Estimating Standing Stock of Juvenile Coho Salmon (*Oncorhynchus kisutch*) and Cutthroat Trout (*O. clarki*) in a Small Stream: A Comparison of Sampling Designs

A.S. Decker, J.M. Bratty, S.C. Riley, and J. Korman

Fisheries and Oceans Canada
Science Branch, Pacific Region
100 Annacis Parkway, Unit 3
Delta, British Columbia
V3M 6A2

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ESTIMATING STANDING STOCK OF JUVENILE COHO SALMON (*Oncorhynchus kisutch)* AND CUTTHROAT TROUT (*O. clarki)* IN A SMALL STREAM: A COMPARISON OF SAMPLING DESIGNS

by

A.S. Decker[1], J.M. Bratty[1], S.C. Riley[2], and J. Korman[3]

Fisheries and Oceans Canada

Science Branch, Pacific Region

100 Annacis Parkway, Unit 3

Delta, British Columbia

V3M 6A2

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[1] UBC Fisheries Centre, 2204 Main Mall, Vancouver, B.C., V6T 1Z4
[2] 310 5th Avenue East, Prince Rupert, B.C., V8J 1R9
[3] 3320 West 5th Avenue, Vancouver, B.C., V6R 1R7

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ABSTRACT

Decker, A. S., J. M. Bratty, S. C. Riley, and J. Korman. 1999. Estimating standing stock of juvenile coho salmon (*Oncorhynchus kisutch)* and cutthroat trout (O. clarki) in a small stream: a comparison of sampling designs. Can. Tech. Rep. Fish. Aquat. Sci. 2282: 34 p.

We estimated standing stocks of juvenile coho salmon and cutthroat trout in a small stream during the fall, and used observed and simulated standing stock estimates to compare the precision and cost effectiveness of alternate sampling designs. Overall, a whole-stream mark-recapture approach produced the most precise coho standing stock estimate, but results were likely biased and the method would not be cost effective in most typical streams. Among removal methods, a stratified random sampling design (stratified by habitat type and reach) produced the most precise and cost effective estimates of coho standing stock. The most precise estimates of cutthroat standing stock, however, were produced by a proportional sampling design because cutthroat were distributed more evenly among habitat types. Simulations suggest that sampling approximately 7 percent of the habitat units in the stream was sufficient to provide a precise (CV = 0.1) estimate of coho standing stock using a stratified random sampling design. However, this result is specific to the study stream and further research is necessary to determine if it applies to other streams. The use of a calibrated one-pass sampling design (single pass capture totals were calibrated with 3-pass removal estimates) with stratified random sampling was marginally more cost-effective than a stratified random design where three-pass removal population estimation was carried out at all sites. Our results show that calibrated one-pass sampling with block nets can provide a reasonable index of coho abundance. However, one-pass estimates made without block nets may be biased, and installing block nets may make this design relatively less cost-effective. If quantitative population data are required for juvenile coho stock assessment in British Columbia, we recommend a stratified random sampling design in place of the current representative index site program.

Key words: bootstrap, coho salmon, cutthroat trout, sampling designs, spatial distribution, standing stock.

RESUME

Decker, A. S., J. M. Bratty, S. C. Riley, and J. Korman. 1999. Estimating standing stock of juvenile coho salmon (*Oncorhynchus kisutch)* and cutthroat trout (*O.* clarki) in a small stream: a comparison of sampling designs. Can. Tech. Rep. Fish. Aquat. Sci. xxxx: 34 p.

Nous avons estimé les stocks actuels de jeunes saumons cohos et de jeunes truites fardées présents dans un petit cours d'eau à l'automne. Nous avons ensuite utilisé les estimations de stocks issues de l'observation et des simulations pour comparer la précision et le coût des différentes procédures d'échantillonnage. Toutes méthodes confondues, la plus grande précision pour l'estimation du stock actuel de saumons cohos a été obtenue par la technique de marquage-recapture portant sur la totalité des habitats. Les résultats étaient cependant probablement biaisés et la méthode serait trop coûteuse à mettre en œuvre dans la plupart des cours d'eau. Parmi les méthodes mettant en jeu la mise de côté des spécimens capturés, la technique d'échantillonnage aléatoire stratifié (par type et surface d'habitat) s'est révélée la plus précise et la plus économique pour la production d'estimations de stocks actuels de saumons cohos. Pour ce qui est de la truite fardée, les estimations de stock les plus précises ont cependant été obtenues à l'aide d'une technique d'échantillonnage proportionnel, les truites fardées étant en effet distribuées de façon plus uniforme que le saumon coho sur l'ensemble des types d'habitat. Des simulations ont permis de montrer qu'un échantillonnage portant sur approximativement 7 pour cent des unités d'habitat du cours d'eau étudié suffisait à produire une estimation précise (CV = 0,1) du stock réel de saumons cohos en utilisant la technique d'échantillonnage aléatoire stratifié. Ce résultat est cependant spécifique au cours d'eau étudié et des études supplémentaires sont nécessaires pour déterminer s'il en va de même pour d'autres cours d'eau. L'échantillonnage aléatoire stratifié, effectué en une seule passe et calibré à l'aide des estimations obtenues par la technique de l'échantillonnage sans remise à l'eau en trois passes s'est révélé légèrement plus économique que cette dernière technique. Nos résultats montrent que l'échantillonnage calibré en une passe effectué à l'aide de filets-barrages permet d'obtenir un indice raisonnable de l'abondance du saumon. Effectuées sans filet-barrage, les estimations faites à partir d'échantillonnage en une passe peuvent cependant être biaisées et l'installation de ce type de barrage pourrait rendre la technique relativement plus coûteuse. Si des données quantitatives doivent être obtenues pour l'évaluation de stocks de jeunes saumons cohos en Colombie-Britannique, nous recommandons d'utiliser la méthode d'échantillonnage aléatoire stratifié à la place de la méthode actuelle basée sur l'utilisation d'indices représentatifs par site.

Mots clés : bootstrap, saumon coho, truite fardée, technique d'échantillonnage, distribution spatiale, stock actuel.

INTRODUCTION

The Department of Fisheries and Oceans (DFO) currently conducts limited sampling of 150 to 200 British Columbia streams to provide indices of the abundance of coho salmon (*Oncorhynchus kisutch*) populations. In the majority of streams, only juveniles are sampled due to the difficulty and expense of accurately enumerating adults (English *et al.* 1992). A small number of permanent sites (usually one or two) are surveyed annually on each juvenile coho index stream. This design allows a large number of streams to be sampled at relatively little cost. Fall fry densities are estimated from closed-section removal sampling, and are compared among years to examine trends in coho abundance. The monitoring program is based on the assumption that fry density at the sample sites is correlated with adult escapement (Beland 1996; Ward and Slaney 1993). However, the design does not address within-stream spatial variation in juvenile abundance. It has been shown that variation in fish abundance within and among streams may significantly affect the statistical power of tests for population change over time (Korman and Higgins 1997; Underwood 1993). Sampling designs that account for spatial variance in abundance by providing estimates of whole-stream standing stock may be more sensitive to changes in coho abundance. Therefore, the estimation of coho standing stock in juvenile index streams would be a useful management tool, but the level of sampling necessary to produce precise estimates of standing stock is unknown.

Salmonids are likely to be distributed unevenly within streams (Roper *et al.* 1994; Amiro 1990a), and on both a watershed and tributary scale, spatial factors have been shown to account for as much as 65% of total variation in juvenile salmonid abundance (Milner *et al.* 1993). However, variation in fish abundance among habitat types or reaches in a stream (first stage error) is usually much greater than the second stage error associated with estimating fish populations within sample sites (Hankin 1984, 1986; Paller 1995). Stratified sampling designs reduce first stage error and may therefore produce more precise estimates of salmonid standing stock with less effort than other designs (Bohlin *et al.* 1982). However, some fisheries biologists overlook this approach in favour of selecting "representative" stream sections to obtain estimates of average fish density or standing stock. Stratified sampling designs are often perceived as being more costly because they require a detailed habitat survey, and because more sites must be sampled to provide replication.

Resources are often insufficient to allow the use of time-consuming population estimation techniques (e.g. removal, mark-recapture) at a large number of sampling sites. However, sampling effort can be increased without additional cost by substituting a faster method. For example, Hankin and Reeves (1988) recommend a two-stage sampling design where a relatively quick method of population estimation (e.g., snorkeling) is calibrated with a more precise method (e.g., three-pass removal electrofishing) and used at a relatively large number of sampling sites. In this way, greater precision in standing stock estimates can be achieved in a cost-effective manner by increasing the proportion of sites sampled (Hankin 1984, 1986; Paller 1995).

The goal of this study was to contrast the precision and cost-effectiveness of alternate sampling designs using observed and simulated standing stock estimates. The study was limited to investigating within-stream spatial variability and the role of stratification in the design of juvenile standing stock surveys. We did not directly assess temporal or among stream sources of variation. Our first objective was to compare differences in standing stock estimates for juvenile coho salmon and cutthroat trout (*O. clarki*) produced using several different sampling methods (e.g., mark-recapture, removal, calibrated one-pass) and designs (e.g., simple random sampling, stratified random sampling, proportional sampling, and representative sampling). Our second objective was to use the removal data in bootstrap simulations to investigate relative differences in precision and cost-effectiveness of alternate sampling designs across a range of sampling intensities. Sampling designs that increase precision and cost-effectiveness may improve the ability to detect coho population change over time. They may therefore be useful in future efforts to modify the existing juvenile monitoring program and improve management of coho stocks.

METHODS

STUDY SITE

We estimated fall standing stock of juvenile coho salmon and cutthroat trout in Little Stawamus Creek, a 3.3 km long tributary of the Stawamus River. The watershed drains into the Pacific Ocean through Howe Sound and the Strait of Georgia on the southern coast of British Columbia 60 km north of the city of Vancouver (Fig. 1). Little Stawamus Creek is a small, second order stream with an average width of about 4 m. Substrate is mainly gravel and cobble with some sand and small boulders. Undercut banks and accumulations of small and large woody debris constitute the majority of complex habitat for juvenile salmonids.

HABITAT SURVEY

We conducted a detailed habitat survey of Little Stawamus Creek on September 14 and 15, 1997. The survey crew began at the stream mouth and proceeded upstream, classifying all habitat units as either riffles, runs, or pools based on criteria established by Johnston and Slaney (1996). Riffles were characterized as areas of shallow, turbulent, fast-flowing water. Pools were considered to be areas of slower, deeper water that had a minimum residual depth (maximum depth - average depth at riffle crest at pool tailout) depending on bankfull channel width. Runs were areas of non-turbulent water distinguished from pools by having relatively flat bottoms in cross-section. Other habitat types such as side-channels were rarely encountered. 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.

One member of the survey crew mapped habitat units by recording cumulative distance (to the nearest metre) at the downstream and upstream end of each unit using a hip chain. The other crew member measured 2 to 8 wetted widths (nearest 0.1 m) for each habitat unit (depending on size and uniformity) using a spring-loaded logger's tape. The wetted area of each habitat unit was estimated as the product of average wetted width and the difference between cumulative upstream and downstream

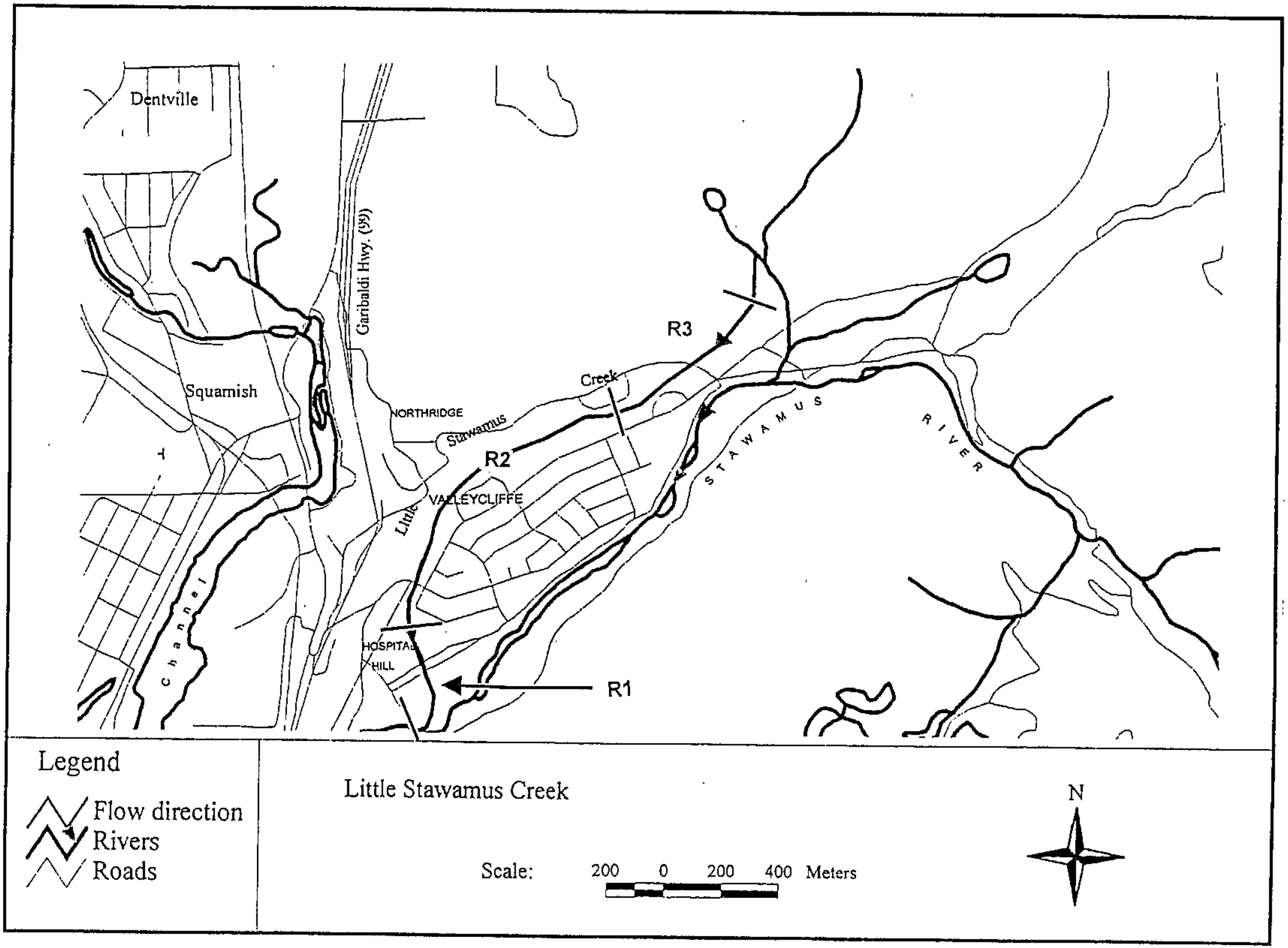

Figure 1. Little Stawamus Creek showing the three study reaches, fall 1997

For each habitat unit, the survey crew also subjectively assigned a habitat quality rating from 1 to 3 to facilitate stratification in the event that habitat ratings were correlated with measured fish abundance; habitat quality ratings were based on the quantity and quality of juvenile salmonid cover within the unit. To facilitate relocation of habitat units selected for fish population sampling, the crew also documented potential access points in their notes and marked the cumulative upstream distance on flagging placed at 50 to100 m intervals. A number of physical habitat characteristics were also estimated at sites where fish populations were sampled. The mean length and width of the sampled areas were estimated using at least three measurements. We estimated the average depth of each site as the mean of at least 5 depths taken at random locations across each width transect. Most habitat units were too shallow for reliable velocity measurements to be taken. The percent of stream substrate made up of four particle size categories: silt (no detectable graininess), sand (< 2 mm), gravel (2-64 mm), cobble (64-256 mm), and boulder (256-4000 mm), was estimated visually. The percent area of the habitat unit that could serve as cover for juvenile salmonids (instream or overhead cover within 1 m of the water surface) was also estimated visually.

FISH POPULATIONS

Removal methods

We sampled fish populations in nine sections of Little Stawamus Creek (Fig. 1) during two periods: 19 to 25 September, and 14 to 15 October, 1997. Sampling from late September to mid-October was precluded by elevated stream flow resulting from high precipitation. Water temperature was always at least 8°C and generally greater than 10°C. Sample sections were identified within reaches by randomly selecting habitat units of the least common type (pools). Upstream and downstream habitat units were then included to form an approximately 100 m long contiguous section. Separate estimates of fish abundance were made for each habitat unit within a 100 m section.

Three-pass removals were conducted consistent with protocol established for the DFO juvenile coho index stream sampling program. Prior to sampling, the upstream and downstream ends of each habitat unit were blocked with 10 mm stretch-mesh seines. Because the habitat units within a 100 m section were contiguous, the downstream net of one unit was also the upstream net of the adjacent one. Each pass began with 5 to 15 downstream pole seining sweeps, the number of which depended on the size of the unit. Pole seining was followed by a thorough upstream electroshocking sweep using a Smith-Root model 11 back-pack unit. The electroshocker was always operated by the same individual. To standardize effort among passes, the number of seine sweeps and time spent electrofishing were recorded. One pass was completed in all habitat units within a 100 m section prior to commencement of the next pass in order to "rest" individual units and minimize among-pass differences in catchability (Peterson and Cederholm 1984). Time between successive passes was always at least 0.5 h and averaged 1.0 h. Fish from each habitat unit were collected and sampled separately. All captured fish were anesthetized (MS-222; stock solution = 5 g/L), counted, measured (fork length to nearest mm) and returned to the stream following the completion of sampling.

We computed maximum likelihood (ML) removal estimates of abundance for coho salmon and cutthroat trout; too few fish of other species were captured to provide reliable estimates. Length frequency distributions suggested that most coho present in the stream were young-of-the-year, while cutthroat were represented by three or possibly four age classes (Fig. 2). However, we did not analyze the coho or cutthroat data by age class. Age classes within species were pooled, and coho and cutthroat data were contrasted to examine the degree to which differences in catchability, distribution and abundance between species influenced the performance of alternate sampling designs.

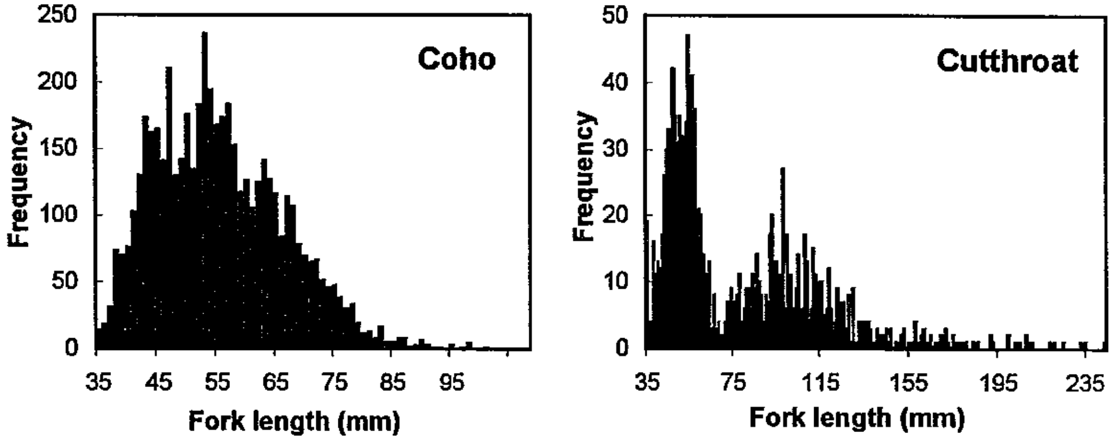

FIGURE 2. Length frequency histograms for coho salmon and cutthroat trout in Little Stawamus Creek, fall 1997.

Mark-recapture method

Coho and cutthroat trout were marked during the three-pass removal population sampling with a small clip on the lower caudal fin. Captured fish were retained in a net enclosure until completion of the final pass each day, and then released throughout an approximately 300 m long reach (100 m sample section plus 100 m upstream and downstream). All mortalities were recorded and subtracted from marked populations. Marked fish likely further redistributed themselves after release.

A stream-wide recapture was conducted from 16 to 18 October, 1997 (2 to 27 days after marking). The recapture consisted of a relatively quick upstream electrofishing sweep by a two person crew. The crew worked their way upstream from the mouth and completed about one km of stream per day. Fish were counted and examined for marks every 100 to 150 m and released downstream. The cumulative distance of the upstream and downstream boundaries of each portion sampled were recorded from the habitat survey flagging.

Whole stream standing stock (SS) estimates for coho and cutthroat were generated using the modified Petersen mark-recapture equation (Chapman 1951):

$$N = (M+1)(C+1) / (R+1)$$

where:

N = *Population estimate or Standing stock*

M = *Number of fish initially marked*
C = *Number of fish in the second capture*
R = *Number of marked fish in the second capture*

Standard error (SE) was approximated by the following equation (Ricker 1975):

$$SE = \sqrt{N^2(C\text{-}R) / (C+1)(R+2)}$$

A 95% confidence interval for the MR estimate was:

$$SS \pm 1.96 \times SE$$

We tested for spatial bias in mark application by stratifying the recovery data into discrete stream sections and comparing observed and expected mark incidences using a chi-square test (Sokal and Rohlf 1981; Schubert *et al.* 1994). Recovery bias was not assessed because this would have necessitated differential marking of fish by 100 m removal sampling section.

ALTERNATE SAMPLING DESIGNS

We examined the relative precision and cost-effectiveness of alternate sampling designs using field data and computer simulations. All designs except the stream-wide mark-recapture were based on the removal method of population estimation (Otis *et al.* 1978; Seber 1982). A brief description of the sampling designs is as follows:

Stratified random sampling (StRS)

This design requires detailed habitat survey information. Stream reaches and habitat types (eg. riffles, runs, and pools) are delineated and fish abundance is sampled in randomly selected habitat units within reach and habitat type strata. The StRS design stratifies sampling effort according to reach and/or habitat unit and thereby addresses the high spatial variability in fish abundance normally occurring in streams (Bohlin *et al.* 1982; Armour *et al.* 1983; Hankin 1984).

Simple random sampling (SRS)

The SRS design is similar to the StRS design except that sample units are not stratified by reach or habitat type. This approach may be desirable if correlations between fish abundance and reach or habitat characteristics are not expected. The SRS design does not require a detailed habitat survey. Habitat units for fish sampling are chosen either randomly, by selecting points along the length of the stream from a map, or systematically, based on a random starting point (e.g., sampling occurs in every *n*th habitat unit). An estimate of total stream length or area is needed to generate an estimate of total fish abundance. Total fish numbers are computed as the product of mean fish density at all sites and estimated stream length or area.

Proportional sampling (PS)

Researchers have found standard characterizations of physical habitat (pools, riffles, etc.) to be good predictors of fish abundance in streams (Aadland 1993; Bisson *et al.* 1981; Nickelson *et al.* 1992; Swales *et al.* 1986). If a large portion of spatial variability in abundance is accounted for by habitat type, an alternative to stratification is to divide sampling effort among habitat types according to the proportion of the stream area they represent. For example, if cost constraints allow for sampling of 20 sites, and the stream is composed of 50% riffles, 40% runs, and 10% pools, mean fish densities would be estimated based on pooled data from 10 riffles, 8 runs, and 2 pools. Although this approach eliminates the need for a detailed habitat survey, a basic survey of a portion of the stream length is required to determine the relative proportions of each habitat type. Total fish numbers are computed as the product of mean fish density at all sites and an estimate of stream length or area.

Representative 100 m sections

Normally, replicate sampling is used to address spatial variation in abundance. However, some fisheries biologists argue that because stream habitats vary in a fairly regular pattern (e.g. pool-riffle), the amount of replication needed can be reduced by sampling long sections of stream that encompass a series of habitat types. These sections are assumed to represent average fish densities in the stream. We felt that 100 m sections were sufficient to represent a typical habitat sequence in our study stream; a 100 m section encompassed 15 to 20 bankfull widths and three to seven habitat units. Representative sections can be chosen either randomly or systematically. This approach also does not require a habitat survey; only an estimate of total stream length or area is needed to generate estimates of fish populations for the stream.

Runs and pools design

A strategy of sampling only certain habitat types is likely to produce biased estimates of fish abundance. However, much of the currently available juvenile coho abundance data in B.C. streams is limited to multiple year observations of abundance in one or two "good" coho sites in each stream, i.e., runs and pools. Therefore, the accuracy of standing stock estimates generated by this type of data is of interest. Fish population sizes are computed as the product of mean fish density at all sites and an estimate of stream length or area similar to the SRS design.

Calibrated one-pass method

Estimating fish numbers by multiple pass electrofishing in closed sections is time consuming, and increasing sampling intensity by substituting a faster method is advantageous. Error in estimation of fish numbers within selected units is normally small compared to error associated with expansion of sampled sections to an entire stream (Bohlin *et al.* 1982; Hankin 1984; 1986). Hankin and Reeves (1988) found that precision could be increased for similar cost by substituting snorkel estimates of fish numbers in a larger number of sampling units. Snorkel estimates were adjusted for possible proportional bias by calibrating them with more precise electrofishing removal estimates from a sub-sample of sites where both methods were applied. However, given the high fish densities and shallow water depths in our study stream, snorkeling was not feasible. As an alternative, we used information from one-pass electrofishing removals (Jones and Stockwell 1995; Riley and Korman 1995; Riley *et al.* 1997), and calibrated one-pass totals with accurate three-pass maximum likelihood removal estimates in a subset of sites. Standing stock estimates were then computed using Hankin's (1984) two-stage ratio estimator approach. We consider the calibrated one-pass method as a variation to any of the removal sampling designs. However, to simplify the presentation of our results, we simulated the calibrated one-pass approach for the StRS design only; a full habitat survey was required and sample sites were selected randomly.

Stream-wide mark-recapture (MR)

We also assessed the feasibility of using a stream-wide mark-recapture to estimate standing stock. This approach addresses spatial variability in abundance by including the entire sampling universe (i.e. the whole stream). If the entire stream is to be sampled, the mark-recapture method is more practical than the removal method because it does not require the majority of fish in a stream be captured to generate a population estimate. Also, some research suggests that the removal method may provide less accurate estimates of numbers of coho in small streams as a result of declining catchability on successive passes (Peterson and Cederholm 1984; Rodgers *et al.* 1992). The MR method does not require habitat information because the stream-wide mark-recapture produces a direct estimate of standing stock.

ANALYSIS

Standing stock estimates for removal designs

We used the fish population data to calculate estimates of total standing stock of coho and cutthroat in Little Stawamus Creek. Estimates and standard errors for the alternate sample designs were compared. The calibrated one-pass and proportional designs were not included in this analysis because computer simulation of data was required to produce values for these approaches. Alternate methods were contrasted primarily by the way fish density estimates were scaled up to produce standing stock estimates. For example, StRS standing stock estimates were computed as follows (Hankin and Reeves 1988):

d_i = *density estimate for habitat type/reach stratum i*
$c_{i,j}$ = *ML population estimate for j units in stratum i*
$a_{i,j}$ = *area sampled for j units in stratum i*
n_i = *number of the units sampled in stratum i*
N_i = *Total number of the units in stratum i*
A_i = *Total wetted area of stratum i*
SS_i = *Standing stock estimate for stratum i*

$$d_i = \Sigma c_{i,j} / \Sigma a_{i,j}$$

$$\text{var}(d_i) = (N_i - n_i)\Sigma(c_{i,j} - da_{i,j})^2 / n_i N_i (A_i/N_i)^2 (n_i - 1)$$

The population estimate and its variance for a stratum i were:

$$SS_i = A_i d_i$$

$$\text{var}(SS_i) = \text{var}(A_i d_i) = \text{A}_i^2 \text{var}(d_i)$$

A 95% confidence interval for SS_i was:

$$SS_i \pm 1.96 \sqrt{\mathrm{Var}(SS_i)}$$

The SRS standing stock estimates were obtained by multiplying the mean density of fish in all habitat units sampled by the total stream area. Standing stock estimates for the runs and pools approach were computed in an identical fashion except riffles were removed from the data set. Removal estimates for the 100 m sections were computed by pooling, by pass, the capture totals for all habitat units in each 100 m site. Standing stock estimates were then computed in a similar approach to the SRS method.

Simulations

Fish population data were assumed to represent the sampling universe for the stream (Hankin 1984), and a bootstrap procedure (Efron and Tibshirani 1993) was used to simulate the relative precision and cost-effectiveness of alternate designs across a range of sampling intensities. The runs and pools and stream-wide mark-recapture methods were omitted from this analysis, the former because it did not contribute to the results, and the latter because it produced a single estimate of fish abundance for the entire sampling universe. Precision was estimated using the coefficient of variation (CV) for standing stock estimates. To compare precision among methods, sampling intensity was expressed as the number of sites (habitat units or 100 m sections) sampled in each iteration of the simulation. For any given design and number of sites, the boot-strapping process first simulated 300 trials, each trial providing a single estimate of total standing stock based on the random selection of units within each stratum with replacement, and then the CV of these 300 estimates was computed. CVs were estimated over a sampling intensity of 1 to 150 sites. A summary of the rules used to simulate the alternate sampling designs is as follows:

Stratified Random Sampling (StRS): The first sample was randomly chosen from the stratum representing the largest area; the second sample from the second largest stratum, and so on. The process repeated after one sample was chosen from each stratum.

Calibrated one-pass method: The model simulated the use of calibrated one-pass estimates by substituting a specified proportion of the three-pass removal estimates with calibrated one-pass estimates. One-pass estimates were regressed against three-pass removal estimates with the slope forced through the origin to produce a calibration factor. Standing stock estimates were computed using this two-stage ratio estimator approach where total variance of the estimate was the sum of first and second stage sampling errors (Hankin 1984). The use of the calibrated one-pass method was simulated as a modification to the StRS sampling design.

Simple random sampling (SRS): The model chose all samples with equal probability.

Proportional sampling (PS): For all sampling intensities, the number of samples the model chose from a particular habitat type was proportional to the amount of stream area that type represents; for example if riffles represented 10 percent of the total area, and sampling intensity was 20, the model chose two riffle samples.

Representative 100 m sections: The model chose all samples with equal probability, but samples were represented by 100 m sections rather than habitat units.

TIME-TASKING

To compare the cost-effectiveness of alternate sampling designs, we recorded the time spent conducting the habitat survey and fish population sampling. Tasks associated with removal sampling were further broken down as follows: set-up (putting nets in, preparing gear), 1st pass, 2nd Pass, 3rd pass, fish processing and packing up. Other survey costs (per diem, travel, etc.) were considered to be proportional to labour costs. Mean areas for 100 m sections and habitat units, and sampling efficiencies (person hours $\cdot$ m^{-2}) were calculated to determine labour cost (hrs $\cdot$ $site^{-1}$) associated with each sampling strategy. Because the study stream was only 3.3 km, we felt that the time required to complete a habitat survey for a "typical" small stream was underestimated. We therefore assumed an average stream length of 8.6 km based on the estimated mean length of nine coho index streams in the B.C. Lower Mainland (Nathan, Salmon, Coghlan, McIntyre, Little Campbell, Post, Siddle, Whonnock, Little Stawamus, and Murray; Brown and Musgrave 1979; Hancock and Marshall 1985; Marshall *et al.* 1979).

We devised correction factors in order to assign realistic labour costs for alternate designs. For the 100 m section design, we decreased the time required to set and remove stop nets, as only two nets were needed if a site was sampled as a contiguous unit. For example, for a 100m section containing four habitat units (i.e., 5 stop nets), the total time spent on net handling was corrected by multiplying by 2/5. The time required for the calibrated one-pass design was calculated in two steps: first it was assumed that three-pass removals with stop nets were conducted for calibration purposes on a subset (20%) of habitat units (no correction necessary); second, time to complete the remaining 80% of units was decreased to reflect that only one pass without stop nets would be performed. The cost of the habitat inventory for the proportional sampling design (PS) was obtained by standardizing the length of stream required to obtain reliable estimates of overall habitat type proportions. Based on an average channel (bankfull) width of 10 m for a "typical" small stream, we estimated that 1 km (100 channel widths) of stream would need to be sampled (D. Hogan, stream morphologist, Ministry of Environment, pers. comm.).

TABLE 1. Summary of Little Stawamus Creek physical habitat characteristics and juvenile coho salmon and cutthroat trout population sampling intensities, mean fork lengths, mean fish densities and associated 95% confidence intervals by reach and habitat type, fall 1997.

												Density (fish · 100 m^{-2})			
		Habitat Units								Fork Length (mm)		Coho		Cutthroat	
Reach	Unit	Total number	Total area (m^2)	Mean area (m^2)	Mean length (m)	Number sampled	Percent sampled	Area sampled (m^2)	Percent sampled	Coho	Cutthroat	Mean	SE	Mean	SE
1	Riffle	8	559	70	17.5	2	25%	274	49%	56.9	61.7	44	0.4	15	3
	Run	9	828	92	17.0	3	33%	301	36%	57.4	80.8	121	1	21	8
	Pool	2	119	60	9.5	2	100%	119	100%	60.1	89.4	125	42	23	5
	Total	19	1,506	79	16.4	7	37%	771	51%	58.0	77.8	100	17	20	3
2	Riffle	36	3,172	88	24.1	5	14%	826	26%	53.6	72.1	83	19	49	8
	Run	28	1,876	67	18.1	6	21%	552	29%	57.8	94.4	242	24	41	8
	Pool	12	507	42	11.4	4	33%	301	59%	53.9	82.3	463	50	105	9
	Total	76	5,555	73	19.9	15	20%	1,679	30%	55.4	83.0	248	42	60	8
3	Riffle	24	2,893	121	36.3	7	29%	521	18%	50.6	69.8	41	6	40	6
	Run	19	2,015	106	25.7	4	21%	411	20%	53.2	81.3	179	34	68	18
	Pool	8	693	87	18.4	3	38%	200	29%	53.9	101.1	177	48	44	3
	Total	51	5,601	110	29.5	14	27%	1,132	20%	52.0	79.8	110	23	49	6
Stream		146	12,662	87	22.8	36	25%	3,582	28%	55.3	81.4	164	-	45	-

TABLE 2. Sample sizes (n), areas sampled, estimated fish densities, standing stocks, their associated 95% confidence limits, and capture probabilities for juvenile coho salmon and cutthroat trout by pooled strata[a], Little Stawamus Creek, fall 1997.

Stratum[a]	Reach	Habitat Type	Total Hab. Units (N)	Hab. Units Sampled (n)	Total Area (m^2)	Area Sampled (m^2)	Density[c] ($\text{fish} \times 100m^{-2}$) Mean	CL (±)	CL (%)	Standing Stock[c] Estimate	CL (±)	CL (%)	Mean Capture Probability
COHO:													
1	1,3	RI	32	9	3,452	795	41	11	27%	1,437	219	15%	0.68
2	1,3	RU, P	38	12	3,655	1,108	155	38	25%	5,393	942	17%	0.64
3	2	RI	36	5	3,172	826	83	54	64%	2,511	1,373	55%	0.48
4	2	RU	28	6	1,876	552	242	62	26%	4,795	1,272	27%	0.62
5	2	P	12	4	507	301	463	158	34%	2,375	750	32%	0.69
Stream			146	36	12,662	3,582	197	-	-	16,511	2,236	14%	0.62
CUTTROAT:													
1	1	ALL	19	7	1,506	771	20	8	42%	289	89	31%	0.73
2	2	P	12	4	507	301	105	27	26%	515	105	20%	0.51
3	2,3	ALL[b]	115	25	10,649	2,510	47	9	18%	4,716	735	16%	0.52
Stream			146	36	12,662	3,582	57	-	-	5,520	748	14%	0.59

[a] Strata composition was based on a nested ANOVA of fish densities by reach and habitat type. Strata among which fish densities were not significantly different ($p < 0.05$) were pooled.

[b] All habitat units except pools in reach 2 (stratum 2).

[c] 95% Confidence Limits (CL)

RESULTS

HABITAT SURVEY

The total length of the stream at the time of the survey was 3.3 km, measured from the confluence with the Stawamus River to the upper limit of wetted flow (Fig. 1). Estimated length did not include a 0.9 km groundwater tributary which entered the creek 0.3 km upstream of the Stawamus River confluence. Estimated total wetted area was 12,662 m^2, which was classified into 146 distinct habitat units (Table 1). Riffles comprised 52% of the total stream area and 47% of habitat units. Runs encompassed 37% of the stream area and 38% of the habitat units. Pools represented 10% of stream area and 15% of habitat units. Stream discharge was near base flow for the majority of the study period. Stream width ranged from 1.2 to 10.5 m, averaging approximately 4 m, and depth ranged from 5 to 35 cm.

We stratified the creek into three reaches based on differences in gradient, cover, and substrate composition (Table 1; Appendix 1). Reach 1 was approximately 300 m in length, and reaches 2 and 3 were both about 1500 m. Substrate consisted mainly of gravel and cobble in all reaches, but there were higher proportions of fines in the lowermost reach (reach 1), and higher proportions of boulders in the uppermost reach (reach 3). Stream gradient was measured (hand-held clinometer) to be less than 1% in reaches 1 and 2, and between 1 and 5% in reach 3. Instream woody debris cover was more abundant in reach 1 than in other reaches (51% compared to 25 and 22% in reaches 2 and 3, respectively). Canopy closure was similar among all reaches, averaging 76% (Appendix 1).

FISH POPULATIONS

We sampled fish populations in 24 to 47 percent of the total area of each habitat type, and in 20 to 51 percent of each reach (Table 1). Estimated capture probabilities (estimated as the ratio of first pass totals to three pass ML removal estimates) were consistently high, averaging 0.63 and 0.56 for coho and cutthroat, respectively (Appendix 2). Coho salmon were generally more abundant than cutthroat trout at all sample sites. Coho densities ranged from 19 to 606 $\text{fish} \cdot 100\ m^{-2}$, and cutthroat densities ranged from 7 to 129 $\text{fish} \cdot 100\ m^{-2}$ (Appendix 2). Mean densities of coho by reach and habitat type ranged over an order of magnitude (41 to 463 $\text{fish} \cdot 100\ m^{-2}$; Table 1). Density of coho was significantly higher in reach 2 (248 $\text{fish} \cdot 100\ m^{-2}$) than in the other reaches, and was significantly lower in riffles than in pools and runs (nested ANOVA, $p < 0.05$). Mean cutthroat densities ranged from 15 to 105 $\text{fish} \cdot 100\ m^{-2}$, and density was significantly lower in reach 1 (20 $\text{fish} \cdot 100\ m^{-2}$) than in the other reaches. Although like coho, cutthroat were most abundant in pools, densities in pools were not significantly higher than those in riffles and runs (nested ANOVA, $p = 0.06$). Coho and cutthroat densities were not correlated with other measures of habitat (e.g., estimated cover, estimated substrate composition, habitat unit quality rating; linear regression, $p > 0.05$).

Standing stock estimates

Log-transformed fish numbers were correlated with sample site areas ($p < 0.05$, by linear regression). Therefore, to improve the precision of our population estimates we converted numbers to densities prior to computing standing stock (Hankin 1984). Fish densities were also log-normally distributed by reach and habitat type. We compared log-transformed densities and found that differences among some reach /habitat type strata, were not significantly different (nested ANOVA, p > 0.05). We pooled these estimates and grouped coho and cutthroat data into five and three strata, respectively (Table 2).

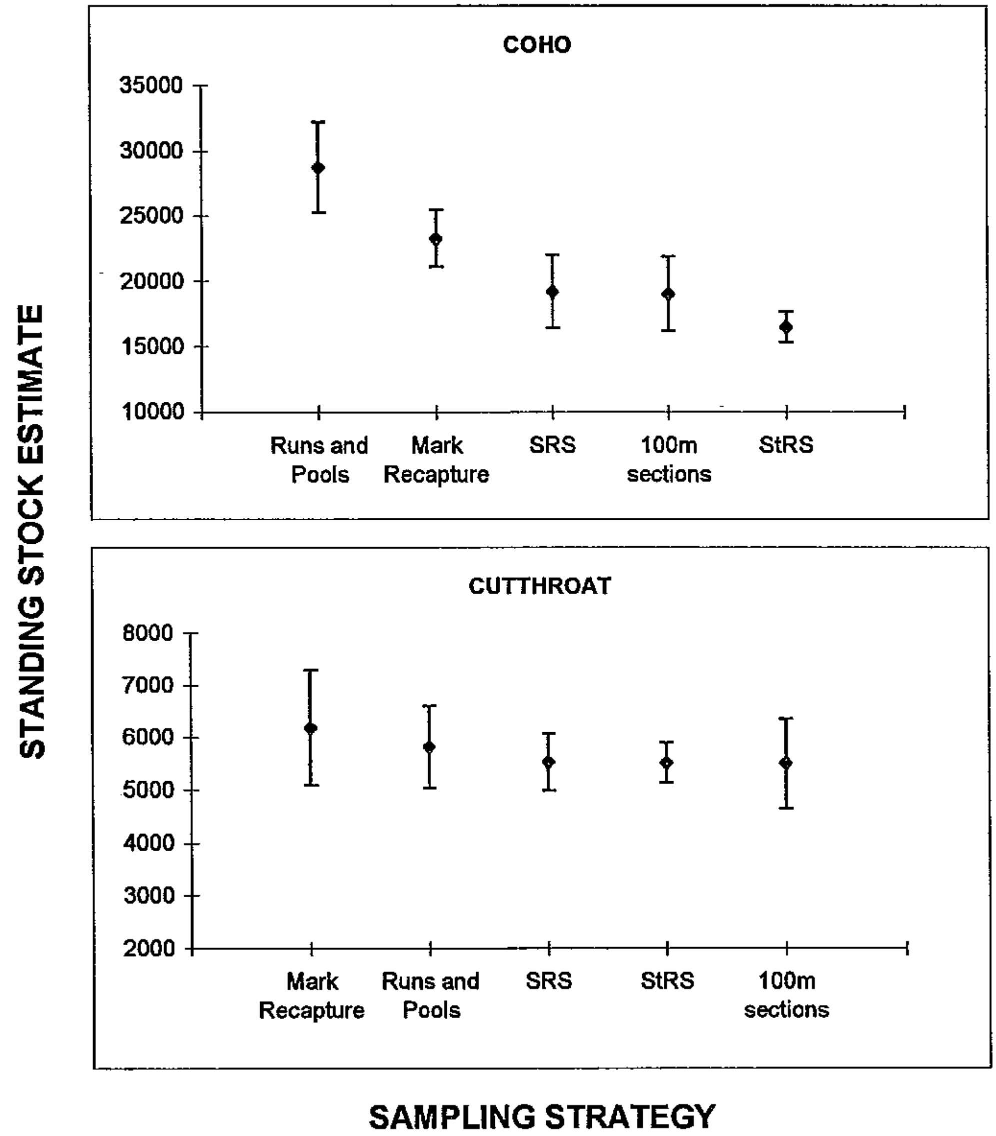

FIGURE 3. Comparison of standing stock estimates and associated 95% confidence intervals for juvenile coho salmon and cutthroat trout for alternate sampling strategies from non-simulated data, Little Stawamus Creek, fall 1997. For a comparison of precision for each design refer to boot-strap simulation results presented in Figure 5.

Standing stock estimates differed markedly depending on the sampling method (i.e., removal or mark-recapture) and design (i.e., stratified random, simple random, runs and pools, or representative section; Fig. 3; Appendix 3). Among removal methods, the StRS design provided the smallest and most precise coho standing stock estimate (16,511 ± 2236 fish; 14%), while the runs and pools design produced the highest (28,772 ± 6754 fish; 23%). The mark-recapture method produced a relatively high coho standing stock estimate (23,291 ± 2176 fish; 9%), but the estimate was more precise than the StRS estimate. Standing stock estimates for cutthroat varied substantially less among sampling methods and designs, ranging from 5508 (± 1676; 30%) fish for the 100 m section design to 6195 (± 1108; 18%) fish for the mark-recapture method. Differences between observed and expected mark recoveries indicated significant spatial bias in mark application for both coho and cutthroat (i.e., marked and unmarked fish were not uniformly mixed throughout the stream; chi-square, $p < 0.05$; Appendix 5). This was likely a result of our non-uniform capture method; we captured, marked and released fish in nine distinct sections of the stream.

SIMULATIONS

Differences in the precision of alternate sampling designs were assessed using a bootstrapping approach. We simulated 300 trials of 150 sampling intensities for four of the designs: simple random sampling (SRS), representative 100 m section, proportional sampling (PS), and two versions of stratified random sampling (StRS): the three-pass removal, and calibrated one-pass methods.

Calibration factors (CF) for the one-pass sampling method were obtained by regressing first-pass capture totals versus three-pass ML removal estimates for all habitat units sampled (Fig.4). The two were highly correlated for both coho ($r^2 = 0.97$), and cutthroat ($r^2 = 0.90$), thus we assigned CFs of 1.45 and 1.90, respectively. Reach or habitat specific CFs were not used because the regressions of three pass estimates on first pass catches did not differ significantly among reaches or habitat types (ANCOVA, $p > 0.05$). Moreover, estimated capture probabilities for the habitat units were not significantly related to mean depth, mean width, proportion of cover, or "habitat quality" as rated by the field crew (linear regression, $p > 0.05$). We estimated second stage error (Hankin and Reeves 1988) for the one-pass calibrated method as the standard error from the regression of log transformed first pass totals and three-pass estimates (SE = 0.26 and 0.47 for coho and cutthroat, respectively). We simulated results for the one-pass method assuming that three-pass removals were conducted in 20% of sample sites for calibration purposes; results were minimally different when a 10% fraction was used.

Using data from removal methods, the simulation results suggested marked differences in precision among the sampling designs, particularly for coho (Fig. 5). The two versions of the StRS design produced the least variable estimates of coho standing stock across all sampling intensities. Although results for the StRS designs were simulated using data grouped according to pooled strata; results were similar when the original reach and habitat type strata were substituted. The SRS design produced the most variable standing stock estimates. The PS and 100 m section designs produced roughly similar estimates of standing stock variability at low sampling intensity, while at

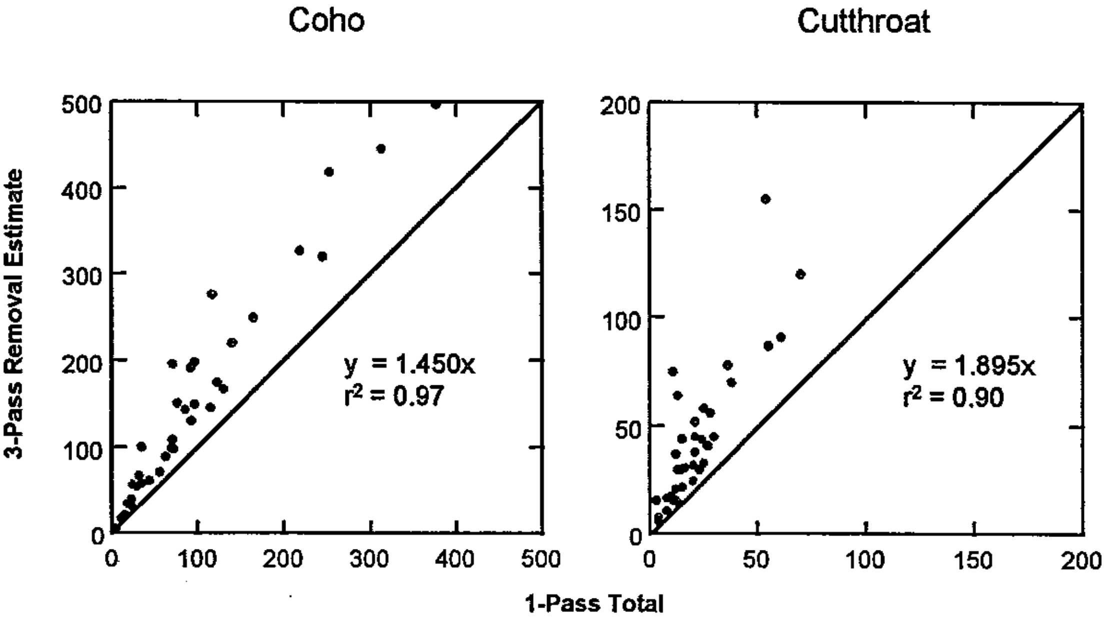

FIGURE 4. Calibrated one-pass correction factors for juvenile coho salmon and cutthroat trout, Little Stawamus Creek, fall 1997. Solid lines in each graph represent the 1:1 relationships between first pass total catch and three-pass removal estimates, while open circles show the observed relationship from population data for 36 habitat units. The correction factors are given by the equation y = bx.

higher intensities, the 100 m section design was less variable. The trend in precision among designs differed for cutthroat. The PS design predicted the least variable cutthroat standing stock estimate, while all other designs predicted roughly similar standing stock CVs over the range of sampling intensities (Fig. 5).

We performed an additional simulation to determine the standing stock precision that might be obtained using information from the existing DFO juvenile coho sampling program. We used population data from runs and pools only and assumed a sampling intensity of two sites per stream. We generated 300 standing stock estimates based on two randomly selected runs or pools (N = 22). Estimates derived using this approach were highly variable, ranging from 6485 to 120,359 for coho (mean = 32,759 fish; CV=0.55) and 10 to 13,264 for cutthroat (mean = 1056 fish; CV=1.24). Estimated fish densities in the two established DFO sample sites yielded standing stock estimates of 28,641 (±41,895) coho and 3,037 (±381) cutthroat.

COST EFFECTIVENESS

The relative cost effectiveness of each sampling method was assessed by converting sampling intensity into equivalent labour cost in hours. Design-specific conversion factors were based on time spent sampling fish populations and estimates of mean site size (Table 3). The calibrated one-pass version of the StRS method required the shortest time per site (5.08 h) because 80% of sites required only one removal pass. The StRS with three-pass removals, PS, and SRS designs required

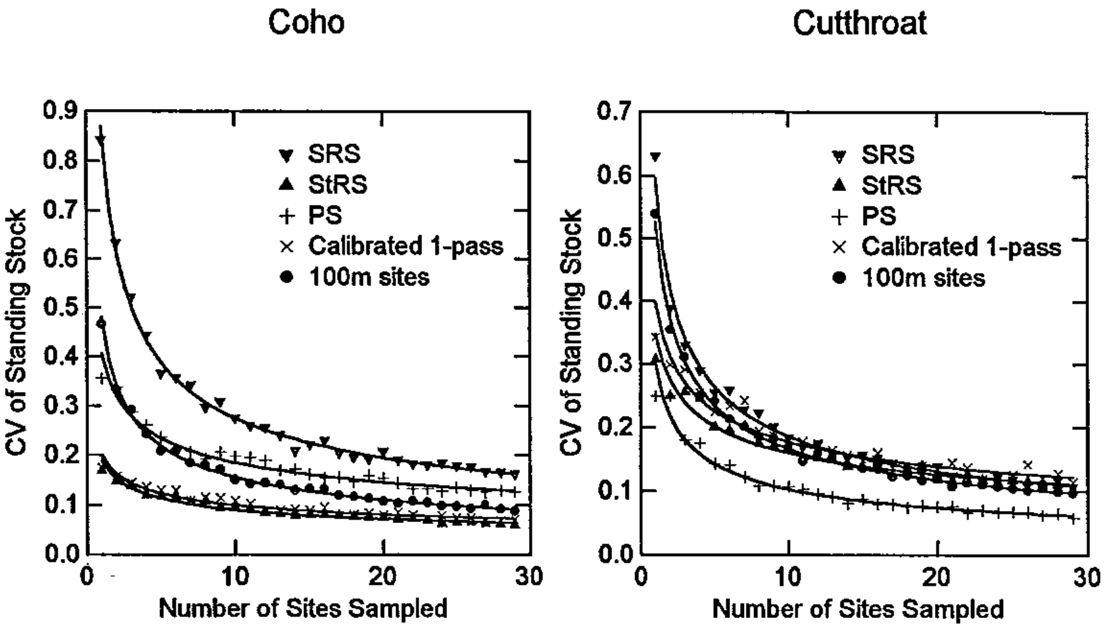

FIGURE 5. Comparison of variation in juvenile coho salmon and cutthroat trout standing stock estimates among sampling designs using boot-strap simulations of the population data collected for Little Stawamus Creek during fall 1997. The horizontal axes have been truncated to better illustrate differences among designs.

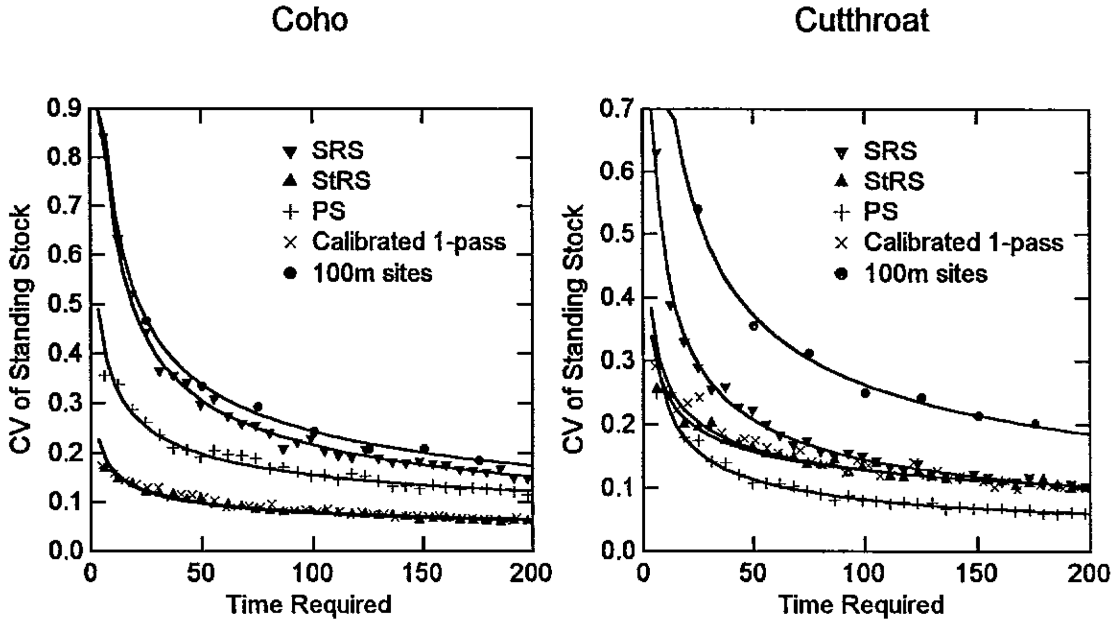

FIGURE 6. Comparison of cost efficiencies among alternate juvenile coho salmon and cutthroat trout standing stock sampling designs using boot-strap simulations of the population data collected for Little Stawamus Creek during fall 1997. The horizontal axes have been truncated to better illustrate differences among designs.

TABLE 3. Estimated labour costs for alternate sampling designs based on time tasking data for standing stock estimates of juvenile coho salmon and cutthroat trout abundance in Little Stawamus Creek, fall 1997.

Sampling Design	Mean labour costs (person hrs * m $^{-2}$)	Mean site area (m ^{2})	Mean labour cost (hrs * site $^{-1}$)	Habitat survey fixed cost [a] (hrs)
Stratified Random Sampling	0.060	104	6.18	25.8
Simple Random Sampling	0.060	104	6.18	0.0
Calibrated 1-Pass using StRS	0.049	104	5.08	25.8
Proportional Sampling	0.060	104	6.18	3.0
Representative sampling	0.058	432	25.12	0.0

[a] See methods for details.

more labour per site (6.18 h) as a result of greater net installation and removal times. Labour costs were highest for the 100 m section design (25.12 h) because average site area was much larger, and the time to complete removal passes was longer.

Conversion factors for the StRS and PS designs were then standardized to account for time spent conducting habitat inventories. We calculated the additional time required to be 25.8 h for both versions of the StRS design, assuming a 'typical' small coho stream length (8.6 km) and a surveying efficiency of 3 hours·km^{-1} stream. The habitat survey for the PS design required 3 hours, assuming the same surveying efficiency and that 1 km of stream was sampled. The additional time required for the habitat surveys was added to the cost of completing the first site (analogous to a fixed cost that decreased in significance as sampling intensity was increased).

The simulations suggested the representative 100 m section design was the least cost-effective method for estimating both coho and cutthroat standing stock (Fig. 6). Although sampling precision for the 100 m section design was moderate in comparison to other designs (Fig. 5), the increased labour cost per site dramatically decreased the design's cost-effectiveness. Relationships among other designs did not differ substantially from trends observed in Fig. 5. The StRS design, using both the calibrated one-pass, and 3-pass removal methods, remained the most cost-effective method for coho, and the PS method was the most cost-effective design for cutthroat.

The cost-effectiveness of the stream-wide mark-recapture (MR) approach could not be simulated using the bootstrapping procedure. However, the MR method was estimated to take approximately 120 h, and cost-effectiveness of the removal designs were contrasted at this level. The standing stock CVs from the MR design were 0.048 for coho, and 0.097 for cutthroat. These values are substantially lower than CVs produced by the two StRS designs for coho (0.071 and 0.073, respectively), and slightly higher than the PS design for cutthroat (0.075) at a sampling intensity of 120 h.

DISCUSSION

We sampled 28 percent of the area of Little Stawamus Creek using three-pass removals, and we assumed that this level of sampling was sufficient to produce relatively unbiased estimates of standing stock for juvenile coho salmon and cutthroat trout. We further assumed our three-pass removal estimates of abundance and density were relatively unbiased because we observed consistent and relatively high capture probabilities and good depletion patterns.

The estimated standing stock of juvenile coho salmon in Little Stawamus Creek was 16,511 ± 2236 (14%) fish using stratified random sampling with three-pass removals. The total standing stock of cutthroat trout was estimated to be 5520 ± 748 (14%) fish, also using the StRS design. Based on simulation results, the StRS design produced the most precise estimates of coho and cutthroat standing stock among removal methods. Simulations showed that the sampling intensity required to produce precise (CV=0.1) estimates of coho standing stock could be reduced to approximately ten habitat units (7% of the total) by using StRS with either three-pass or calibrated one-pass removals. By contrast, estimates made using SRS did not approach this level of precision even when 30 habitat units were sampled. We therefore recommend the use of StRS in future standing stock surveys.

Removal estimates of fish population size can be affected by the physical characteristics of stream sections, especially stream width, depth, and cover (Peterson and Cederholm 1984; Riley et al. 1993). However, we found no evidence that estimated capture probabilities were related to the width, depth or cover in the sections that we sampled. Moreover, the relationship between first pass catch and three-pass population estimates did not differ among habitat types or reaches. Previous authors have similarly reported high coefficients of determination for relationships between first-pass catches and population estimates for stream salmonids (Crozier and Kennedy 1994; Lobon-Cervia and Utrilla 1993; Jones and Stockwell 1995). These relationships may be stream-specific, although Jones and Stockwell (1995) found that relationships of this type varied little among southern Ontario streams.

There is evidence, however, that the removal method may underestimate population size (Mahon 1980; Riley and Fausch 1992; Rodgers *et al.* 1992; Riley *et al.* 1993; Amiro 1990b). As in other studies of coho populations in small streams (e.g., Peterson and Cederholm 1984; Rodgers *et al.* 1992), the mark-recapture estimate (23,291) exceeded estimates obtained with the removal designs (16,511 to 19,233), except when only runs and pools were sampled (28,772). True coho abundance in the Little Stawamus Creek was not known. However, in other studies where known numbers of fish were stocked in streams prior to sampling, it was found that both the mark-recapture and removal methods underestimated true abundance, but the mark-recapture approach provided the most accurate estimate (Peterson and Cederholm 1984; Rodgers *et al.* 1992). This may not have been the case in our study; data from the whole-stream mark-recapture were spatially biased, and thus the assumption of uniform distribution of marked individuals was not met (Ricker 1975). In addition, the marking and relocation of fish to different portions of the stream may have resulted in an overestimate of abundance due to differential mortality of marked and unmarked populations. The whole-stream mark-recapture was also logistically difficult. It had high labour costs (mark-recapture took 120 h vs. approximately 50 h for a reasonably precise estimate using StRS), and would be considerably less cost-effective in more typical, larger streams. Therefore, we do not recommend the use of this method in future standing stock surveys.

From the removal data, it was clear that densities of juvenile coho and cutthroat varied significantly among reaches and habitat types, and also among 100 m stream sections. When spatial variability of this magnitude is evident, sample sections cannot be considered representative, and a large number of sections may be needed to obtain precise standing stock estimates (Bohlin 1990). High spatial variability in the abundance of fish among habitat units and reaches in streams is a common observation (Amiro 1990a; Fraser and Sise 1980; Gillis and Kramer 1987; Hankin and Reeves 1988; Milner *et al.* 1993; Roper *et al.* 1994), and the value of using StRS designs to address this variability has been well demonstrated (Bohlin *et al.* 1982; Hankin 1984, 1986). Yet, some biologists continue to base juvenile stock assessment programs on representative site sample designs. In Little Stawamus Creek, fish densities in the 100 m sections were highly variable despite the fact that the sections included 3 to 7 distinct habitat units. In addition, the frequency of habitat types in streams generally varies in proportion to bankfull width (Richards 1982), and therefore the representative site approach may be even less cost-effective in larger streams because sample sections would have to be longer in order to include several habitat types. We do not recommend the use of representative site sampling in future standing stock surveys.

Differences in the accuracy and precision of standing stock estimates obtained from alternate sampling designs were not as great for cutthroat trout as for coho, which is probably indicative of species-related differences in spatial distribution patterns. Although both species were found throughout the system and in all habitat types, coho densities were more highly correlated with habitat type than were cutthroat trout. Coho were more spatially heterogeneous, and failing to account for this explicitly with a stratified sampling method resulted in relatively higher variability in standing stock.

The PS design was less efficient than the StRS design for coho because it required that sampling effort be distributed among habitat types in proportion to the stream area represented by each type. For example, the PS design assigned half the sampling effort to riffles because this habitat type comprised 52% of stream area. Conversely, sampling effort in riffles was only 39% for the StRS design. The StRS design produced more precise coho standing stock estimates because sampling effort was relatively higher in runs and pools where the majority of coho were found (76%). Proportional sampling was more effective than StRS for cutthroat trout because this species was distributed more evenly among habitat types. These results suggest sampling efficiency in the StRS design may be substantially improved if effort among strata is adjusted based on reliable a *priori* assumptions of fish distributions. Suggestions concerning the optimal allocation of sampling effort in stream surveys are provided by Hankin and Reeves (1988).

For several of the sampling designs (mark-recapture, PS, SRS), the potential increase in cost-effectiveness compared to the StRS design depended upon their lack of reliance on a detailed habitat survey. However, our results show that the cost of performing the habitat survey was relatively low compared to the cost of fish population sampling, and the most cost-effective approach was to use the habitat information to stratify sampling effort among reaches and habitat types. For long-term monitoring programs such as the juvenile coho sampling program, the StRS design would compare even more favourably because the cost of the habitat survey would only be incurred the first year. Information from habitat surveys could also be used for other purposes such as comparing the similarity of index streams, and setting criteria for the selection of additional streams. Also, if repeated periodically, habitat surveys could be used to investigate potential correlations between changing freshwater rearing conditions and coho abundance over time.

Our simulations show that the sampling intensity currently used in the DFO juvenile coho sampling program (1 or 2 sites per stream) produces highly imprecise standing stock estimates. Data from this program are used primarily to infer annual trends in coho abundance, but if reliable estimates of standing stock were also desired, the present level of sampling would need to be increased. Moreover, sampling would have to be distributed among all habitat types to reduce the bias associated with only sampling relatively "good" coho sites. Our study confirmed that sampling coho abundance in runs and pools resulted in a much higher standing stock estimate than obtained from more unbiased sampling designs.

Sampling only the best coho habitats may also be a relatively insensitive measure of annual trends in abundance for conservation purposes. The distribution of fish (Fraser and Sise 1980; Gillis and Kramer 1987; Bult *et al.* 1998) and other organisms (Taylor *et al.* 1978) may vary among habitat types depending on density, and there is evidence that some habitats support relatively high densities of juvenile coho even when total numbers in the stream are low (J. Bratty, unpublished data). At escapement levels sufficiently low to limit freshwater production, spawner distribution and fry dispersal patterns may also influence fall fry distribution (Lestelle *et al.* 1993). Stratified estimates of standing stock are more sensitive to changes in spatial distribution that may occur at the stream or watershed scale, and therefore may be more informative for monitoring populations, particularly when abundance is low.

The power to detect changes in abundance over time within permanent index sites may also be reduced by annual variation in stream discharge and morphology. Estimates of fish density in index sites depend on measures of wetted stream area, and surveys are conducted during the "low flow" period in early fall. However at low flow, even relatively small changes in discharge have a large effect on wetted channel dimensions (Hogan and Church 1988). As well, in small streams, the physical morphology of a reach can change dramatically following high flows, resulting in a change in wetted area and habitat characteristics for a given flow. Coho may also redistribute themselves in early fall following an increase in discharge and/or a reduction in water temperature (Bilby and Bisson 1987; Cederholm and Scarlett Peterson 1982). Stream-wide estimates of standing stock are less sensitive to these factors, and are therefore better suited for detecting change in populations over time.

The number of habitat units that need to be sampled to produce precise estimates of coho standing stock may vary spatially and temporally. For example, spatial variability in juvenile salmonid density can vary among rivers (Bohlin *et al.* 1989; Amiro

1990a), or among seasons (Nickelson *et al.* 1992) and years (Egglishaw and Shackley 1982) within the same river. Although the amount of spatial variability in coho fry abundance within streams compared to among streams has not been examined, a recent study shows a degree of correlation in adult escapement among nearby streams (Labelle *et al.* 1997). However, correlations in coho smolt abundance were limited to streams occurring within the same watershed (Bradford *In press).* Further research should be undertaken to determine the extent to which juvenile coho index site data are influenced by annual variability in spatial distribution within streams. This information could be used to optimize the allocation of available stock assessment resources (i.e. trade-off between numbers of streams sampled and number of sites per stream).

Our simulations show that the time required to obtain precise (CV ≤ 0.1) coho standing stock estimates using a stratified random design was similar for both the three-pass removal and the calibrated one-pass methods, suggesting that there may be little benefit in using a two-stage design in a small stream like Little Stawamus Creek. However, other studies have clearly demonstrated that sampling a large number of sites using the one-pass method can be less expensive than sampling fewer sites using the multiple-removal method while still producing similar precision (Hankin and Reeves 1988) or statistical power (Paller 1995). The relative cost of performing three-pass removals was somewhat understated in this analysis because of the small size of the study stream and the close proximity of sites within 100 m sections.

Our estimates of cost-effectiveness for the calibrated one-pass design assume that block nets were not used at one-pass sites. However, calibration factors between first-pass catches and population estimates were calculated using block nets, and these relationships may differ if block nets are not used (Riley *et al.* 1997). In our study, the increase in cost-effectiveness associated with the calibrated one-pass approach would have been negligible had the use of block nets been simulated (i.e. included net set-up and removal times in time tasking factors), because a large amount of time was spent installing and taking down nets. In larger streams where net-handling is more time consuming, the potential gains in cost-effectiveness associated with the calibrated one-pass design would be further negated if stop net installation and removal were considered (Riley and Korman 1995). Very few studies have addressed the effects of block nets on salmonid population estimation, but it seems likely that a significant number of juvenile salmonids could emigrate from unblocked sections during electrofishing and result in a biased density estimate. Therefore, although a calibrated one-pass sampling design may result in greater cost-effectiveness, we caution that if one-pass indices of salmonid density are used, this potential source of bias should be considered.

In larger streams, snorkeling may be feasible and could be used instead of one-pass electrofishing. This would increase sampling efficiency and eliminate the need for block nets (cf. Hankin and Reeves 1988). However, the use of this method may be limited; the accuracy of estimates of fish populations by snorkeling are strongly sensitive to factors such as turbidity (Thurow 1994), diver experience (Hankin and Reeves 1988; Slaney and Martin 1987), fish species and behaviour, stream temperature (Hillman *et al.* 1992), time of day, and season (Rodgers *et al.* 1992).

SUMMARY AND RECOMMENDATIONS

1. Simulations show that among removal methods, the stratified random sampling design produced the most precise estimates of coho standing stock in Little Stawamus Creek, and we recommend this sampling design be used for future standing stock surveys. The StRS design requires a habitat survey, but detailed habitat information may be useful for other purposes. Baring substantial changes in stream structure over time, additional costs associated with the habitat survey are relatively inexpensive and are incurred only once during the course of a multi-year stock assessment program. However for cutthroat trout, the proportional sampling design was most precise and cost-effective because cutthroat were more uniformly distributed among habitat types.

2. Our simulations suggest that sampling approximately seven percent of the habitat units in Little Stawamus Creek was sufficient to provide a precise (CV = 0.1) estimate of standing stock using the stratified random sampling design. However, the sampling effort required may change due to spatial and temporal variation in salmonid distribution and abundance, and this estimate is stream-specific. Further studies should be conducted to determine how well this applies to other streams and years.

3. Our study does not evaluate the ability of the existing DFO juvenile coho sampling program to reflect observed trends in coho abundance. However, within stream spatial variability may affect the power of tests of population change over time, and whole-stream standing stock estimation may therefore be a more effective approach for stock assessment purposes. This study indicates that sampling intensity within individual streams would need to be increased from present levels if reliable standing stock estimates were desired.

4. The use of the calibrated one-pass method with the stratified random sampling design was marginally more cost-effective than the use of three-pass removals. In larger rivers, however, the calibrated one-pass method could provide substantial cost savings, and we recommend its use in situations where resources are insufficient to apply removal methods at all sites. Our results show that one electrofishing pass with block nets can provide a good index of coho abundance. We caution, however, that one-pass estimates made without block nets may be biased, and that installing block nets may make this design relatively less cost-effective. In larger streams, snorkeling might be used instead of one-pass electrofishing to increase sampling efficiency and eliminate the need for block nets.

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APPENDICES

APPENDIX 1. Summary of physical habitat data for Little Stawamus Creek, fall 1997.

	Estimated mean values								
Reach	Wetted idth (m)	Depth (cm)	Substrate (%)				Cover (%)		Average Rating (1-3)[a]
			Fines	Gravel	Cobble	Boulder	In stream	Canopy	
1	5	21	31	64	4	0	51	76	2.6
2	3	17	3	62	34	1	25	63	2
3	4	22	3	52	35	10	22	89	2.6
Stream	4	20	12	59	25	3	33	76	2.4

[a] Based on a subjective habitat quality index, see text for details.

APPENDIX 2a. Juvenile coho salmon population data by habitat unit, Little Stawamus Creek, fall 1997[a].

Reach	Habitat Type[d]	Strata	Area (m^2)	No. of coho Pass 1	Pass 2	Pass 3	Total	ML[b] Pop. Estimate	SE	95% CL ±	Density (fish · 100 m^{-2})	Capture Prob.	Length[c] (mm)
1	P	2	89	96	23	21	140	149	4.9	9	167	0.60	56
1	P	2	107	62	17	8	87	89	2.2	3	83	0.69	65
1	RI	1	51	15	7	0	22	22	0.7	1	43	0.76	53
1	RI	1	223	71	17	8	96	98	2.0	3	44	0.71	61
1	RU	2	116	85	24	22	131	143	6.3	12	123	0.56	50
1	RU	2	46	29	14	7	50	55	4.4	7	120	0.54	63
1	RU	2	139	129	23	13	165	167	2.0	3	120	0.75	60
2	P	5	82	377	80	32	489	497	3.6	7	606	0.74	54
2	P	5	103	253	90	48	391	419	8.8	17	407	0.59	53
2	P	5	71	245	39	30	314	320	3.2	6	451	0.73	57
2	P	5	45	122	32	15	169	174	3.1	6	387	0.69	55
2	RI	3	144	35	16	5	56	59	2.9	4	41	0.62	50
2	RI	3	345	116	65	41	222	276	19.7	39	80	0.42	54
2	RI	3	103	32	23	6	61	68	5.3	9	66	0.52	58
2	RI	3	97	76	34	22	132	151	9.3	18	156	0.49	52
2	RI	3	137	35	20	17	72	100	19.0	33	73	0.34	54
2	RU	4	128	164	47	27	238	249	5.1	10	195	0.64	59
2	RU	4	81	70	55	25	150	196	20.8	41	242	0.38	59
2	RU	4	33	44	14	3	61	62	1.4	2	188	0.73	66
2	RU	4	63	92	22	13	127	131	2.9	5	208	0.68	59
2	RU	4	115	218	56	38	312	327	5.9	12	284	0.64	51
2	RU	4	132	313	78	41	432	446	5.2	10	338	0.68	53
3	P	2	46	56	11	4	71	71	1.0	1	154	0.79	58
3	P	2	100	70	21	12	103	108	3.5	6	108	0.63	53
3	P	2	54	114	26	4	144	145	1.3	2	269	0.80	51
3	RI	1	114	16	4	2	22	22	0.8	1	19	0.73	53
3	RI	1	99	19	11	3	33	35	2.6	4	35	0.59	55
3	RI	1	93	23	12	3	38	40	2.4	3	43	0.61	51
3	RI	1	89	24	19	6	49	57	6.6	10	64	0.47	56
3	RI	1	37	11	5	2	18	18	1.2	1	49	0.67	49
3	RI	1	29	5	1	0	6	6	0.1	0	21	0.86	43
3	RI	1	60	23	8	2	33	33	1.0	1	55	0.73	47
3	RU	2	107	139	45	24	208	220	5.5	11	206	0.62	56
3	RU	2	82	96	48	27	171	198	11.4	22	241	0.48	59
3	RU	2	102	91	60	18	169	191	9.5	19	187	0.51	51
3	RU	2	120	69	16	11	96	99	2.6	4	83	0.67	47

[a] One site was omitted due to unreliable depletion data
[b] ML = maximum likelihood (Warren 1994)
[c] Fork length
[d] P = pool, RI = riffle, RU = run

APPENDIX 2b. Juvenile cutthroat trout population data by habitat unit, Little Stawamus Creek, fall 1997[a].

				No. of coho						95%			
	Habitat		Area	Pass	Pass	Pass		ML[b] Pop.		CL	Density	Capture	Length[c]
Reach	Type[d]	Strata	(m^2)	1	2	3	Total	Estimate	SE	±	(fish · 100 m^{-2})	Prob.	(mm)
1	P	1	89	12	4	0	16	16	0.41	0.4	18	0.80	92
1	P	1	107	23	5	2	30	30	0.73	0.71	28	0.77	86
1	RI	1	51	4	2	0	6	6	0.38	0.37	12	0.75	63
1	RI	1	223	27	8	5	40	41	1.87	2.33	18	0.66	60
1	RU	1	116	4	3	1	8	8	1.06	1.03	7	0.62	67
1	RU	1	46	13	2	0	15	15	0.17	0.16	33	0.88	97
1	RU	1	139	20	8	3	31	32	1.75	2.22	23	0.65	78
2	P	2	82	55	14	13	82	87	3.85	6.27	106	0.60	83
2	P	2	103	61	20	15	96	91	11.7	20.5	88	0.41	62
2	P	2	71	38	18	8	64	70	4.55	7.46	99	0.55	86
2	P	2	45	25	19	6	50	58	6.42	10.3	129	0.48	98
2	RI	3	144	70	29	13	112	120	4.86	8.76	83	0.59	55
2	RI	3	345	54	35	24	113	155	22.5	43	45	0.35	60
2	RI	3	103	16	10	3	29	31	2.74	3.69	30	0.57	92
2	RI	3	128	15	13	6	34	44	9.83	14.6	34	0.47	90
2	RI	3	97	30	9	5	44	45	1.82	2.29	46	0.67	74
2	RI	3	137	11	15	8	34	75	59.2	78.5	55	0.18	61
2	RU	3	128	36	20	11	67	78	7.64	13	61	0.38	82
2	RU	3	81	14	10	3	27	30	3.6	5.02	37	0.52	105
2	RU	3	33	3	3	3	9	16	17.3	20.5	48	0.23	108
2	RU	3	63	21	9	5	35	38	3.28	4.71	60	0.56	116
2	RU	3	115	8	1	5	14	17	5.09	6.49	15	0.41	64
2	RU	3	132	25	5	3	33	33	0.88	0.86	25	0.75	91
3	P	3	46	15	5	2	22	22	0.96	0.94	48	0.71	106
3	P	3	100	12	7	7	26	37	13	18.3	37	0.33	120
3	P	3	54	20	4	1	25	25	0.49	0.48	46	0.81	77
3	RI	3	114	12	6	2	20	21	1.81	2.27	18	0.61	70
3	RI	3	99	21	14	5	40	45	4.75	7.15	45	0.51	57
3	RI	3	93	13	8	10	31	64	47.1	62.7	69	0.20	60
3	RI	3	89	13	12	2	27	30	3.6	5.02	34	0.52	88
3	RI	3	37	11	3	2	16	16	0.9	0.88	43	0.70	68
3	RI	3	29	8	3	0	11	11	0.38	0.38	38	0.79	62
3	RI	3	60	10	4	3	17	18	2.11	2.57	30	0.57	84
3	RU	3	107	28	20	4	52	56	3.76	5.68	52	0.57	87
3	RU	3	82	21	11	9	41	52	9.68	15	63	0.40	82
3	RU	3	120	24	12	5	41	44	3.25	4.69	37	0.57	73

[a] One site was omitted due to unreliable depletion data

[b] ML = maximum likelihood (Warren 1994)

[c] fork length

[d] P = pool, RI = riffle, RU = run

APPENDIX 3. Comparison of juvenile coho salmon and cutthroat trout standing stock estimates and 95% confidence limits for alternate sampling designs, Little Stawamus Creek, fall 1997.

Strategy	Species	Number of Sites	Estimated Standing Stock	95% Confidence Intervals (±)	± %
Runs and Pools	Coho	22	28,772	6,754	23%
Mark Recapture	Coho	N/A	23,291	2,176	9%
Simple Random Sampling	Coho	36	19,233	5,488	29%
100 m representative sites	Coho	9	19,034	5,540	29%
Stratified Random Sampling	Coho	36	16,511	2,236	14%
Mark Recapture	Cutthroat	N/A	6,195	1,108	18%
Runs and Pools	Cutthroat	21	5,824	1,542	26%
Simple Random Sampling	Cutthroat	36	5,534	1,058	19%
Stratified Random Sampling	Cutthroat	36	5,520	748	14%
100 m representative sites	Cutthroat	9	5,508	1,676	30%

APPENDIX 4. Juvenile coho salmon and cutthroat trout population data from representative 100 m section sampling, Little Stawamus Creek, fall 1997.

				No. of coho								
Site	Reach	Distance upstream	Area (m^2)	Pass 1	Pass 2	Pass 3	Total	ML[a] Pop. Estimate (N)	95% CL of N ±	± %	Density (fish·100 m^{-2})	Capture Prob.
COHO:												
1	1	0	255	196	54	43	293	314	15.02	5%	123	0.59
2	1	319	515	291	71	36	398	410	9.29	2%	80	0.69
3	2	464	400	910	225	115	1250	1290	17.00	1%	323	0.68
4	2	917	518	402	144	83	629	681	24.35	4%	131	0.57
5	2	1066	280	238	114	47	399	439	22.70	5%	157	0.55
6	2	1408	480	642	188	118	948	1005	23.33	2%	209	0.61
7	3	2455	541	349	131	63	543	582	20.27	3%	108	0.59
8	3	2788	328	196	105	38	339	375	22.11	6%	114	0.54
9	3	3003	262	211	51	17	279	284	5.31	2%	108	0.74
CUTTHROAT:												
1	1	0	255	20	9	1	30	30	0.94	3%	12	0.73
2	1	319	515	83	23	10	116	119	3.99	3%	23	0.69
3	2	464	400	224	81	49	354	385	19.29	5%	96	0.57
4	2	917	518	115	74	41	230	292	43.86	15%	56	0.40
5	2	1066	280	54	32	14	100	115	15.78	14%	41	0.49
6	2	1408	480	74	30	21	125	142	16.74	12%	30	0.50
7	3	2455	541	110	64	32	206	244	28.40	12%	45	0.46
8	3	2788	328	46	29	21	96	132	38.58	29%	40	0.35
9	3	3003	262	62	23	9	94	98	5.13	5%	37	0.64

[a] ML = maximum likelihood (Warren 1994)

APPENDIX 5. Summary of stream-wide mark-recapture data for Little Stawamus Creek, fall 1997. Recovery section is given as distance (m) upstream from the Stawamus River confluence.

Recovery Section [a]	Area Sampled (m^2)	Total Marked	Mark Recovery	Total Recovery	Mark Incidence	Population Estimate (N)	95 % CL of N	
							±	± %
COHO:								
0-428	1611	684	48	322	15%	4515	1153	26%
428-994	2060	1725	99	288	34%	4988	787	16%
994-2208	4432	1353	143	717	20%	6751	983	15%
2208-2722	1980	538	60	309	19%	2739	611	22%
2722-3218	2580	615	40	285	14%	4297	1203	28%
Total	12663	4915	390	1921	20%	23291	2176	9%
CUTTHROAT:								
0-428	1611	140	8	35	23%	564	303	54%
428-994	2060	543	57	145	39%	1369	271	20%
994-2208	4432	253	43	335	13%	1940	528	27%
2208-2722	1980	203	32	165	19%	1026	309	30%
2722-3218	2580	188	6	47	13%	1296	830	64%
Total	12663	1327	146	727	20%	6195	1108	18%

[a] Recovery section given by distance upstream from Stawamus River confluence.