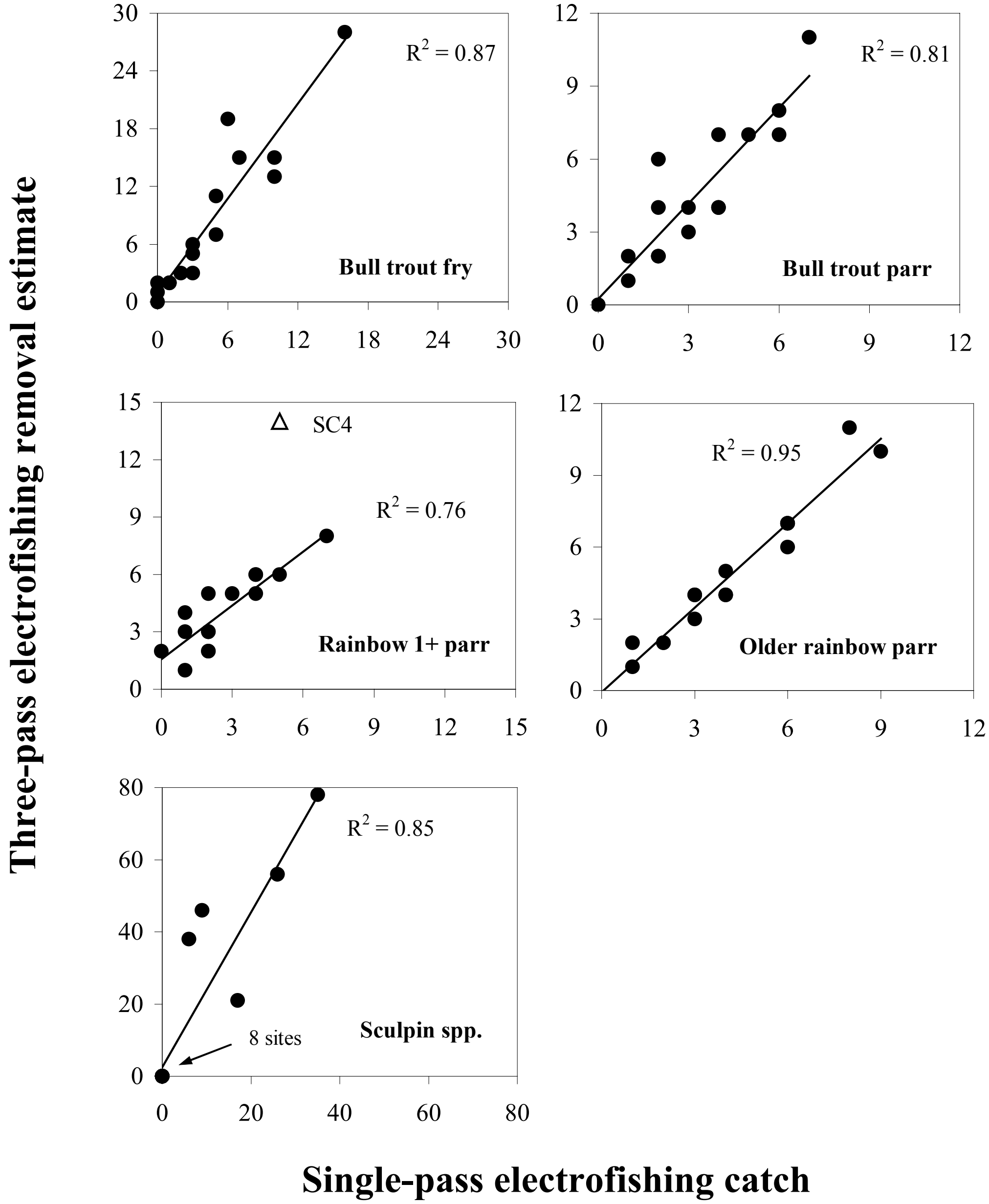

Figure 5. Scatter-plots of three-pass removal estimates on single-pass electrofishing totals at 16 calibration sites in Sheep Creek and the South Salmo River during 2001. Missing data points for some graphs are a result of zero fish being captured during the three passes. The labelled data point appearing as an open triangle in the graph for 1+ rainbow trout parr indicates an outlier.

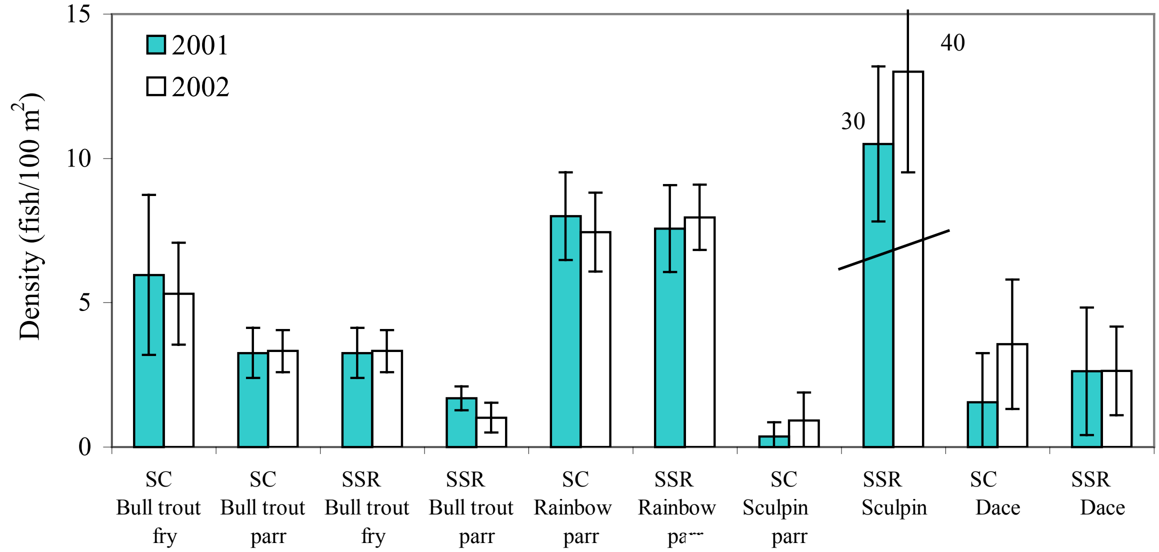

Figure 6. Mean fish densities (fish/100 m^2) for bull trout fry and parr, rainbow trout parr, sculpin and longnose dace in Sheep Creek (SC) and the South Salmo River (SSR) in 2001 and 2002. Error bars represent 95% confidence intervals.

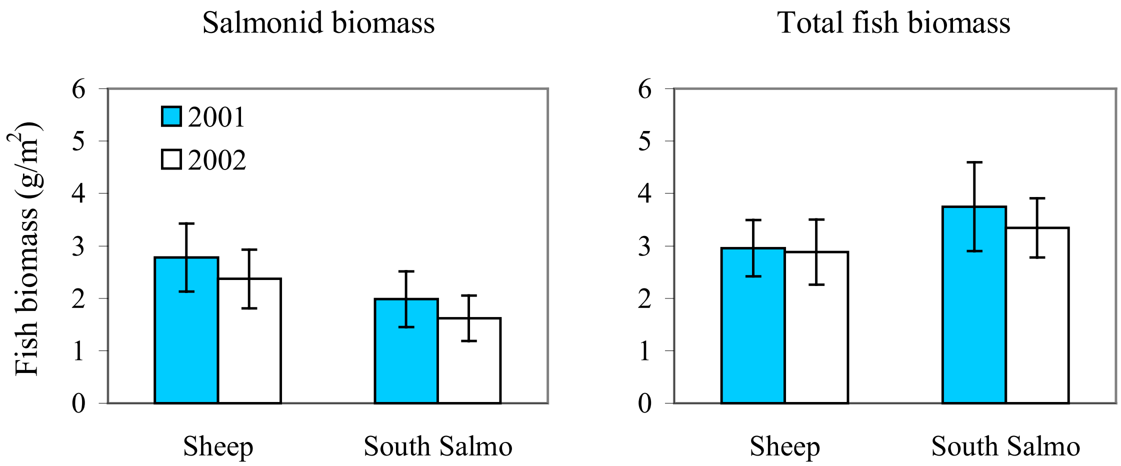

Figure 7. Mean salmonid and fish (all species) biomass (g/m^2) in Sheep Creek and the South Salmo River in 2001 and 2002. Error bars represent 95% confidence intervals.

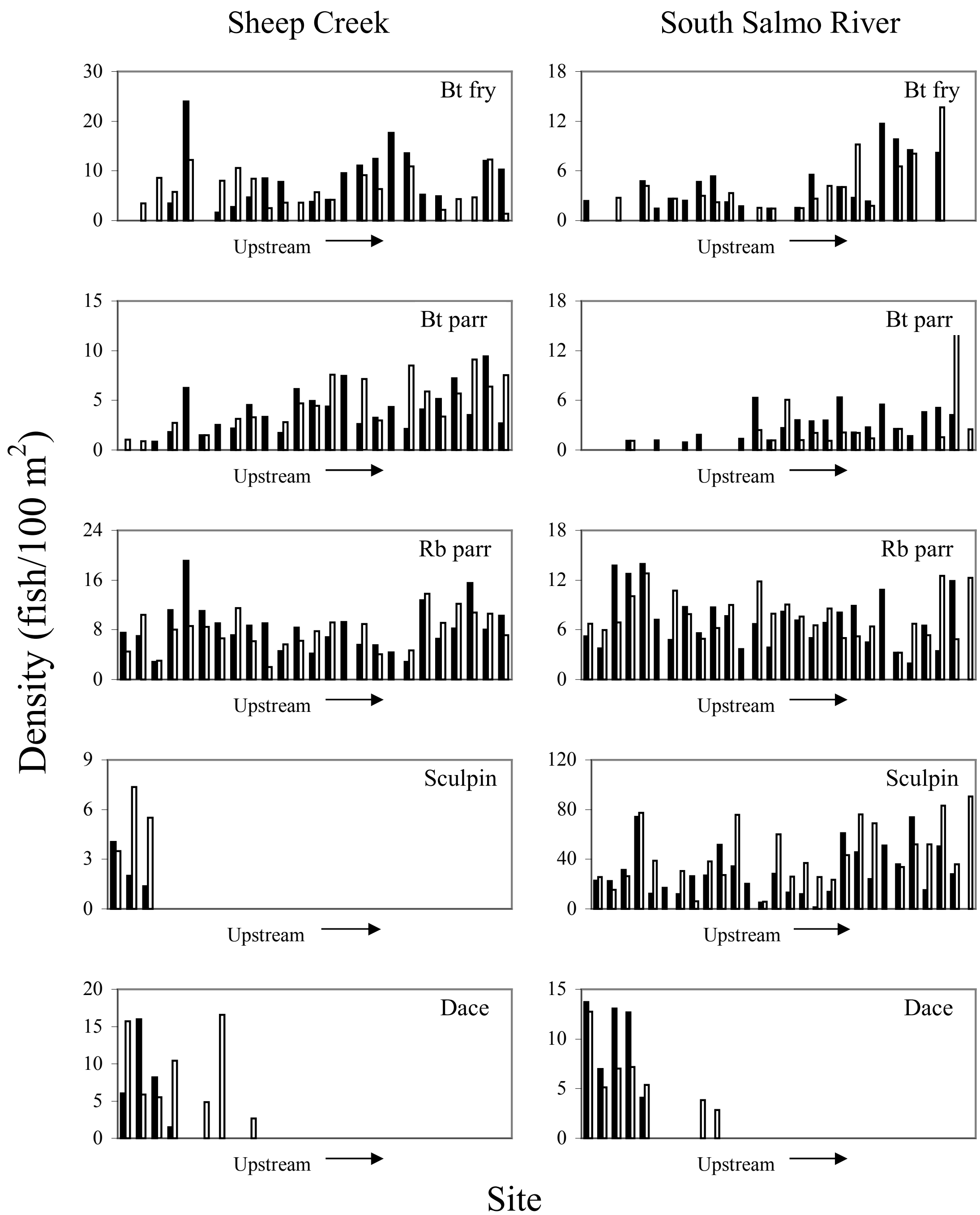

Figure 8. Variation in fish density (fish/100 m^2) among sites in Sheep Creek and the South Salmo River in 2001 (shaded bars) and 2002 (unshaded bars). Bars represent sample sites arranged in a downstream to upstream (left-right) order.

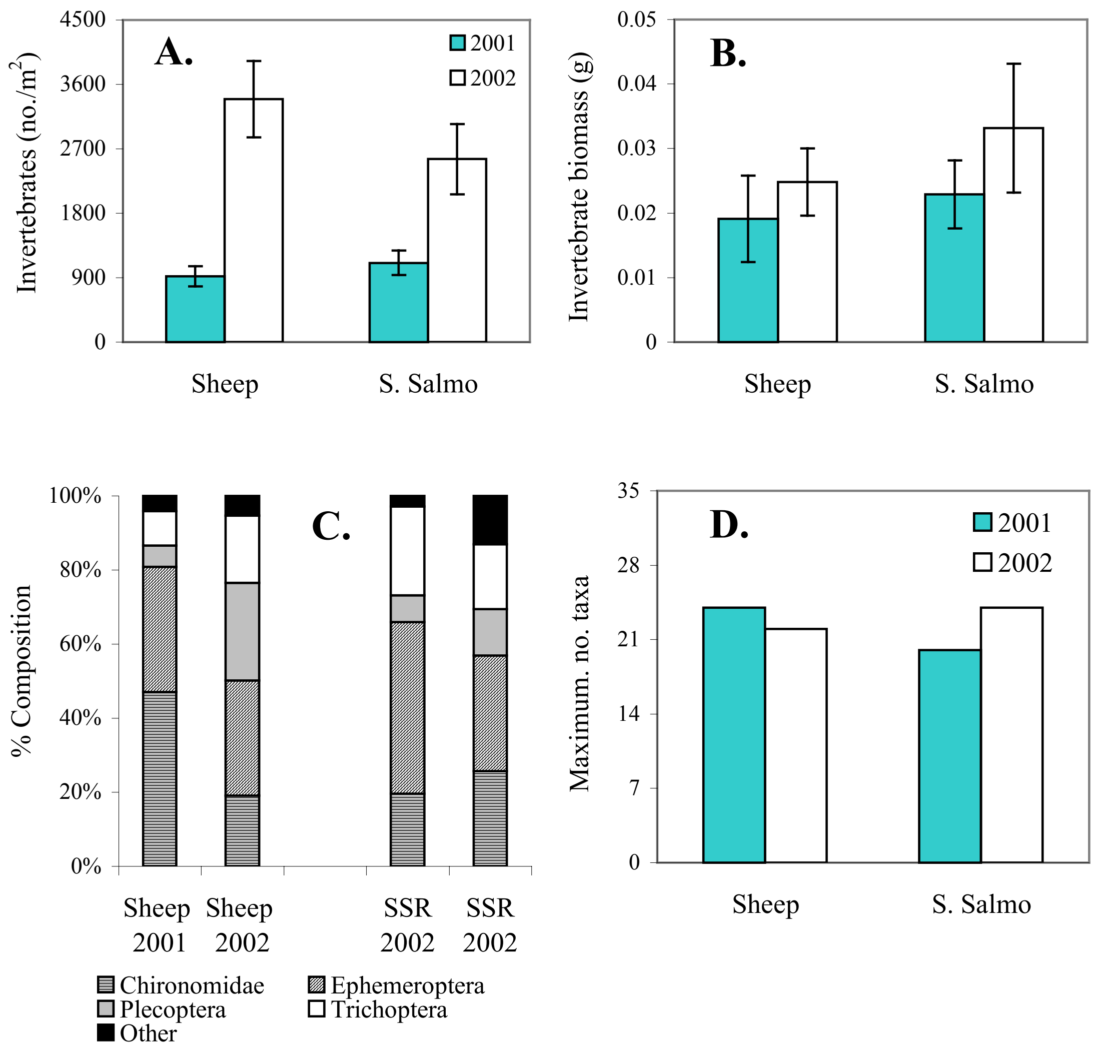

Figure 9. Macroinvertebrate density (graph A) (all taxa pooled; numbers/m^2 of stone surface area), biomass (graph B) (g (dry weight) /m^2), % composition by major group (graph C), and maximum number of taxonomic families observed (graph D) for Sheep Creek and the South Salmo River in 2001 and 2002.

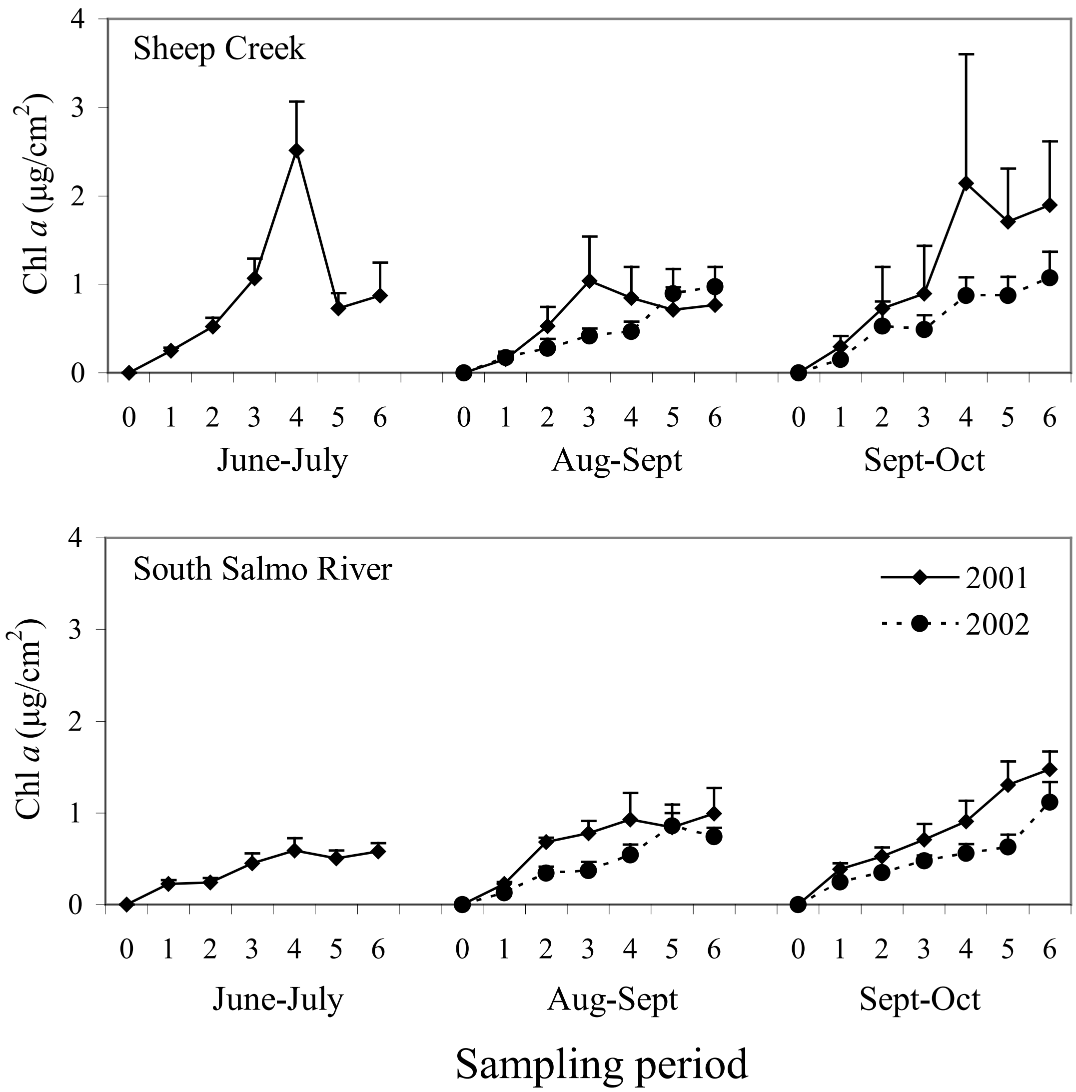

Figure 10. Weekly series of chlorophyll *a* accrual on artificial substrate in Sheep Creek (n=3 for each data point) and the South Salmo River (n=6 for each data point) during three periods in 2001 and two periods in 2002 Error bars represent ± one standard error.

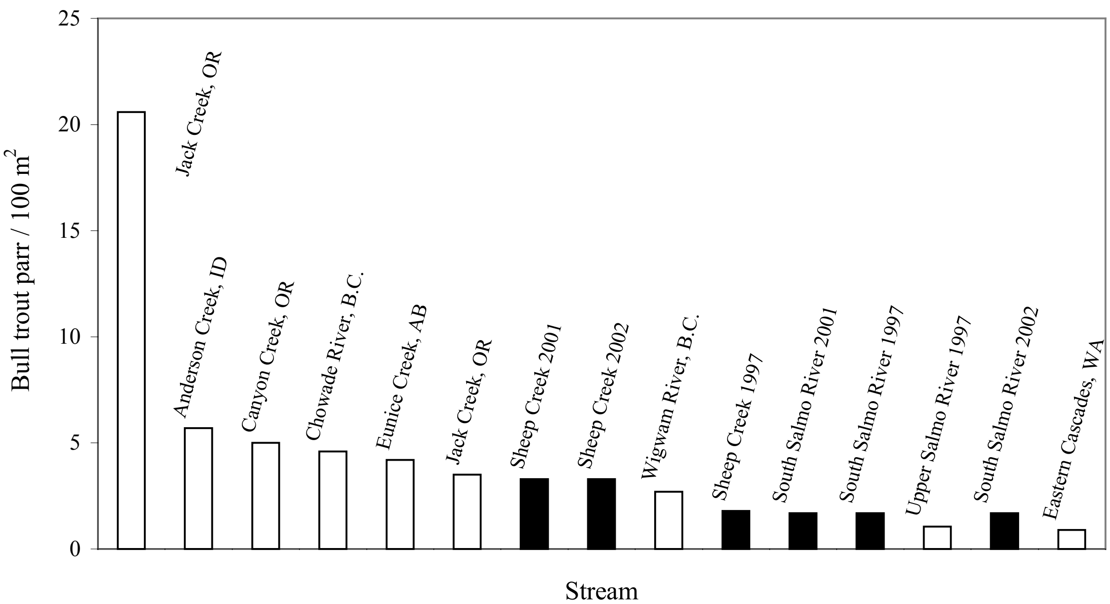

Figure 11. Comparison of bull trout parr densities (all age classes pooled) in Sheep Creek and the South Salmo River (shaded bars) to parr densities reported in studies of bull trout in other Cascade and Rocky Mountain region streams (unshaded bars).

Appendix 1. Summary of computational methods and bootstrap procedures for generating fish population statistics.

1. Electrofishing capture probabilities

$$\text{Cap. Prob.} = T_{total} / (p_{total}N - \sum (p_{total} - p_i)T_i) \qquad (1.1)$$

where

p_i = ith pass number

T_i = number of fish captured on the ith pass

N = ML estimate of abundance

2. Juvenile steelhead standing stock estimates by reach

Separate population estimates were computed for each age class of bull trout and rainbow trout present in the study streams and for all age classes combined for sculpin and longnose dace. To address the problem of sparse or non-normally distributed data for many of the strata, I computed estimates of mean fish density using a non-parametric bootstrap procedure (Efron and Tibshirani 1993; Haddon 2001). For each bootstrap iteration density (Xi) and standing stock (Pi) were computed according to

$$X_i = \sum_{j=1}^{n} X_{ij}(\beta_{ij}) / n_i \qquad (1.2)$$

$$P_i = X_i (L_i) \qquad (1.3)$$

where

X_i = mean unadjusted fish density (fish / linear m of stream) for stratum i

i = reach strata

X_{ij} = mean fish density at a randomly selected sample site j in stratum i

β_{ij} = regression coefficient appropriate for site j in stratum i

n_i = number of sample sites in stratum i

P_i = standing stock for stratum i

L_i = total stream area (m^2) for stratum i

The bootstrap iterations were computed using a Visual Basic macro embedded in a Microsoft Excel spreadsheet. For each age class and reach/habitat type strata, 5000 iterations of equations 1.2 and 1.3 were computed with the bootstrap model choosing sample sites with equal probability and with replacement. Standing stock and the associated upper and lower 95% confidence limits were estimated as the 50%, 97.5% and 2.5% percentiles, respectively, from the cumulative distribution of the 5000 bootstrap iterations (Haddon 2001).

Error in the estimation of mean fish density and standing stock is the result of, among other factors, spatial variation in fish abundance and variation among sites in capture probability during the 1st electrofishing pass. I accounted for additional measurement error associated with uncertainty in estimating the slope coefficient values for the calibration regressions by stochastically simulating the values of β in each iteration of the above bootstrap procedure. To do this, each sample of fish density selected by the bootstrap algorithm for a particular reach strata was calibrated by stochastically modifying β_{ij} in equation 1.2 as follows:

$$\beta_{ij} \times (\text{random normal value} \times \text{SE } \beta_{\text{regression}}) \tag{1.4}$$

where SE β is the standard error of the slope coefficient (β), and random normal values are based on a mean of 0, and a standard deviation of 1.

To compute total standing stocks for each study tributary as a whole, standing stock estimates for the appropriate reach strata were summed during each bootstrap iteration, and the 50%, 97.5% and 2.5% percentiles, respectively, from the cumulative distribution of the summed estimates were used to estimate standing stock and the upper and lower confidence limits, similar to how these values were computed for individual strata. For example,

$$P_{total} = \text{Percentile}_{0.50} \left(\sum_{i=1}^{n} P_i\right) \tag{1.5}$$

where P_{total} is the total standing stock for Sheep Creek.

Appendix 2. Frequencies by fork length category (mm) for age 0+, 1+, 2+, 3+ and 4+ bull trout and rainbow trout in Sheep Creek and the South Salmo River that were sampled for scale age data in 2001 and 2002. Ages were determined by analysis of scale annuli.

Fork	Sheep Creek								South Salmo River					
length	Reach 1				Reach 2				Reach 1			Reach 2		
(mm)	0	1	2	3	0	1	2	3	0	1	2	0	1	2
50-54	2	-	-	-	2	-	-	-	1	-	-	1	-	-
55-59	1	-	-	-	2	-	-	-	6	-	-	1	-	-
60-64	1	-	-	-	-	-	-	-	8	-	-	-	-	-
65-69	-	-	-	-	-	-	-	-	3	-	-	-	-	-
70-74	-	-	-	-	-	-	-	-	-	-	-	-	-	-
75-79	-	-	-	-	-	-	-	-	-	-	-	-	-	-
80-84	-	-	-	-	-	-	-	-	-	-	-	-	2	-
85-89	-	-	-	-	-	1	-	-	-	-	-	-	3	-
90-94	-	2	-	-	-	4	-	-	-	-	-	-	3	-
95-99	-	3	-	-	-	5	-	-	-	-	-	-	2	-
100-104	-	2	-	-	-	2	-	-	-	1	-	-	2	-
105-109	-	2	-	-	-	6	-	-	-	1	-	-	4	-
110-114	-	1	-	-	-	1	-	-	-	-	-	-	3	-
115-119	-	3	-	-	-	1	-	-	-	-	-	-	2	-
120-124	-	2	-	-	-	1	-	-	-	1	-	-	-	1
125-129	-	-	-	-	-	1	2	-	-	-	-	-	2	-
130-134	-	-	1	-	-		2	-	-	-	-	-	-	2
135-139	-	-	-	-	-	1	3	-	-	-	1	-	1	-
140-144	-	-	3	-	-	1	4	-	-	-	-	-	-	1
145-149	-	-	2	-	-	-	2	-	-	-	1	-	-	2
150-154	-	-	-	-	-	-	1	-	-	-	-	-	-	2
155-159	-	-	-	-	-	-	-	1	-	-	-	-	-	2
160-164	-	-	-	1	-	-	1	-	-	-	-	-	-	2
165-169	-	-	-	-	-	-	-	-	-	-	-	-	-	-
170-174	-	-	-	-	-	-	-	1	-	-	-	-	-	-
175-179	-	-	-	-	-	-	-	1	-	-	-	-	-	-
180-184	-	-	-	1	-	-	-	2	-	-	-	-	-	-
185-189	-	-	-	-	-	-	-	1	-	-	-	-	-	-

Appendix 3a. Data summary for all sample sites in Sheep Creek in 2001. Fish density estimates are based on single-pass electrofishing catches that were calibrated with three-pass maximum likelihood removal estimates at a portion of the sites.

						Fish/100 m^2									
Year	Stream	Reach	Site	Habitat type	Site area (m^2)	Bt age 0.0	Bt age 1.0	Bt age 2.0	Bt age 3.0	Rb age 1.0	Rb age 2.0	Rb age 3.0	Rb age 4.0	Sculpin spp.	Longnose dace
2001	Sheep	1	sc01	ri	111	0.0	0.0	0.0	0.0	6.5	1.0	0.0	0.0	4.0	6.1
2001	Sheep	1	sc02	p	113	0.0	0.0	0.0	0.0	3.9	0.0	1.0	2.1	2.0	16.0
2001	Sheep	1	sc03	ri	165	0.0	0.0	0.8	0.0	2.1	0.7	0.0	0.0	1.4	8.2
2001	Sheep	1	sc04	ri	150	3.5	0.9	0.9	0.0	4.2	3.9	2.3	0.8	0.0	1.5
2001	Sheep	1	sc05	ri	44	24.0	6.3	0.0	0.0	16.5	2.7	0.0	0.0	0.0	0.0
2001	Sheep	1	sc06	ri	92	0.0	0.0	1.5	0.0	4.7	2.5	2.5	1.3	0.0	0.0
2001	Sheep	1	sc07	ri	108	1.6	2.5	0.0	0.0	5.8	1.1	1.1	1.1	0.0	0.0
2001	Sheep	1	sc08	ri	127	2.8	2.2	0.0	0.0	3.5	1.8	1.8	0.0	0.0	0.0
2001	Sheep	1	sc09	ri	150	4.6	3.6	0.9	0.0	4.8	1.6	2.3	0.0	0.0	0.0
2001	Sheep	1	sc10	ru	123	8.5	2.2	1.1	0.0	4.3	3.8	0.9	0.0	0.0	0.0
2001	Sheep	2	sc11	ri	157	7.8	1.7	0.0	0.0	1.6	2.2	0.7	0.0	0.0	0.0
2001	Sheep	2	sc12	ri	133	0.0	5.1	0.0	1.0	4.0	1.7	1.7	0.9	0.0	0.0
2001	Sheep	2	sc13	c	138	3.8	3.0	2.0	0.0	2.5	0.8	0.0	0.8	0.0	0.0
2001	Sheep	2	sc14	p	125	4.2	1.1	3.3	0.0	1.3	1.9	1.9	1.9	0.0	0.0
2001	Sheep	2	sc15	ri	128	9.6	3.2	3.2	1.1	2.0	0.9	0.9	5.5	0.0	0.0
2001	Sheep	2	sc16	ri	158	11.1	0.9	0.9	0.9	3.4	0.7	0.7	0.7	0.0	0.0
2001	Sheep	2	sc17	ri	126	12.4	2.2	1.1	0.0	2.7	1.8	0.0	0.9	0.0	0.0
2001	Sheep	2	sc18	ri	158	17.7	2.6	1.7	0.0	2.2	0.7	1.5	0.0	0.0	0.0
2001	Sheep	2	sc19	ri	129	13.6	1.1	1.1	0.0	1.9	0.0	0.9	0.0	0.0	0.0
2001	Sheep	2	sc20	c	133	5.2	1.0	3.1	0.0	7.5	1.7	3.5	0.0	0.0	0.0
2001	Sheep	2	sc21	c	106	4.9	2.6	0.0	2.6	3.2	2.2	1.1	0.0	0.0	0.0
2001	Sheep	2	sc22	c	76	0.0	1.8	1.8	3.6	2.1	0.0	4.6	1.5	0.0	0.0
2001	Sheep	2	sc23	c	78	0.0	3.5	0.0	0.0	8.0	1.5	4.5	1.5	0.0	0.0
2001	Sheep	2	sc24	ru	87	12.1	4.7	3.1	1.6	4.0	1.3	2.7	0.0	0.0	0.0
2001	Sheep	2	sc25	c	102	10.3	2.7	0.0	0.0	3.4	1.1	3.4	2.3	0.0	0.0

Appendix 3b. Data summary for all sample sites in the South Salmo River in 2001.

						Fish/100 m^2									
Year	Stream	Reach	Site	Hab. type	Site area (m^2)	Bt age 0.0	Bt age 1.0	Bt age 2.0	Bt age 3.0	Rb age 1.0	Rb age 2.0	Rb age 3.0	Rb age 4.0	Sc spp.	Long nose dace
2001	S.Salmo	1	ssr01	ri	148	2.4	0.0	0.0	0.0	3.6	0.8	0.8	0.0	22.8	13.7
2001	S.Salmo	1	ssr02	ri	161	0.0	0.0	0.0	0.0	1.6	1.5	0.7	0.0	22.4	7.0
2001	S.Salmo	1	ssr03	c	86	0.0	0.0	0.0	0.0	8.4	0.0	5.4	0.0	31.4	13.1
2001	S.Salmo	1	ssr04	ri	124	0.0	0.0	1.1	0.0	8.1	1.9	2.8	0.0	74.2	12.7
2001	S.Salmo	1	ssr05	ri	110	4.8	0.0	0.0	0.0	6.5	3.2	3.2	1.1	12.2	4.1
2001	S.Salmo	1	ssr06	ri	119	1.5	1.1	0.0	0.0	5.3	2.0	0.0	0.0	17.0	0.0
2001	S.Salmo	1	ssr08	ri	149	4.7	1.8	0.0	0.0	4.8	0.8	0.0	0.0	27.1	0.0
2001	S.Salmo	1	ssr09	ru	131	2.7	0.0	0.0	0.0	4.8	0.0	0.0	0.0	12.0	0.0
2001	S.Salmo	1	ssr10	c	146	2.4	0.0	0.9	0.0	5.6	3.2	0.0	0.0	26.2	0.0
2001	S.Salmo	1	ssr11	ri	130	5.4	0.0	0.0	0.0	3.4	3.6	1.8	0.0	51.7	0.0
2001	S.Salmo	1	ssr12	ri	158	2.2	0.0	0.0	0.0	4.0	1.5	1.5	0.7	34.2	0.0
2001	S.Salmo	2	ssr13	ru	87	0.0	3.2	1.6	1.6	4.0	1.3	0.0	1.3	5.2	0.0
2001	S.Salmo	2	ssr14	ri	102	0.0	2.7	0.0	0.0	7.0	1.1	0.0	0.0	13.2	0.0
2001	S.Salmo	2	ssr15	ri	157	5.6	2.6	0.0	0.9	2.8	2.2	0.0	0.0	1.4	0.0
2001	S.Salmo	2	ssr16	ri	114	1.5	1.2	2.4	0.0	3.0	0.0	4.1	0.0	11.9	0.0
2001	S.Salmo	2	ssr17	ri	115	0.0	3.6	0.0	0.0	3.8	1.0	2.0	0.0	13.7	0.0
2001	S.Salmo	2	ssr18	ri	150	2.3	1.8	0.9	0.0	2.9	0.8	0.8	0.0	23.9	0.0
2001	S.Salmo	2	ssr19	ri	119	1.5	1.1	0.0	0.0	2.9	0.0	1.0	0.0	28.3	0.0
2001	S.Salmo	2	ssr20	ru	106	9.8	2.6	0.0	0.0	3.2	0.0	0.0	0.0	35.9	0.0
2001	S.Salmo	2	ssr21	ri	82	8.5	1.7	0.0	0.0	1.9	0.0	0.0	0.0	73.9	0.0
2001	S.Salmo	2	ssr22	ri	128	2.7	2.1	0.0	0.0	3.4	0.9	3.6	0.9	45.7	0.0
2001	S.Salmo	2	ssr23	ri	129	4.1	5.3	1.1	0.0	2.7	2.7	0.9	1.8	61.0	0.0
2001	S.Salmo	2	ssr24	ri	89	0.0	3.1	1.5	0.0	3.9	1.3	1.3	0.0	15.1	0.0
2001	S.Salmo	2	ssr25	c	107	8.2	3.8	1.3	0.0	2.3	1.1	0.0	0.0	50.5	0.0
2001	S.Salmo	2	ssr27	c	64	0.0	4.3	0.0	0.0	8.3	0.0	1.8	1.8	28.0	0.0
2001	S.Salmo	2	ssr28	c	100	1.7	1.4	0.0	0.0	2.5	1.2	0.0	0.0	20.2	0.0
2001	S.Salmo	2	ssr29	ri	75	11.7	1.8	1.8	1.8	4.6	1.6	4.7	0.0	51.1	0.0

Appendix 3c. Data summary for all sites in Sheep Creek in 2002.

						Fish/100 m^2									
					Site	Bt	Bt	Bt	Bt	Rb	Rb	Rb	Rb	Scul	Long
				Hab.	area	age	age	age	age	age	age	age	age	pin	nose
Year	Stream	Reach	Site	type	(m^2)	0.0	1.0	2.0	3.0	1.0	2.0	3.0	4.0	spp.	dace
2002	Sheep	1	sc01	ri	129	0.0	0.0	0.0	1.1	2.7	0.9	0.9	0.0	3.5	15.7
2002	Sheep	1	sc02	p	153	3.4	0.9	0.0	0.0	6.5	1.5	0.8	1.5	7.4	5.9
2002	Sheep	1	sc03	ri	122	8.6	0.0	0.0	0.0	2.1	1.0	0.0	0.0	5.5	5.5
2002	Sheep	1	sc04	ri	151	5.8	1.8	0.0	0.9	4.1	2.3	1.5	0.0	0.0	10.4
2002	Sheep	1	sc05	ri	86	12.2	0.0	0.0	0.0	7.3	1.4	0.0	0.0	0.0	0.0
2002	Sheep	1	sc06	ri	93	0.0	1.5	0.0	0.0	4.7	2.5	1.3	0.0	0.0	4.9
2002	Sheep	1	sc07	ri	109	8.0	0.0	0.0	0.0	2.3	3.2	1.1	0.0	0.0	16.6
2002	Sheep	1	sc08	ri	131	10.6	3.1	0.0	0.0	6.2	3.5	1.8	0.0	0.0	0.0
2002	Sheep	1	sc09	ri	166	8.4	3.3	0.0	0.0	2.6	2.8	0.7	0.0	0.0	2.7
2002	Sheep	1	sc10	ru	139	2.5	0.0	0.0	0.0	1.1	0.8	0.0	0.0	0.0	0.0
2002	Sheep	2	sc11	ri	194	3.6	2.1	0.7	0.0	3.2	1.2	1.2	0.0	0.0	0.0
2002	Sheep	2	sc12	ri	145	3.6	3.8	0.0	0.9	3.0	2.4	0.8	0.0	0.0	0.0
2002	Sheep	2	sc13	c	123	5.7	4.4	0.0	0.0	5.9	0.9	0.9	0.0	0.0	0.0
2002	Sheep	2	sc14	p	126	4.1	5.4	2.2	0.0	2.7	0.9	2.8	2.8	0.0	0.0
2002	Sheep	2	sc16	ri	115	9.1	5.9	0.0	1.2	3.8	2.0	1.0	2.0	0.0	0.0
2002	Sheep	2	sc17	ri	137	6.4	3.0	0.0	0.0	3.2	0.8	0.0	0.0	0.0	0.0
2002	Sheep	2	sc19	ri	128	10.9	8.5	0.0	0.0	2.0	1.8	0.9	0.0	0.0	0.0
2002	Sheep	2	sc20	c	116	0.0	4.7	1.2	0.0	7.8	4.0	1.0	1.0	0.0	0.0
2002	Sheep	2	sc21	ri	81	2.2	0.0	3.4	0.0	1.9	2.9	2.9	1.4	0.0	0.0
2002	Sheep	2	sc22	c	120	4.4	0.0	5.7	0.0	4.4	1.9	4.9	1.0	0.0	0.0
2002	Sheep	2	sc23	c	75	4.7	9.1	0.0	0.0	4.6	3.1	1.6	1.6	0.0	0.0
2002	Sheep	2	sc24	ru	85	12.3	6.4	0.0	0.0	5.1	2.7	2.7	0.0	0.0	0.0
2002	Sheep	2	sc25	c	127	1.4	5.4	2.2	0.0	3.5	0.9	1.8	0.9	0.0	0.0

Appendix 3d. Data summary for all sites in the South Salmo River in 2002.

						Fish/100 m^2									
					Site	Bt	Bt	Bt	Bt	Rb	Rb	Rb	Rb	Scul	Long
				Hab.	area	age	age	age	age	age	age	age	age	pin	nose
Year	Stream	Reach	Site	type	(m^2)	0.0	1.0	2.0	3.0	1.0	2.0	3.0	4.0	spp.	dace
2002	S.Salmo	1	ssr01	ri	141	0.0	0.0	0.0	0.0	5.1	0.8	0.8	0.0	25.5	12.8
2002	S.Salmo	1	ssr02	ri	132	0.0	0.0	0.0	0.0	3.3	0.0	1.8	0.9	15.4	5.1
2002	S.Salmo	1	ssr03	ri	128	2.7	0.0	0.0	0.0	4.1	1.8	0.9	0.0	26.3	7.0
2002	S.Salmo	1	ssr04	ri	125	0.0	1.1	0.0	0.0	7.2	1.9	0.0	0.9	77.3	7.2
2002	S.Salmo	1	ssr05	ri	168	4.2	0.0	0.0	0.0	9.3	2.8	0.7	0.0	38.9	5.4
2002	S.Salmo	1	ssr08	ri	117	3.0	0.0	0.0	0.0	2.9	0.0	2.0	0.0	38.3	3.8
2002	S.Salmo	1	ssr09	ri	132	2.6	0.0	0.0	0.0	9.0	0.0	1.8	0.0	30.6	0.0
2002	S.Salmo	1	ssr10	c	108	0.0	0.0	0.0	0.0	5.8	1.1	0.0	1.1	6.2	0.0
2002	S.Salmo	1	ssr11	c	157	2.2	0.0	0.0	0.0	4.0	1.5	0.7	0.0	27.1	2.9
2002	S.Salmo	1	ssr12	ri	157	3.3	0.0	0.0	0.0	4.6	2.2	1.5	0.7	75.7	0.0
2002	S.Salmo	2	ssr13	ru	114	1.5	2.4	0.0	0.0	4.7	5.1	2.0	0.0	5.9	0.0
2002	S.Salmo	2	ssr14	c	113	0.0	3.6	2.4	0.0	3.9	2.1	3.1	0.0	25.9	0.0
2002	S.Salmo	2	ssr15	ri	131	2.7	2.1	0.0	0.0	4.8	0.0	1.8	0.0	25.6	0.0
2002	S.Salmo	2	ssr16	ri	116	1.5	1.2	0.0	0.0	4.6	1.0	2.0	0.0	36.9	0.0
2002	S.Salmo	2	ssr17	ri	125	4.2	0.0	1.1	0.0	5.8	1.9	0.9	0.0	23.4	0.0
2002	S.Salmo	2	ssr18	ri	98	1.8	0.0	0.0	1.4	6.4	0.0	0.0	0.0	68.9	0.0
2002	S.Salmo	2	ssr19	ri	120	1.5	0.0	1.1	0.0	6.0	1.9	0.0	0.0	59.9	0.0
2002	S.Salmo	2	ssr20	ru	107	6.5	2.6	0.0	0.0	3.2	0.0	0.0	0.0	33.7	0.0
2002	S.Salmo	2	ssr21	ri	65	8.1	0.0	0.0	0.0	6.7	0.0	0.0	0.0	51.9	0.0
2002	S.Salmo	2	ssr22	ri	133	9.2	1.0	1.0	0.0	2.6	0.9	0.9	0.9	76.1	0.0
2002	S.Salmo	2	ssr23	ri	130	4.0	1.1	1.1	0.0	4.1	0.9	0.0	0.0	43.3	0.0
2002	S.Salmo	2	ssr24	ri	87	0.0	0.0	0.0	0.0	4.0	1.3	0.0	0.0	52.0	0.0
2002	S.Salmo	2	ssr25	c	89	13.7	1.5	0.0	0.0	11.2	1.3	0.0	0.0	83.1	0.0
2002	S.Salmo	2	ssr26	ri	55	0.0	2.5	0.0	0.0	8.0	0.0	4.3	0.0	90.5	0.0
2002	S.Salmo	2	ssr27	c	56	0.0	4.8	7.3	2.4	2.8	0.0	2.1	0.0	35.9	0.0

Appendix 4. B.C. Water Quality Criteria for trace metals.

Parameter	Drinking Water and Recreation[1]	Freshwater Aquatic Life
Aluminum, Dissolved-Al	0.2 mg/L (maximum)	0.05 mg/L (30-day average), 0.1 mg/L (maximum) where pH ≥ 6.5
Antimony, Total-Sb	6 μg/L (proposed interim maximum)	0.005 mg/L (maximum)
Arsenic, Total-As	25 μg/L (maximum)	1 mg/L (30-day average), 5 mg/L (maximum)
Barium, Total-Ba	1 mg/L (maximum)	5.3 μg/L (maximum)
Boron, Total-B	5 mg/L (maximum)	
Cadmium, Total-Cd	5 μg/L (maximum)	
Chromium, Total-Cr	50 mg/L (maximum)	
Conductivity (specific0	700 μS/cm (maximum)	
Copper, Total-Cu	≤1 mg/L (aesthetics)	3.85 mg/L (30-day average),
		9.22 mg/L (maximum)
Lead, Total-Pb	10 μg/L (maximum)	6.34 mg/L (30-day average),
		77.64 mg/L (maximum)
Magnesium, Total-Mg	100 mg/L taste threshold for sensitive people	
Manganese, Total-Mn	≤50 mg/L (aesthetics)	1.60 mg/L (maximum)
Molybdenum, Total-Mo		≤1mg/L (30-day average), 2mg/L (maximum)
Selenium, Total-Se	10 μg/L (maximum)	
Silver, Total-Ag		1. 5 μg/L (30-day average), 3.0 μg/L (maximum)
Turbidity	1 NTU (maximum), ≤5 NTU (aesthetic)	
Uranium, Total-U	100 μg/L (maximum)	
Zinc, Total-Zn	≤5 mg/L (aesthetics)	37.6 μg/L (maximum)

[1]Drinking water and recreation criteria are for drinking water unless otherwise stated.

Appendix 5. Minimum detection limits for nutrient and trace metal concentrations in water samples.

MINIMUM DETECTION LIMITS

Sample ID	N/A
Date Sampled	N/A
Time Sampled	
ALS Sample ID	N/A
Nature	Water
Physical Tests	
Conductivity (uS/cm)	2
Hardness CaCO3	0.7
pH	0.01
Dissolved Anions	
Alkalinity-Total CaCO3	1
Nutrients	
Ammonia Nitrogen	0.005
Nitrate Nitrogen	0.005
Nitrite Nitrogen	0.001
Dissolved ortho-Phosphate	0.001
Total Metals	
Aluminum T-Al	0.01
Antimony T-Sb	0.01
Arsenic T-As	0.001
Barium T-Ba	0.02
Beryllium T-Be	0.005
Boron T-B	0.1
Cadmium T-Cd	0.0002
Calcium T-Ca	0.1
Chromium T-Cr	0.01
Cobalt T-Co	0.01
Copper T-Cu	0.001
Iron T-Fe	0.03
Lead T-Pb	0.001
Lithium T-Li	0.05
Magnesium T-Mg	0.1
Manganese T-Mn	0.01
Mercury T-Hg	0.0002
Molybdenum T-Mo	0.001
Nickel T-Ni	0.05
Selenium T-Se	0.001
Silver T-Ag	0.0001
Sodium T-Na	2
Thallium T-Tl	0.0002
Uranium T-U	0.0002
Vanadium T-V	0.03
Zinc T-Zn	0.05

Appendix 6. Summary of all water quality data collected in Sheep Creek (SC) and the South Salmo River (SSR) in 2001. Results are expressed as mg/L except where noted. Concentrations below detectable limits are indicated by a "<" symbol.

Stream **Site**	**SSR** **Upper**	**SSR** **Middle**	**SSR** **Lower**	**SSR** **Upper**	**SSR** **Middle**	**SSR** **Lower**	**SSR** **Upper**	**SSR** **Middle**	**SSR** **Lower**
Date Sampled	3-Aug	3-Aug	3-Aug	10-Sep	10-Sep	10-Sep	4-Jul	4-Jul	4-Jul
Physical Tests									
Conductivity (µS/cm)	105	145	157	136	187	201	82	107	114
Hardness $CaCO_3$	47.4	71.4	77	61.3	85.7	92.4	37.7	51.6	55.1
pH	8.05	8.24	8.24	7.81	8.03	8.21	7.91	8.09	8.13
Dissolved Anions									
Alkalinity $CaCO_3$	48	72	76	56	88	96	40	70	53
Nutrients									
Ammonia Nitrogen	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrate Nitrogen	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrite Nitrogen	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001			
Phosphorus SRP	<0.001	0.001	<0.001	0.002	0.002	0.002	<0.001	<0.001	<0.001
Total Metals									
Aluminum T-Al	0.011	0.01	0.013	<0.01	<0.01	<0.01	0.024	0.018	0.02
Antimony T-Sb	<0.2	<0.2	<0.2	<0.01	<0.01	<0.01	<0.2	<0.2	<0.2
Arsenic T-As	<0.2	<0.2	<0.2	<0.001	<0.001	<0.001	<0.2	<0.2	<0.2
Barium T-Ba	0.01	0.02	0.02	<0.02	<0.02	0.02	0.01	0.01	0.01
Beryllium T-Be	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Boron T-B	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium T-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium T-Ca	14.4	21	23.9	18.4	25	28.6	11.3	15.2	17.1
Chromium T-Cr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cobalt T-Co	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper T-Cu	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.01	<0.01	<0.01
Iron T-Fe	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Lead T-Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium T-Li				<0.05	<0.05	<0.05			
Magnesium T-Mg	2.8	4.6	4.2	3.7	5.7	5.1	2.3	3.3	3
Manganese T-Mn	<0.005	<0.005	<0.005	<0.01	<0.01	<0.01	<0.005	<0.005	<0.005
Mercury T-Hg	<0.00005	<0.00005	<0.00005	<0.0002	<0.0002	<0.0002	<0.00005	<0.00005	<0.00005
Molybdenum T-Mo	<0.03	<0.03	<0.03	<0.001	<0.001	<0.001	<0.03	<0.03	<0.03
Nickel T-Ni	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Selenium T-Se	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Silver T-Ag	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sodium T-Na	<2	<2	<2	2	<2	<2	<2	<2	<2
Thallium T-Tl	<0.0001	<0.0001	<0.0001	<0.0002	<0.0002	<0.0002	<0.0001	<0.0001	<0.0001
Uranium T-U	0.00024	0.00034	0.00067	0.0004	0.0005	0.0009	0.00012	0.00019	0.00039
Vanadium T-V				<0.03	<0.03	<0.03			
Zinc T-Zn	<0.005	<0.005	<0.005	<0.05	<0.05	<0.05	<0.005	<0.005	<0.005

Appendix 6 continued.

Stream Site	SC Upper	SC Middle	SC Lower	SC Upper	SC Middle	SC Lower	SC Upper	SC Middle	SC Lower
Date Sampled	3-Aug	3-Aug	3-Aug	10-Sep	10-Sep	10-Sep	4-Jul	4-Jul	4-Jul
Physical Tests									
Conductivity (µS/cm)	45	59	115	52	69	144	30	37	81
Hardness $CaCO_3$	18.6	24.3	54.1	21.6	28.7	66.3	12.8	17.3	39.8
pH	7.87	7.93	8.11	7.88	7.82	8.01	7.56	7.66	7.89
Dissolved Anions									
Alkalinity $CaCO_3$	17	22	55	22	28	66	14	18	37
Nutrients									
Ammonia Nitrogen	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Nitrate Nitrogen	<0.005	<0.005	<0.005	0.01	0.005	<0.005	0.015	0.007	<0.005
Nitrite Nitrogen	0.001	<0.001	<0.001	0.001	<0.001	<0.001			
Phosphorus SRP	<0.001	<0.001	0.002	0.002	0.004	0.009	<0.001	<0.001	0.001
Total Metals									
Aluminum T-Al	0.018	0.016	0.023	0.02	0.02	0.01	0.026	0.024	0.018
Antimony T-Sb	<0.2	<0.2	<0.2	<0.01	<0.01	<0.01	<0.2	<0.2	<0.2
Arsenic T-As	<0.2	<0.2	<0.2	<0.001	<0.001	<0.001	<0.2	<0.2	<0.2
Barium T-Ba	0.02	0.02	0.03	<0.02	<0.02	0.03	0.01	0.01	0.02
Beryllium T-Be	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Boron T-B	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Cadmium T-Cd	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002	<0.0002
Calcium T-Ca	6.58	8.27	17.4	7.7	9.8	21.2	4.48	5.92	12.9
Chromium T-Cr	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Cobalt T-Co	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Copper T-Cu	<0.01	<0.01	<0.01	<0.001	<0.001	<0.001	<0.01	<0.01	<0.01
Iron T-Fe	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03	<0.03
Lead T-Pb	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Lithium T-Li				<0.05	<0.05	<0.05			
Magnesium T-Mg	0.5	0.9	2.6	0.6	1	3.2	0.4	0.6	1.9
Manganese T-Mn	<0.005	<0.005	<0.005	<0.01	<0.01	<0.01	<0.005	<0.005	<0.005
Mercury T-Hg	<0.00005	<0.00005	<0.00005	<0.0002	<0.0002	<0.0002	<0.00005	<0.00005	<0.00005
Molybdenum T-Mo	<0.03	<0.03	<0.03	<0.001	<0.001	<0.001	<0.03	<0.03	<0.03
Nickel T-Ni	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Selenium T-Se	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Silver T-Ag	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Sodium T-Na	<2	<2	<2	<2	<2	<2	<2	<2	<2
Thallium T-Tl	<0.0001	<0.0001	<0.0001	<0.0002	<0.0002	<0.0002	<0.0001	<0.0001	<0.0001
Uranium T-U	0.00003	0.00004	0.00048	<0.0002	<0.0002	0.0007	0.00003	0.00003	0.00025
Vanadium T-V				<0.03	<0.03	<0.03			
Zinc T-Zn	<0.005	<0.005	0.006	<0.05	<0.05	<0.05	<0.005	<0.005	0.005