Cheakamus Project Water Use Plan

Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring

Implementation Year 5

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Cheakamus River Steelhead Adult Abundance, Fry Emergence-timing, and Juvenile Habitat Use and Abundance Monitoring Fall 2011 – Spring 2012

Study Period: 2011

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Cheakamus River Steelhead
Juvenile and Adult Abundance Monitoring
Fall 2011 – Spring 2012

Final Report

Prepared for BC Hydro

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Abstract

The Cheakamus River once supported a large and productive wild winter-run steelhead population and a well-known steelhead fishery, and there is a desire among stakeholders to improve freshwater rearing conditions to increase the abundance of this population. A proportion of the Cheakamus River is diverted to the Squamish River for power generation. In 2006, rules controlling the timing and extent of the diversion, which affects the flow regime in the river downstream of Daisy Dam, were modified based on recommendations from a Water Use Planning (WUP) process. The objectives of this project are to determine if the number of juvenile and adult steelhead in the Cheakamus River, and the freshwater survival rate of various juvenile stages, are affected by the WUP flow regime, and more broadly, to determine how flow affects steelhead production in this system. This will be accomplished through long-term monitoring of juvenile abundance and adult returns.

Adult Returns

Escapement of steelhead to the Cheakamus River has been conducted annually since 1996 and is determined by combining data from snorkel swim counts and radio telemetry. In 2012, only six surveys were conducted (March 8th - April 18th). An early and large freshet occurred in 2012 and eliminated survey opportunities after April 24th. The expected value for wild- and hatchery-origin escapement in 2012 was 568 (CV=0.17). The 2012 estimate was more dependent on assumptions effecting run-timing, which is based on data from other years, as there were no swims conducted after approximately mid-April.

Average steelhead escapement from the 1996-2001 pre-IFA period was 181 fish, and the average escapement during the IFA period, which was based on returns from 2002-2007, was 362 fish. There was strong statistical evidence for a large increase in escapement derived from juveniles that reared in the Cheakamus River during the IFA period. There was a highly significant ($p<0.001$) increase in minimum flows during winter from an average of 9.2 $m^3 \cdot sec^{-1}$ to 13.5 $m^3 \cdot sec^{-1}$ between pre-IFA and IFA periods. It is possible that the doubling in escapement between these periods was in part caused by higher minimum flows. Wild-origin escapement declined over two consecutive years for returns produced from juveniles that were present in the river during the sodium

hydroxide spill (escapement in 2008, 2009) and this decline fit the predictions of the model used to assess spill impacts. However, because of the exceptional escapements from 2010 through 2012, the 2008-2012 post-spill average of wild-origin steelhead (471) was higher than the IFA/pre-spill average. There was no evidence of a decline in steelhead escapement based on fish that reared in the river after February 1996 when the WUP was implemented. Average escapement of wild steelhead from 2010-2012 was 667, well above the post-IFA/pre-spill average of 177 (2008-2009) or the pre-spill average of 362 (2002-2007).

Steelhead escapement to Brohm River estimated by reds counts in 2012 was 40 spawners. There was relatively good agreement between estimates of steelhead escapement to Brohm River based on redd counts and from the resistivity counter in years when both methods were used. There was also good agreement between escapement estimates from redd counts and those derived based on the product of the Cheakamus escapement estimate and the telemetry-derived Brohm immigration rate. Given the very limited effort to derive a Brohm estimate from redd counts (4-5 days for one biologist), we recommend continuing this effort.

Juvenile Abundance

Estimates of juvenile steelhead abundance were derived for fall and spring periods in Brohm and Cheakamus Rivers beginning in fall 2008.. These values can be used to track abundance and survival rates through time and to relate these patterns to spawning escapement and changes in flow. Fall abundance estimates were based on electrofishing, while spring estimates were based on both electrofishing and snorkeling. Mark-recapture experiments in fall and spring were used to characterize detection probability (the proportion of fish captured or detected). These values were used to expand counts at a large number of index sites sampled by a single pass of effort. A hierarchical Bayesian model (HBM) integrated these data to estimate abundance and uncertainty in abundance estimates.

Index sampling sites covered 11% and 6% of the total useable shoreline length in Brohm and Cheakamus Rivers in fall 2011, and 44% and 18% in spring 2012, respectively. Median abundance estimates of age-0+ steelhead in the Cheakamus River in fall ranged from a high of 392,000 in fall 2011, to a low of 71,000 in 2010. Parr abundances in the Cheakamus River in fall are likely biased low due to overestimation of river-wide detection probability. Age-0+ and -1+ and abundance estimates in spring, all of which are unbiased, ranged from 22,000-88,000 and 6,000-20,000, respectively. Most abundance estimates for the Cheakamus and Brohm Rivers had coefficients of variation of 0.2 or less.

Survival rates for various life stages were computed from changes in abundance estimates across sample periods. In the Cheakamus River, egg – fall fry (age-0+) survival rates ranged from a high of 43% for the 2008 spawning cohort, to a low of 4% for the 2010 cohort. Survival from fall fry to the spring two winters later (when fish were age 1+) ranged from 4-28% in the Cheakamus River, and 5-12% in Brohm River. Coefficient of variation in these survival rates ranged from 0.16-0.30, which is relatively low considering the challenges of estimating survival rates in moderate-sized river systems like the Cheakamus.

The most significant finding from the juvenile analysis conducted to date is the demonstration that reasonable precision in estimates of survival rates across various freshwater juvenile life stages can be achieved. This will likely allow evaluation of the effects of major changes in flow and other abiotic and biotic factors on juvenile survival rates. Although sample size is limited, the 1st four years of data indicate that that high flows during the emergence period in July and August, coupled with sudden reductions in flow over this period, could reduce the egg-fry survival rate for steelhead in the Cheakamus River.

Glossary of Terms and Abbreviations

Adipose Fin:	A soft, fleshy fin found on the back of a fish behind the dorsal fin and just forward of the caudal fin (tail).
AIC:	The Akaikie Information Criteria is a model selection criterion based on parsimony where more complicated models, which may fit the data better, are penalized for the inclusion of additional parameters.
Anadromous:	Fish that migrate from the sea to fresh water to spawn.
Beta Distribution:	In probability theory and statistics, the beta distribution is a family of continuous probability distributions defined on the interval (0, 1).
Bias:	How far the average statistic lies from the parameter it is estimating.
Binomial Distribution:	A calculation that measures the likelihood of events taking place where the probability is measured between 0 (the event will certainly not occur) and 1 (the event is absolutely certain).
CV:	The Coefficient of Variation is a measure of the ability to repeatedly obtain the same value for a single sample or method (i.e., duplicate or replicate analyses). It is computed by dividing the standard deviation by the mean.
Detection Probability:	The fraction of a population in a specific area (e.g., a fish sampling site) that is detected by a unit of effort (e.g., a single pass of electrofishing).
Escapement:	That portion of a migrating fish population that is not harvested and escapes to natural or artificial spawning areas.
Fry:	A stage of development in young salmon or trout. During this stage the fry is usually less than one year old, has absorbed its yolk sac, is rearing in the stream, and is between the alevin and parr stage of development.
GIS:	A Geographic Information System is used to store and display spatially-reference data.
HV:	Horizontal visibility used in this study to measure the clarity of water which effects detection probability.

Lognormal Distribution:	Statistical distribution for which the log of the random variable is distributed normally.
HBM:	A Hierarchical Bayesian Model is most useful for data that is composed of exchangeable groups, such as fish sampling sites, for which the possibility is required that the parameters that describe each group might or might not be the same.
IFA/IFO:	Instream Flow Agreements and Instream Flow Orders are operating rules used to regulate discharge in rivers.
Length-Frequency:	An arrangement of recorded lengths, which indicates the number of times, each length or length interval occurs.
Maiden Spawner:	A steelhead adult returning to freshwater that has not spawned before.
Mark-Recapture:	A method to estimate the size of a population. It usually involves live-capturing salmon, marking or tagging them and releasing them back into the water at one location.
Maximum Likelihood:	Maximum likelihood estimation (MLE) is a popular statistical method used for fitting a statistical model to data.
Orthophotograph:	An orthophoto or orthophotograph is an aerial photograph geometrically corrected ("orthorectified") such that the scale is uniform.
Parr:	life stage of salmonid fishes, usually in first or second year, when body is marked with parr marks
Poisson Distribution:	A theoretical distribution that is a good approximation to the binomial distribution when the probability is small and the number of trials is large.
Posterior Distribution:	The expected distribution of parameter values determined from a Bayesian analysis that is based on prior information about the parameter as well as data being directly used in the estimation.
Precision:	The measure of the ability to repeatedly obtain the same value for a single sample or method (i.e., duplicate or replicate analyses). Precision can be quantified by calculated the coefficient of variation (CV).

Prior Distribution:	In Bayesian statistics, a prior probability distribution, often called simply the prior, expresses prior knowledge about the uncertainty in a parameter.
Q:	An abbreviation for discharge.
Radio Telemetry:	Automatic measurement and transmission of data from remote sources via radio to a receiving station for recording and analysis. In this context, it refers to the deployment of radio tags to provide information on the movement and distribution of adult steelhead while in freshwater.
Redd:	A egg nest formed in the gravel by salmon and other fish.
Repeat Spawner:	A steelhead adult returning to freshwater that has spawned before.
Smolt:	A juvenile salmonid that is undergoing the physiological change to migrate from fresh to salt water
Stock-Recruitment:	The relationship between the abundance of animals at one life stage (e.g., spawners) relative their abundance at a later stage (e.g., smolts).
Survey Life:	The length of time a surveyed object (e.g., a fish or redd) is visible to an observer (e.g., how long a steelhead spends in the surveyed area).
Thalweg:	The deepest part of a stream's channel.
TRIM:	Electronic and hard copy maps of topography, streams, and other features in BC at a 1:20,000 scale.
WUP:	The Water Use Planning process was used to define new flow regimes and monitoring programs for dams operated by BC Hydro.

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1.0 General Introduction

The Cheakamus River is a productive tributary of the Squamish River that supports populations of steelhead, chinook, coho, pink, and chum salmon, as well as resident populations of rainbow trout, bull trout, and other species. Daisy Lake Dam impounded the river in 1957 and a proportion of the water entering Daisy Lake Reservoir is diverted to the Squamish River for power generation. The Cheakamus River, downstream of Daisy Lake Reservoir, extends 26 km to its confluence with the Squamish River (Fig. 1.1). Only the lower 17.5 kilometers of this river are accessible to anadromous salmon and steelhead. As a result of the diversion, the Cheakamus River downstream of the dam receives only a portion of its natural discharge, and there is much interest in understanding how this altered flow regime effects fish populations.

The Cheakamus River once supported a large and productive wild winter-run steelhead population and a well-known steelhead fishery. Although adult steelhead returns are likely much smaller today, the run still attracts considerable angling effort and is likely one of the more productive wild steelhead population in southern BC (Van Dischoeck 2000). Steelhead juveniles rear for two to four years in the Cheakamus River before migrating to sea as smolts. Steelhead juveniles are potentially more sensitive than other juvenile salmonids in the Cheakamus River to changes in flow because they have a longer period of freshwater residency. All these factors contribute to a strong interest among resource users and fisheries managers in determining whether changes in the flow regime below Daisy Lake Dam are affecting steelhead in the Cheakamus River.

The timing and volume of diversion rates from the Cheakamus River, which effects flow downstream of the dam, have varied considerably since impoundment. From 1958-1994, diversions were largely driven by power generation within the constraints of the original water license. Historical operations did not always follow these constraints and the pattern of violations ultimately led the Department of Fisheries and Oceans to issue an instream flow order (IFO) to BC Hydro in 1997. This order was subsequently modified to become an instream flow agreement (IFA). The IFA specified that the greater of 5 $m^3 \cdot sec^{-1}$ or 45% of the previous seven days average inflow be released downstream (within a daily range of 37-52%). In February 2006, the operating constraints were modified based on a recommended flow regime from the Water Use Plan (WUP). The

WUP flow regime was based on meeting minimum flows at the dam and further downstream at Brackendale. Operating rules no longer depend on releasing a fixed fraction of inflows to the reservoir. Under the WUP regime, flows from the dam must now exceed 3 $m^3 \cdot sec^{-1}$ (November 1-March 31st) or 7 $m^3 \cdot sec^{-1}$ (April 1st-Octber 31st), and additional water must be released to maintain minimum flows at Brackendale of 15 $m^3 \cdot sec^{-1}$ (November 1st-March 31st), 20 $m^3 \cdot sec^{-1}$ (April 1st-June 30th), or 38 $m^3 \cdot sec^{-1}$ (July 1st – August 15th or 31st).

Dam-induced changes to the flow regime during winter and summer have the potential to effect steelhead incubation and rearing habitat, and operations at Daisy Lake Dam have led to a number of changes in the flow regime. As many of the operating rules focus on minimum flows, and the effect of operations on flow in the Cheakamus River is greatest during winter when inflows are lowest (when the diversion is a greater proportion of the inflow), there has been a noticeable change in minimum flows during winter under different operating regimes (Fig. 1.2). Operations during late spring and summer are dominated by local inflows, which often exceed the storage capabilities of the reservoir and the capacity of the tunnels (~60 $m^3 \cdot sec^{-1}$) which divert water to the Squamish River. Occasional maintenance on Daisy Lake Dam and the tunnels temporarily reduces reservoir storage and diversion capacity, which affects flows below the dam, including peak inflow periods (Fig. 1.3). Flows into the Cheakamus River downstream of the dam have been greater in years when maintenance has occurred when diversions were reduced (e.g., 2010 and 2011). Other operations during this period have occasionally led to sudden reductions in flow (e.g. drops in early and mid-August 2010 to help Chinook broodstock collection).

There was considerable debate during the Cheakamus River WUP process on the effects of flow regime on juvenile salmon and steelhead production (Marmorek and Parnell 2002). Proponents of the IFA regime argued that both seasonal and daily elements of the hydrograph could be important to juvenile salmonid production and that higher flows would provide benefits in off-channel rearing areas that were not accounted for in the WUP fish habitat modeling efforts. Proponents of the WUP flow regime had more confidence in the fish habitat modeling results, which suggested that dam operations do not affect the quantity or quality of mainstem and side channel rearing areas except at very low flows (Fig. 1.4). Much of the debate focused on steelhead, which is a highly valued species in the watershed and hypothesized to be more susceptible to flows than other salmonids because of its longer freshwater rearing period.

As part of the new water license agreement for the Cheakamus River, BC Hydro currently supports a number of monitoring programs to assess the effects of the WUP flow regime on fish populations downstream of the dam (BC Hydro 2007). Two projects provide information on steelhead abundance and survival and are the focus of this report. CHEAKMON#1a enumerates the number of fry and smolts outmigrating past a Rotary Screw Trap (RST) from late winter through spring, and in some years this program provides estimates of steelhead smolt abundance. CHEAKMON#3 provides estimates of the abundance of returning adult steelhead spawners, juveniles rearing in the river, and survival rates among various juvenile stages. The central objectives of these programs are to determine if the number of adult returns, juvenile abundance, and smolt production are affected by the WUP flow regime, and more broadly, to determine how flow affects steelhead production in this system. The overall approach of the projects are relatively straightforward: 1) quantify escapement and juvenile abundance in the fall and spring, and smolt production in the spring; 2) use these metrics to determine the survival rate between life stages and define life stage-specific stock-recruitment relationships; and 3) over time, compare abundance, survival rates and stock-recruitment relationships under different flow regimes, and relate changes in these metrics to particular flow regimes or unique flow events (Fig. 1.5).

Steelhead escapement to the Cheakamus River has been consistently assessed since 1996 (Korman et al. 2007, Korman et al. 2011a). The historical time series of escapement in part reflects the rivers capacity to produce steelhead under at least 3 different flow regimes (pre-IFA, IFA, and WUP). The simplest way to determine whether changes in flow have affected steelhead production is to compare escapement over these regimes (e.g., Fig. 1.5a). However, as escapement is also determined by parental abundance and marine survival, inferences regarding changes in freshwater habitat due to dam operations from this comparison may be weak unless flow effects are very large relative to these other factors. To address this limitation, estimates of steelhead parr and smolt abundance in the spring can be used to index freshwater productivity (e.g., Fig.

1.5b). Each annual estimate of escapement and parr or smolt abundance also contribute a single data point for freshwater stock-recruitment relationships between escapement and parr abundance, or escapement and smolt abundance. These relationships control for the effects of escapement on juvenile production, and removes any remaining effects associated with changes in marine survival (e.g., Fig. 1.5c). As data points accumulate (Fig. 1.6), it will be possible to relate outliers from the escapement-to-parr or escapement-to-smolt stock-recruitment relationships, which indicate substantially higher or lower juvenile steelhead production per unit escapement, to particular aspects of the flow regime, such as the frequency and magnitude of high flow events during the summer, or the duration of minimum flow periods during the winter. If the flow regime changes in the future, the escapement-to-parr or-smolt stock-recruitment relationships developed under the current WUP flow regime can be compared to a relationship estimated under the new regime (e.g., Fig. 5c).

Escapement-to-parr or -smolt stock-recruitment relationships are necessary for evaluating population-level effects of flow, but provide little insight into what life stages are most affected or which elements of the flow regime have the biggest effect on juvenile steelhead survival. For example, higher flows during summer or sudden reductions in flow over this period could increase mortality of recently emerged age-0 steelhead, but this mortality may not effect subsequent age-1+ abundance and overall freshwater production because of compensatory survival responses over the winter due to lower densities (i.e., better survival because of lower density). To account for such dynamics, it is necessary to quantify survival rates and stock-recruitment relationship for multiple juvenile life stages. We therefore develop relationships between escapement and age-0+ steelhead in the fall (fry), between age-0+ fish in the fall and the following spring (parr), and between age-0+ and age-1+ fish in the spring (Fig. 1.6). The first relationship quantifies incubation success and survival from emergence (summer) into the fall. The second quantifies age-0+ overwintering survival. The third quantifies the annual survival rates for parr.

This report summarizes and interprets data from the fifth year of the Cheakamus River WUP steelhead monitoring project, covering the fall 2011 and spring 2012 surveys (Fig. 1.4). See Korman 2008 (year 1) and Korman et al. 2010a (year 2), 2011b (year 3), and 2011a (year 4) for annual reports from previous years. The year 5 report is divided into two main chapters. Chapter two summarizes the adult escapement methods and results and chapter three summarizes the methods and results from the juvenile abundance program.

2.0 Adult Returns

2.1 Introduction

A program to estimate the annual number of adult steelhead returning to the Cheakamus River (escapement) was initiated by BC Hydro in 1996. Escapement is estimated by fitting parameters of a run-timing model to count data from repeat swim surveys conducted over the adult migration and spawning season (Korman et al. 2007). Estimates of diver detection probability, survey life and departure timing, determined from swim survey and radio telemetry data, are also incorporated in the model. This section of the report provides an estimate of steelhead escapement to the Cheakamus River in 2012. A synthesis of relevant physical data, other supporting information required to generate the 2012 escapement estimate, and counts of resident rainbow trout and char are also provided. We also provide the full time series of steelhead escapement estimates from 1996 to the present.

We conducted a series of redd counts in Brohm River in 2012 to estimate escapement. Brohm River is a tributary to the Cheekye River that enters the Cheakamus River at the downstream boundary of the swim survey area (Fig. 1.1). Radio telemetry has shown that between 6 to 41% (average 15%) of the tagged steelhead that enter the lower survey area in the mainstem Cheakamus River eventually move into Brohm River and spawn (Korman et al. 2011a). Because of this behaviour, escapement estimates currently generated for the Cheakamus River is an aggregate measure which includes the escapement to the Cheakamus proper as well as some or all of the escapement to Brohm River. By removing an estimate of the number of fish spawning in Brohm River from this aggregate estimate, or a proportion of that estimate, it is possible to estimate escapement to the Cheakamus River proper. Alternatively, the total escapement and the Brohm River immigration rate can be used to estimate escapement in this tributary. Development of independent time series of escapements for these two systems offers two advantages. First, a time series of Brohm escapement estimates could potentially be used as an ‘experimental control’ to compare with trends in the Cheakamus River, since the production of Brohm River smolts is not affected by flow regulation. As trends in estuarine and marine survival rates for these two stocks are likely similar, any differences in escapement trends would be attributed to differences in trends in freshwater productivity between systems. However, Brohm River may only act as a pseudo-control, since some juveniles fertilized there may migrate into the Cheakamus River and be effected by flow releases from Daisy Lake Dam. Second, it is important to use Cheakamus-specific escapement estimates in the development of escapement-juvenile stock-recruitment relationships to assess flow effects.

A sodium hydroxide spill from a train derailment in the Cheakamus River canyon in August 2005 killed approximately 90% of the juvenile steelhead population (McCubbing et al. 2006). An experimental hatchery program was implemented shortly after the spill to mitigate its effects on adult steelhead returns and speed the recovery rate of the population. Approximately 20,000 steelhead smolts were released in the spring of 2007 and 2008 resulting in hatchery-origin adult returns in 2009 through 2011. An accurate assessment of the effects of the spill and the hatchery mitigation program on adult steelhead returns is necessary in order to sensibly interpret the escapement time series with respect to flow regime effects (via direct changes or escapement-juvenile stock-recruit analysis). For example, we need to determine the extent to which the spill reduced wild adult returns in evaluating returns that were produced from juveniles that reared in the river under IFA and WUP conditions. It is essential to remove hatchery-origin adult returns from the WUP analysis of the escapement time series since these fish were not produced in the Cheakamus River, and therefore were not affected by flow regime. The returns from fish that reared in the river during the spill provide a useful check on the sensitivity of wild escapement for detecting changes in freshwater productivity. If a 90% mortality of juvenile fish cannot be detected in the escapement trend, the trend is unlikely to be able to detect differences caused by the switch from the IFA regime to the WUP regime.

2.2 Methods

2.2.1 Swim Counts and Angler Surveys in the Cheakamus River

Swim Counts

The Cheakamus River, downstream of Daisy Lake Reservoir, extends 26 km to its confluence with the Squamish River. Only the lower 17.5 kilometers of this river are accessible to anadromous salmon and steelhead (Fig. 1.1). The area surveyed for returning steelhead was limited to the upper 14.5 km of the anadromous portion of the river, and begins approximately 500 m below a natural barrier, extending to the confluence with the Cheekye River. Higher turbidity and turbulence downstream of the Cheekye confluence severely limit opportunities to conduct informative swim surveys. In 2012, only six surveys were conducted (March 8th - April 18th). An early and large freshet occurred in 2012 and eliminated survey opportunities after April 24th (Fig. 2.1).

Survey methods were the same as previous assessments (Korman et al. 2011a). On each survey, a team of three divers floated the entire survey area in four to six hours. The survey area is divided into 34 sections averaging 500 m in length. The number of steelhead (*Oncorhynchus mykiss* approximately >40 cm, purple-silver hue, few black spots, fusiform shape), resident rainbow trout (*Oncorhynchus mykiss* approximately 20-40 cm, darker coloration, black spots common and large, more 'blocky' shape), and bull trout (*Salvelinus confluentus*) observed in each section was recorded. Horizontal visibility (HV) was estimated by measuring the maximum distance from which a diver could detect a dark object held underwater at 1 m depth. Horizontal visibility was measured at 14.25 (section 4) and 7.65 (section 21) river kilometers (rkm) upstream of the Squamish River confluence to index conditions upstream and downstream of Culliton Creek, respectively (Fig. 1.1).

Mean daily discharge (Q) over the survey period was computed from the Water Survey of Canada (WSC) hourly discharge record at the Brackendale gauge (WSC 08GA043). Hourly water temperatures were recorded with an Onset Tidbit temperature logger placed at the North Vancouver Outdoor School just downstream of the WSC Brackendale gauge.

2.2.2 Ageing

Steelhead were captured by skilled volunteer anglers fishing both within and downstream of the survey area (Fig. 1.1). These anglers were given scale envelopes, measuring tapes and logbooks to provide information on the size and age structure of the 2012 returns. Freshwater and ocean ages were estimated by scale reading. Approximately five scales from each fish were collected from the preferred area above the lateral line and immediately below the dorsal fin. Samples were placed in coin envelopes marked with appropriate data for cross-reference. After a period of air-drying, scales pressed under heat to provide images on soft plastic strips. These images were magnified using a microfiche reader following the methods of Mackay et al. (1990). Age determination was undertaken by the methods outlined in Ward et al (1989) and were the same as those used in previous years. Two persons examined each scale sample set without knowledge of the size or time and location of capture of the sampled fish. Samples were discarded when a consensus between both persons could not be reached. At least one consistent scale reader has been used since the inception of the program. We compare the 2011 age estimates with those from previous years.

2.2.3 Steelhead Escapement Model

In order to determine the total escapement of returning spawners from periodic swim counts, the proportion of fish observed by divers (detection probability) and the fraction of the total run that is present on each survey is estimated (Korman et al. 2007). Detection probability can be estimated based on the fraction of marked fish present in the survey area that are observed, or by predicting it from river conditions. The fraction of the run that is present on any survey can be estimated based on difference between the cumulative proportion of the run that has arrived and the cumulative proportion that has departed. An escapement estimation model quantifies these processes. The model consists of three main elements. A process model predicts the number of fish present on each day of the run and the departure schedule based on the total escapement and relationships simulating arrival timing and survey life (the duration a fish resides in the surveyed area given its date of entry). An observation model simulates the number of marked and unmarked fish observed on each survey based on the number of tags known to be in the survey area, predictions of the number of unmarked fish that are present, and predictions of detection probability. A statistical model is then used to fit model predictions to observations to compute the most likely estimates (MLEs) of model parameters and to quantify uncertainty in these estimates.

Process and observation model parameters are estimated by maximizing the value of a likelihood function that integrates data on the number of marked and unmarked fish observed on each survey, the number of marks present in the survey area, survey life, and departure timing. Data for the latter three elements were collected by marking fish with an external spaghetti tag that could be identified by divers, and through radio telemetry. This marking-telemetry program has been undertaken in eigth (2000, 2001, 2003-2005, 2009-2011) of 16 years that the swim surveys have been conducted (1996-2012, excluding 1998). The model can be applied in years when marking-telemetry is not conducted by assuming that data on the relationship between detection probability and river conditions, survey life and date of entry, and data on departure schedules are exchangeable among all years.

In order to estimate hatchery-origin steelhead escapement from 2009-2011, we modified the Korman et al. (2007) model to predict escapement, and arrival and departure timing for both wild- and hatchery-origin fish. The model predicts the numbers of both stocks that are present on each survey, which in turn is used to determine the proportion that are of wild origin by survey date. These proportions are statistically compared to proportions based on the angler catch of wild- and hatchery-origin fish via an additional term in the likelihood function. We assume that hatchery- and wild-origin stocks have similar detection probabilities, survey lives (standardized by date of entry), and vulnerabilities to being captured by anglers (see Appendix A of Korman et al. 2011b). More details of the model are described below.

Process Model

The proportion of the total escapement entering the survey area each day is predicted separately for wild- and hatchery-origin stocks using a beta distribution (eqn. 2.1a, Tables 2.1 and 2.2). The beta distribution is parameterized so that β is calculated based on estimates of the day when the peak arrival rate occurs (μ, or the mode of arrival timing) and the precision of arrival timing (τ, eqn. 2.2), following the formulation in Gelman et al. (2004). Note that small values of τ represent a low and constant rate of arrival over the duration of the run, while larger values represent a shorter and more concentrated arrival timing. A more flexible arrival model, which is not constrained by a parametric function like the beta distribution, was included as an option in the new escapement model. In this case, we estimate the proportion of the run arriving between adjacent surveys (eqn. 2.1b). We refer to this latter model as the 'deviate' arrival-timing model.

Survey life, that is, the number of days a fish spends in the survey area, is predicted using a negative logistic function with respect to date of entry (i.e., fish that arrive later have a shorter survey life, eqn. 2.3). We assume that wild- and hatchery-origin stocks have the same survey life – date of entry relationship. Mean departure day for fish arriving each day of the run is predicted based on the sum of the arrival day and the survey life for fish arriving on that day (eqn. 2.4). The proportion of fish that arrive on day i and depart on day j, which we term the arrival-departure matrix, is predicted from a normal distribution (eqn. 2.5) and accounts for variation in survey life for a given arrival day. Matrix values are standardized so that proportions across all departure days for each arrival day sum to one, that is, all fish must exit the survey area by the assumed last day of the run. The proportion of fish departing on each day is a function of arrival timing and the arrival-departure matrix (eqn. 2.6). As the former values vary by stock origin, departure timing also varies by origin. The number of fish present in the survey area by stock on each day is the product of the total escapement and the difference in the cumulative arrival and departure proportions (eqn. 2.7). Estimates of the cumulative proportion of wild-origin steelhead that have arrived by model day are required for the two-stock model. These proportions are determined based on the ratio of the cumulative arrivals of wild-origin steelhead to the sum of cumulative arrivals across both stocks (eqn. 2.8).

Observation and Statistical Models

Escapement, arrival timing, and survey life parameters, and those defining the relationship between detection probability and the ratio of horizontal visibility to discharge (HV/Q), are jointly estimated by maximum likelihood. Independent likelihood terms are developed for different components of the model, and the log-likelihoods are added together to give a total likelihood function.

The likelihoods of the number of marked (L_r) and unmarked (L_u) fish observed are assumed to follow a Poisson distribution (eqn.'s 2.9 and 2.10). The terms L_r and L_u, as for all that follow, represent the sum of log-transformed probabilities across observations. Note that detection probability is a nuisance parameter that does not need to be directly estimated. Instead, it is evaluated at its conditional maximum likelihood estimate for each survey based on equation 2.11 (see Korman et al. 2007). That is, detection probability is simply the ratio of the total number of fish observed (data) to the total number predicted to be present. As predictions of the number present ($U_{o,i}$) are not independent across surveys because they are linked through the model structure, the number of unmarked fish contributes to the conditional estimate of detection probability. Detection probability is assumed to be equivalent among hatchery- and wild-origin steelhead in the two-stock model and is therefore based on the ratio of the total fish observed to the total present.

The ratio of horizontal visibility to discharge is a good predictor of detection probability in the Cheakamus River (Korman et al. 2011a). Physically-based detection probability estimates are required to estimate the number of fish present on surveys where there are no tagged fish in the survey area. In this analysis, we recognize that physically-based detection probability predictions can also be used on surveys where tags are present. Precision of a purely tag-based estimate of detection probability will be very poor when the total number of tags present or the true detection probability, is very low. In this situation, estimates of detection probability from the physically-based model, which incorporates information on detection probability from multiple surveys within and across years under similar environmental conditions, will make an important contribution to the estimate of the numbers present.

A logistic model is used to predict detection probability based on the ratio of horizontal visibility to discharge (eqn. 2.12). Two additional likelihoods for the observed number of marked (L_{pr}) and unmarked (L_{pu}) fish can now be computed by replacing the conditional detection probabilities (q_i) in eqn.'s 2.9 and 2.10 with detection probabilities by the physical model (p_i, eqn.'s 2.13 and 2.14). Parameters of the p-HV/Q relationship are jointly estimated with other model parameters using data from all surveys when tags were present (eqn. 2.15). Two sets of p-HV/Q parameters are estimated for data collected between 2000-2005 and 2009-2011. Escapement estimates prior to 2009 are based on the former set, while estimates after that are based on the latter. Note that L_{pr} is the sum of likelihoods across surveys in the year that escapement is being estimated for. L_p is the sum of likelihoods across all surveys when tags were present over all years when telemetry was conducted, excluding observations used in calculating L_{pr} to avoid double counting.

The likelihood of the survey life data (L_s) is computed assuming normally distributed error (eqn. 2.16). Note that the term σ_{sl} in this likelihood function is a nuisance parameter that is calculated at its conditional maximum likelihood estimate based on eqn. 2.17 (Ludwig and Walters 1994). The likelihood of the observed number of fish departing the lower survey area in a downstream direction by stock origin ($L_{o,d}$) is computed assuming multinomial error (eqn. 2.18).

Estimates of the proportion of cumulative arrivals that are wild in origin by survey date (eqn. 2.8) are compared to observed estimates of stock proportions determined by the number of wild- and hatchery-origin steelhead landed by anglers. The likelihood of the catch of wild-origin steelhead up to each survey date (L_f) is computed assuming Poisson error, and depends on the total catch (wild and hatchery) up to each survey date and the predicted cumulative proportion of wild fish (eqn. 2.19). This approach assumes that wild- and hatchery-origin fish are equally vulnerable to anglers, which is supported based on a re-analysis of data from the Chilliwack River designed in part to test this assumption (see Appendix A or Korman et al. 2011a).

The total log-likelihood for all the data given a set of model parameters $\theta = \varepsilon_o, \mu_o, \tau_o, \lambda_m, \lambda_h, \lambda_s, \rho_h, \rho_s$, was determined by summing all component log-likelihoods and the penalty function (eqn. 2.20). In years when hatchery-origin steelhead are expected to return (2009-2011), ε_H, μ_H, τ_H are estimated by including L_{dH}, and L_f in the total likelihood. When estimating parameters for any particular year, note that the first four terms of the total likelihood and L_f (eqn. 2.20) are evaluated based only on data collected in that year, while the latter 4 terms depend on data collected over all years when telemetry was conducted. The denominator of 2 in the total likelihood formula accounts for the fact that observations of marked and unmarked fish are double-counted in the overall likelihood because they are evaluated using both conditional MLE values (q from eqn. 11) and physically-based predictions of detection probability (p from eqn. 2.12). The first term of eqn. 2.20 does not contribute to the total likelihood in years where tagging was not conducted, or for surveys where tags are not present in years when tagging is conducted.

We used the year-independent model to estimate the historical time series of escapement for the Cheakamus River steelhead population. This model estimates all model parameters independently for each year. In years with only wild-origin steelhead returning, eight parameters are separately estimated for each year. An additional 3 parameters are estimated in years when hatchery-origin fish are returning. To derive estimates of the number of wild-origin fish from 1996-2012 and hatchery-origin fish from 2009-2011, a total of 137 parameters are estimated (1998 is excluded as no surveys were conducted).

Escapement estimates were computed using the AD model builder software (Otter Research 2004). Non-linear optimization was used to quickly find the maximum likelihood estimates (MLEs) of parameter values. Uncertainty in MLEs was computed using the delta method. Estimates of the expected (average) parameter values and 90% credible intervals (10th and 90th percentiles) were calculated from posterior distributions generated using Monte Carlo Markov Chain (MCMC) simulation. The posterior distributions for each year were derived from a total of 50,000 simulations. Every 5th value was retained to remove auto-correlation among adjacent estimates. Of the 10,000 remaining simulations, the first 1,000 records were discarded to remove initialization (i.e., burn-in) effects. This sampling strategy was sufficient for the model to produce stable posterior distributions (model convergence) for all parameters in all years.

2.2.4 Stock-Recruit Analysis

The number of adult steelhead returning to the Cheakamus River will be determined by freshwater and marine survival rates as well as the number of spawners that produced the returns, often termed brood escapement or spawning stock. We examined the relationship between spawning stock in each brood year and the resulting adult returns using a stock-recruit analysis. To do this, the recruitment (R_t) paired with the escapement ($\varepsilon_{W\,t}$) in brood year t was calculated from,

$$R_t = \varepsilon_{W,t+3} P_{t+3,3} + \varepsilon_{W,t+4} P_{t+4,4} + \varepsilon_{W,t+5} P_{t+5,5} + \varepsilon_{W,t+6} P_{t+6,6} \,,$$

where ε_W is the wild-origin escapement in year $t+a$ and P is the proportion of maiden fish returning in year t at total age a. Age proportions were specific to years when ageing was conducted, which occurred in years when telemetry was done (2000, 2003-2005, 2009-

2011). Age proportions in other years (including 2012 because so few scale samples were obtained) were held constant at the multi-year average. As no escapement estimate was available for 1998, we averaged escapements from 1997 and 1999 to calculate escapement for this year. This was necessary to compute the spawning stocks for the 2001-2003 return years. Stock-recruit analyses of adult data are traditionally only applied to semalparous species, or to immature stages of iteroparous species. In the case of steelhead, which are iteroparous, the number of repeat spawners must be removed from the number of recruits or they would be double-counted in the stock-recruit analysis. We used the average repeat spawner rate based the complete ageing dataset to compute the number of maiden recruits (maiden recruits = total recruits * (1-repeat spawner fraction)). We then plotted the number of maiden adult recruits as a function of the spawning stock that produced it.

Estimates of spawning stock that determine subsequent recruitment can be improved by accounting for inter annual variation in sex ratios and fecundity of spawners. To evaluate these factors for Cheakamus steelhead, we computed egg deposition in years when information on sex ratio and female fork length was available from angling surveys. Annual egg deposition was computed as the product of total escapement, the proportion of the escapement made up of females, and fecundity. The latter was computed based on annual average female fork length from the Cheakamus River and a fecundity-female fork length relationship for steelhead from the Keogh River (Ward and Slaney 1993). The ratio of egg deposition to escapement was then computed to determine how much variability in spawning stock across years is driven by differences in the sex and size structure of returning adults.

2.2.6 Redd and Resistivity Counter Data from Brohm River

We used a visual count of steelhead redds, or egg nests, to estimate escapement in Brohm River. Redd surveys can be an effective, precise and unbiased indicator of escapement if survey methods are consistent and if conditions are suitable (Dunham et al. 2001,Gallagher and Gallagher 2005). Brohm River is well suited to steelhead redd counts for several reasons: its small size and clear water allow a single person to observe the entire cross section of the riverbed with minimal lateral movement; there is high contrast between disturbed and undisturbed gravel; and flow is relatively stable over the migration and spawning period. All these attributes help ensure all redds constructed between surveys are counted by the observer, a critical assumption in the assessment. We assumed that all redds were created by steelhead, rather than resident rainbow trout. This is likely the case, as otolith microchemistry indicated that over 90% of juvenile trout sampled in Brohm River in spring 2009 had an anadromous maternal parent (Korman et al. 2010a).

In 2012, we conducted three surveys of the entire 2.4 km of Brohm River that is accessible to steelhead at roughly two-week intervals between April 24th and May 23rd. The approximate two-week interval between surveys was the assumed longest time period where a redd constructed immediately after one survey would still be visible during the next survey (Gallagher and Gallagher 2005), which was confirmed in Brohm River in 2009 (Korman et al. 2010a). A single observer wearing polarized glasses walked downstream searching the entire stream cross section for redds. The observer also carried a dive mask and snorkel to check areas where surface turbulence or depth prevented a clear view of the riverbed. Redds were identified by several characteristics: a) circular or dish-shaped depressions often of brighter appearance than the surrounding area with a zone of deposition along the downstream margin or ‘back-stop’; b) a deposit of unsorted bed material in the depression; and c) over-steepened walls with substrate perched on the edge of the depression (an indication of excavation by tail strokes rather than scour by flow). We distinguished between ‘test digs’ and completed redds by the former’s more elongated shape and lack of a ‘back-stop’ and deposition in the depression. In circumstances where the disturbed area was much larger than typical redds, we looked for indications that more than one redd was present based on the formation of multiple deposits and signs of superimposition.

We recorded the position of each redd using a Garmin 60CX GPS and marked them with a fluorescent pin. This allowed us to avoid counting the same redds on different surveys, and therefore to determine the number of unique redds created over the spawning period. The number of unique redds was converted to the number of female spawners based on the assumption that each female digs on average 1.2 redds (Jacobs et al. 2002). The number of females was then converted to the total number of spawners by assuming a 1:1 sex ratio. Under these assumptions, the total number of redds can be converted to the total escapement by multiplying it by a redd-to-spawner conversion of 1.7 (i.e., 2 spawners/female / 1.2 redds/female = 1.7 spawners/redd).

A resistivity counter was installed in Brohm River approximately 75 m upstream from the confluence with the Cheekye River in spring 2010, 2011, and 2012 (McCubbing and Melville 2010). The objectives of this project were to derive an independent estimate of steelhead escapement (relative to redd counts) and to better understand the relationship between migratory timing of adult returns and flow in Brohm River[1]. In 2012, there were a number of problems with the counter which did not allow us to obtain an escapement estimate.

We compare estimates of the number of spawners in Brohm River and entry timing derived from redd counts with those determined by the resistivity counter. We compared these values with a tag-based estimate of escapement for Brohm River, calculated as the product of the proportion of steelhead radio tagged in the Cheakamus River that moved into Brohm River and the total escapement estimate for the Cheakams River.

2.3 Results

2.3.1 Swim Counts and Creel Survey

Discharge in the Cheakamus River was generally low and steady through mid-April, but then rose above levels where swims can be conducted due to an early and large freshet (Fig. 2.1). This resulted in us completing only six of the 10-12 surveys we had planned on, and not completing any surveys after April 19th (Table 2.3). Counts of steelhead, rainbow trout, and bull trout across surveys ranged from 31-86, 24-74, and 57-185 fish, respectively.

2.3.2 Age structure

A total of only 14 resident rainbow trout and steelhead were captured by volunteer anglers and were sampled for age in 2012 (Table 2.4). Five of these 14 fish

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[1] The resistivity counter was not funded or approved for funding by BC Hydro. This project was supported solely by Instream Fisheries Research and will be summarized in detail in a report prepared for Ministry of Environment.

were classified as resident rainbow trout based on their scale ages, which included one hatchery-origin fish.

Only 4, 8, and 3 freshwater, ocean, and total ages could be obtained from the 9 steelhead that were sampled for scales in 2012 (Table 2.5). The ocean age for all but one fish was 3 years, indicating that the vast majority of the 2012 run originated from the 2009 smolt run. The total age structure for steelhead in 2012 was very similar to that in 2011, though sample size in 2012 was extremely limited. Only three of five resident rainbow trout could be reliably aged at ages of 5 or 6 (Table 2.6). These fish were larger than those at the same age sampled in 2011, though sample sizes are too small to make any quantitative comparisons.

2.3.3 Escapement Estimates

The expected value for wild escapement to the Cheakamus River in 2012 was 568 (CV=0.17). We assumed no hatchery-origin steelhead returned in 2012 as the last smolt release year was 2008. The 2012 estimate was more dependent on assumptions effecting run-timing, which is based on data from other years, as there were no swims conducted after approximately mid-April (Fig. 2.2). The 2012 estimate is 1.75-fold larger than the average across all previous years. The historical escapement trend for the Cheakamus River can be segregated into 3 periods (Fig. 2.3). Returns were low (average 181) in years when the juveniles that produced these returns reared in freshwater prior to the imposition of the Instream Flow Agreement (IFA, escapement from 1996-2001), and the average was twice as high after this but prior to the sodium hydroxide spill (362, escapement from 2002-2007). This difference was statistically significant (p=0.008). Wild-origin escapement declined over two consecutive years for returns produced from juveniles that were present in the river during the spill (escapement in 2008, 2009). However, because of the exceptional escapement from 2008-2012, the post-spill average of wild-origin steelhead (471) was higher than the IFA/pre-spill average (362).

2.3.4 Stock-Recruit Analysis

We did not attempt to fit a formal stock-recruitment model to the data (e.g., a Beverton-Holt model) as the initial slope of that relationship is poorly defined due to the absence of very low escapement values (Fig. 2.4). There is no indication that recruitment declines with escapement over the range of estimates that are available. The estimates suggest that escapements as low as 100 fish are sufficient to fully seed the river, and that the replacement level (intersection of 1:1 and stock-recruit lines) is approximately 300 spawners. The 2006 positive outlier highlights the exceptional survival for this brood. This was the first brood that spawned following the sodium hydroxide spill. There is too much uncertainty in steelhead smolt size estimates to determine if smolt production in 2008 was higher, perhaps due to lack of intra- and inter-specific competition and predation due to spill-related mortality. The exceptional total survival rate for this brood was likely mostly driven by an increase in marine survival as inferred from the hatchery return rate for the 2008 release (see Korman et al. 2011a). The 2004 negative outlier was likely caused by the sodium hydroxide spill which severely limited freshwater production from this brood year. The 2005 brood year is not a negative outlier, which is surprising as these returns were produced from incubating fry and recently emerged from in the river at the time of the spill. Increased freshwater survival at low density combined with higher marine survival for 3 yr smolts from this brood (entering the ocean in 2008) are the likely causes for the average recruitment from this brood.

There was substantive variation in the number of eggs deposited per spawner across years due to differences in sex ratios and the average size of female spawners (Table 2.7). Average fecundity varied from a low of 3,206 (2010) to a high of 5,733 (2012). The proportion of the escapement that were females varied from a low of 0.41 (2001) to a high of 0.63 (2012). Egg deposition varied from a low of 171,000 (2000) to a high of 3,178,000 (2011). The ratio of egg deposition (in '000s) to total escapement varied from a low of 1.4 (2010) to a high of 3.6 (2012) with an average of 2.1. Returning fish in 2012 were larger than average due to the high proportion of ocean age 3 year fish, which resulted in the highest fecundity on record. As a result, the total egg deposition estimate for 2012 is higher than in 2010 even though escapement was two-fold higher in 2010.

Sex- and size-structure information is only available for about ½ of years where escapement estimates are available. In other years, an average multiplier of 2.1 would need to be applied to translate spawning stock to egg deposition on the x-axis of the stock-recruit curve. As most of the points on that curve do not have year-specific estimates, this results in an equal shift along the x-axis for most points, resulting in a very similar stock-recruit relationship. However, year-specific estimates of egg deposition will be useful in the computation of egg-fry survival rates from the more recent juvenile data collected in years when sex- and size-structure data for the escapement is available (see Section 3).

2.3.5 Redd and Resistivity Counter Data from Brohm River

A total of 24 unique redds were enumerated over three surveys in 2012, which translated to 50 spawners based on the 1.7 spawner-per-redd conversion (Table 2.8). The 2012 escapement estimate is a little more than ½ of the estimates for 2010 and 2011. Spawn timing in Brohm River in 2012, based on the temporal pattern in the cumulative number of redds was similar to the timing in 2011 (Fig. 2.5). The escapement estimate from red surveys could not be compared to an independent estimate from the resistivity counter which could not be derived due to operational problems.

The estimated number of spawners in Brohm River in 2012, based on the product of the total escapement to the Cheakamus River (568, which can include fish destined to spawn in Brohm River) and the 2010-2011 average Brohm migration rate (6.2%), was 35 fish, close to the estimate of 40 fish based on redd counts (Table 2.8).

2.4 Discussion

Steelhead escapement to the Cheakamus River in 2012 was 568 spawners (CV=0.17). The precision of the estimate is relatively good considering that only 6 swim surveys were conducted, and that no surveys were conducted after about mid-April. Typically, only about ½ of the total run has arrived by that date. The assumption of that survey life and departure timing relatinships are exchangeable across years results in the relatively precise 2012 estimate given the low numbers of swim surveys. Thus, relative to most other annual estimates, the estimate for 2012 is more dependent on run timing data from other years.

Average steelhead escapement from the 1996-2001 pre-IFA period was 181 fish, and the average escapement during the IFA period, which was based on returns from 2002-2007, was 362 fish. Based on a t-test, there was less than a 1% chance that this two-fold increase in escapement across periods could be due to chance alone. Thus, there is strong statistical evidence for a large increase in escapement derived from juveniles that reared in the Cheakamus River during the IFA period. There was a highly significant ($p<0.001$) increase in minimum flows during winter from an average of 9.2 $m^3 \cdot sec^{-1}$ to 13.5 $m^3 \cdot sec^{-1}$ between pre-IFA and IFA periods. It is possible that the doubling in escapement between these periods was in part caused by higher minimum flows. Wild-origin escapement declined over two consecutive years for returns produced from juveniles that were present in the river during the sodium hydroxide spill (escapement in 2008, 2009). This decline fit the predictions of the model used to assess spill impacts. However, because of the exceptional escapements from 2010 through 2012, the 2008-2012 post-spill average of wild-origin steelhead (471) was higher than the IFA/pre-spill average.

There was no evidence of a decline in steelhead escapement based on fish that reared in the river after February 1996 when the WUP was implemented. Average escapement of wild steelhead from 2010-2012 was 667, well above the post-IFA/pre-spill average of 177 (2008-2009) or the pre-spill average of 362 (2002-2007). Escapement was dominated by ocean age 2 fish in 2010 and ocean age 3 fish in 2011, both of which left as smolts in 2008. Marine survival rates for hatchery-origin smolts released in 2008 (4.1%) were over 5-fold greater than the survival rate of smolts released in 2007 (0.75%). It is very likely that the large escapements in 2010 and 2011, and perhaps 2012, were due to the elevated marine survival rate, rather than changes in freshwater survival rates associated with WUP flows. Such changes in marine survival rates confound our ability to make evaluations of flow effects on freshwater survival based on escapement data.

The number of maiden adult returns to the Cheakamus River appeared to be relatively independent of the number of spawners that produced them, which indicates strong density dependence in spawner-to-adult return survival rates. This result is not surprising as many steelhead trout and coho salmon stock-recruitment relationships indicate that relatively few spawners are needed to adequately seed available habitat, and that the majority of density dependence occurs during the freshwater stage of the life cycle (Ward and Slaney 1993, Bradford et al. 2000, McCubbing and Ward 2008). There is considerable uncertainty about the productivity (initial slope of the recruitment curve) of Cheakamus River steelhead, however the data from 2001-2004 indicate that it is likely a minimum of 3 recruits/spawner. In its current form, this relationship is useful for assessing impacts of fishing mortality and it suggests that considerable harvest will not influence future returns until escapement drops below ~ 100 fish.

The 2006 and 2007 brood year data points were influenced by WUP flows and show no evidence of reduced productivity. The positive outlier for the 2006 brood year highlights the exceptional survival for this brood. This was the first brood that spawned following the sodium hydroxide spill. The exceptional total survival rate for this brood was likely mostly driven by an increase in marine survival, as inferred from hatchery return rates, which were 5-fold greater for smolts outmigrating in 2008 compared to 2007. The 2004 negative outlier was likely caused by the sodium hydroxide spill, which severely reduced freshwater production. Interestingly, there is no evidence for an effect on the 2005 brood year even though post-emergent fry were in the river at the time of the spill in August 2005. This brood out-migrated in 2007 for the most part, prior to the increase in marine survival. Thus, there may have been a strong compensatory survival response for the component of the 2005 brood that survived the spill due to low density and reduced predator abundance.

There was relatively good agreement between estimates of steelhead escapement to Brohm River based on redd counts (70) estimates from the resistivity counter (65 and 54) in years when those could be compared (2010 and 2011). There is also good agreement between escapement estimates from red counts and those derived based on the product of the Cheakamus escapement estimate and the telemetry-derived Brohm immigration rate. Given the very limited effort to derive a Brohm estimate from redd counts (4-5 days for one biologist), we recommend continuing that effort.

3.0 Juvenile Steelhead Abundance

3.1 Introduction

This section summarizes the methods and results from steelhead juvenile abundance surveys conducted in Cheakamus and Brohm Rivers in fall 2011 and spring 2012 (Fig. 1.6). It also provides revised estimates of abundance from previous surveys. Changes in juvenile abundance over multiple years can be related to changes in flow regime or other habitat changes to make inferences about how freshwater habitat quantity and quality effects juvenile steelhead production (Fig. 1.5b). The evaluation of habitat effects includes assessing potential benefits and impacts of the new WUP flow regime. Differences in the abundance within age classes between fall and spring surveys can be used to estimate apparent survival rates between these periods. The over-winter period (fall to spring surveys) is important to assess since flows in the Cheakamus River are most affected by regulation from Daisy dam during periods of low inflows, which are common during winter, and winter flow regimes have been shown to be important determinants of juvenile salmonid production and/or mortality in some systems (Hvidseten 1993, Bradford et al. 1995, Jensen and Johnsen 1999, Saltveit et al. 2001, Mitro et al. 2003). The summer period (spring to fall surveys) is important because habitat availability shortly after emergence (Elliot 1994, Nislow et al. 2004) or during low flow periods in late summer (Berger and Gresswell 2009, Harvey at al. 2005) have been shown to be important determinants of juvenile production as well, and most of the hypotheses during the Cheakamus WUP for steelhead focused on effects of low flow periods in the fall (Marmorek and Parnell 2002). Juvenile abundance can be related to escapement via estimation of life-stage specific stock-recruitment relationships so density-dependent effects can be accounted for when interpreting changes in juvenile abundance and survival through time (Fig. 1.5c). Estimates of juvenile abundance in Brohm and Cheakamus River can be compared to determine what fraction of the aggregated population rears in Brohm River, which is not effected by flow regulation from Daisy Dam.

The evaluation of the effects of habitat, flow, and escapement on juvenile abundance and survival can only be accomplished with a relatively long-term dataset.

The juvenile component of this project began in fall 2007 (Korman 2008) and only five years of juvenile abundance data are available (Fig. 1.6). Sampling for juvenile steelhead prior to 2007 has been limited and based on the non-random selection of sites thought to contain high quality parr habitat (see review in Van Dishoeck 2000). Changes in abundance estimates from such studies are unlikely to reflect river-wide changes in abundance because many factors, including variation in juvenile density, will affect patterns of habitat use (Bohlin 1978, Rosenfeld and Boss 2001, Girard et al. 2004, Rosenfeld et al. 2005, Gibson et al. 2008). The outmigrant trapping program has enumerated steelhead smolts since 2000, but estimates of steelhead smolt outmigration abundance are available for only a subset of these years, and uncertainty in these estimates may be significantly underestimated due to logistical and analytical challenges (Melville and McCubbing 2011). Given these historical difficulties and limitations, the emphasis of our analysis of the juvenile data collected in the early phases of this project focused on evaluating potential bias and the precision of abundance estimates. In year 1, we investigated a variety of sampling techniques (Korman 2008), which guided the sampling design of the intensive program initiated in year 2. In this chapter, we report on the results from surveys conducted in year 5. A key assumption in our methodology is that data on detection probability of juvenile steelhead based on mark-recapture experiments is exchangeable among years. We combine data from mark-recapture experiments across years using a hierarchical Bayesian model (HBM) to compute year-specific abundance estimates. Thus, previously published juvenile abundance estimates for the Cheakamus and Brohm Rivers must be updated to reflect the addition of fall 2011 and spring 2012 mark-recapture data. Given the additional mark-recapture data, this chapter includes revised values for previously published estimates (Korman et al. 2011a).

3.2 Methods

We used a multi-gear two-phase sampling design to estimate the abundance of age 0-, 1-, and 2-yr old juvenile steelhead in the Cheakamus and Brohm Rivers. We first conducted habitat surveys in both systems to quantify the length of shoreline that was potentially useable by juvenile steelhead. In the Cheakamus River, we classified useable shoreline habitat into riffle, shallow, and deep habitat types and used different gears to sample these types depending on season (fall or spring) and age. Gear stratification was based on the depth limitations of the sampling gear (snorkeling not possible in riffles, electrofishing difficult and inefficient in deep habitat types), seasonal gear restrictions (snorkeling not possible in fall due to high turbidity), and previous evaluations of the habitat and life stage-specific effectiveness of each gear (Korman 2008, Korman et al. 2010b) which showed that electrofishing provides the most unbiased and precise estimates of age 0 abundance in habitat types where the gear can be applied, while snorkeling provides the most unbiased and precise estimates of abundance for age 1 and older juvenile steelhead (hereafter referred to as parr or age 1+ fish). In addition, the top priority of the juvenile program is to estimate the abundance of steelhead parr in the spring prior to outmigration, given the need to provide a reliable index of freshwater juvenile production. Given these various constraints, statistical considerations and priorities, fall estimates of abundance were based exclusively on electrofishing. Spring abundance estimates were based on data from both electrofishing and snorkel surveys. For estimates of age 0 abundance, we used data from riffle and shallow sites sampled by electrofishing, and deep sites sampled by snorkeling. For estimates of age 1+ juvenile steelhead, we used data from riffle and shallow sites sampled by electrofishing, and shallow and deep sites sampled by snorkeling.

Abundance was estimated using a two-phase sampling design. We sampled a large number of index sites using a single pass of effort. At a sub-sample of sites, we conducted two-day mark-recapture experiments to quantify detection probability. We define detection probability as the proportion of individuals at a site that are either captured by electrofishing or seen by a diver based on a single pass of effort. Abundance at index sites was estimated by expanding the observed number of fish by the estimates of detection probability determined from mark-recapture experiments. The abundance of fish in the shorelines that were not sampled was estimated based on average fish densities and variation in density across sampled sites. The total estimate of abundance for the river was the sum of estimates from sampled and unsampled shorelines. We developed a Hierarchical Bayesian Model (HBM) to implement this approach to estimate posterior distributions of abundance, from which expected values (means), medians, and 95% credible intervals could be computed.

3.2.1 Sample Site Selection and Field Methods

A total of 10 and 100 index sites were electrofished (EF) for the fall 2011 abundance estimates in the Brohm and Cheakamus Rivers, respectively (Table 3.1). Six mark-recapture experiments were completed in fall 2011 in the Cheakamus River. A total of 221 and 209 index sites were sampled in spring 2012 using either electrofishing and snorkeling in Brohm and Cheakamus Rivers, respectively.

Sample sites for the surveys were selected at random based on information in the habitat survey database. The database includes a list of coordinates for the entire shoreline in the Cheakamus and Brohm Rivers at an interval of 10 m. After excluding unusable habitat and habitat that cannot be safely accessed (only 7% of total), we used an Excel program to randomly select points that determined our index sampling locations. For the spring survey, EF locations were restricted to riffle and shallow habitat types while SN locations were restricted to shallow and deep habitat types. In the fall survey when only electrofishing was conducted, sampling points were drawn from all habitat types. The coordinates of the randomly selected sites were uploaded to GPS units and a list of the habitat units to be sampled was compiled. This information was used to locate the sites in the field. The coordinates represented the midpoint of the sample sites.

Electrofishing and snorkeling index sites were 30 and 50 m long, respectively. Electrofishing sites were sampled during the day by a two-person crew using a model 12B Smith-Root electrofisher (settings: 300V, frequency and pulse I4-J5). Each site was sampled by methodically traversing the site in an upstream direction and capturing all fish that were observed. Sites were not enclosed, and sampling was conducted as far into the thalweg as safely possible, or from bank to bank when sampling in side-channels and narrower braids. We followed the method of Decker et al. (2009) for snorkel surveys. A single diver traversed the site in an upstream direction searching for fish with the aid of an underwater light. Snorkeling sites were sampled only at night, beginning 1 hr after sunset. Divers recorded the species, fork length (to the nearest 5 mm for fish < 100 mm, and to 10 mm for fish > 100 mm) for all fish that were observed within the site.

Mark-recapture experiments were conducted over a two-night period. On the first night, fish were captured for marking by backpack electrofishing (at electrofishing sites) or by snorkeling with dip nets (at snorkel sites). Fish were identified to species and measured, and juvenile steelhead were marked and released back into the site. We returned to the site 24-hours later to conduct the second sampling event using the same gear, where the number and fork length of marked and unmarked fish was determined. Due to relatively low fish densities, mark-recapture sites were generally at least twice as long as index sites (> 100 m). We attempted to mark a minimum of 20 age 0 and 20 age 1+ steelhead at each site. Sample sizes generally exceeded these targets for most gear-age combinations.

We followed the method of Decker et al. (2009) for snorkel mark-recapture experiments. During the first sampling event, a single diver traversed the site in an upstream direction searching for fish with the aid of underwater lights affixed to forearm and mask strap. This left the diver's hands free to use two 27 x 27 cm aquarium nets affixed to 80 cm handles to capture fish. The diver moved through the site slowly and methodically to avoid chasing fish from their holding locations. In near-shore areas too shallow to search from an underwater position, the diver searched for and captured fish by walking slowly through the habitat. At the time of capture, fish were handed to a second crew member standing nearby who immediately measured fork length, removed a scale in some cases for ageing, and tagged the fish. Fish were not anaesthetized because of uncertainty about behavioral effects of the anesthetic. Immediately following marking, fish were returned to the original lie they had been holding in prior to capture. We were unable to acquire suitable commercially made tags for this application so manufactured our own. These consisted of a 10-15 mm-long piece of colored chenille attached to a size 16-20 barbed, fine wire fishhook with a short (3-4 mm) length of heat-shrink tubing. Tags were inserted by placing the hook shallowly at the posterior insertion of the dorsal fin.

We used methods developed by Korman et al. (2010b) for electrofishing-based mark-recapture experiments. A two-person crew, using a Smith-Root 12b electrofisher (settings: 300V, frequency and pulse I4-J5), traversed the site in an upstream direction. Electrofishing was very methodical, requiring 0.75-1.5 hrs of effort to sample each site. After electrofishing, fish were anesthetized using clove oil and fork lengths were measured to the nearest mm. Fish were marked using red biological dye (fall) or a small caudal fin clip (spring). Dying is a more efficient method for marking many small fish that are commonly captured in the fall, but the dye can result in behavioral changes or mortality at very low water temperatures in the spring. For dying, fish were placed in an aerated bucket with neutral red biological stain (2 g per 15 L, Sigma-Aldrich Ltd.) for 20 minutes and then transferred to aerated buckets of clear water to recover. The fork lengths of the very small proportion of dead fish and those that were not actively swimming after processing were recorded so they could be excluded from the count of marked fish released into the site. The remaining fish were released throughout the sample site, avoiding areas with high water velocity and areas within 5 m from the upstream and downstream boundaries of the site. We felt this release strategy provided a more suitable environment for recovery and would minimize emigration from the site if fish were disoriented or unable to maintain their position immediately following release. We assumed that marked fish would resume an undisturbed distribution within the site before the second sampling event 24-hours later.

We returned to mark-recapture sites for the second sampling event 24-hours after the first sampling event and recorded the number of fish by species, their sizes, and whether the fish was marked. During the recapture events we used the same techniques and level of effort applied at single pass index sites to ensure that detection probabilities at mark-recapture sites would represent values encountered at index sites. At snorkel sites, divers also sampled 25 m upstream and downstream of the mark-recapture site to record the number and size of marked fish that had emigrated. This sampling allowed us to evaluate the assumption that populations within mark-recapture sites can be treated as effectively closed for the 24-hour period between sampling events. Water temperature was recorded at all mark-recapture sites with a hand-held electronic thermometer and at all sampling sites in Brohm River. Continuous recording temperature loggers recorded temperature at the ‘stables area’ downstream of the Cheekye River confluence. Horizontal visibility was measured at snorkel mark-recapture sites as the maximum distance a diver could detect a dark submerged object.

A fish length-stratified random sampling approach was use to collect scales for freshwater age determination. Age determinations were made for 80 and 102 juvenile rainbow trout from the Cheakamus Rivers in fall 2011 and spring 2012, respectively. Ages have not yet been determined from Brohm samples, but will be completed prior to next years reporting. Scales were taken from a location approximately 2-4 rows above the lateral line and between the back of the dorsal fin and the origin of the anal fin. Scales from individual fish were mounted on standard glass microscope slides and viewed under 47x magnification using a microfiche reader. Regions of closely spaced circuli on the scale were identified as annuli (i.e., winter growth ‘checks’). We designate fish age relative to the time from emergence, which for Cheakamus River steelhead occurs in July and August. Thus fish captured in their first fall and spring since emergence are given an age class designation of 0+, while fish capture in their second fall and spring are designated as 1+. Note this convention differs from the one where juvenile age is determined by the number of winters spent in freshwater. Under this designation, which is used in reporting of the Cheakamus outmigrant data, fish we classify as age 0+ and 1+ in the spring sample would be one- and two-years old (one and two winters), respectively.

3.2.2 Analytical Methods

We developed a hierarchical Bayesian model (HBM) similar to model I of Wyatt (2002 and 2003) to estimate juvenile steelhead abundance. The model consists of two levels or hierarchies (Fig. 3.1). Site-specific estimates of detection probability and fish density at the lowest level of the hierarchy are considered random variables that come from hyper-distributions of detection probability and density at the higher level. The HBM jointly estimates both site- and hyper-parameters. The process component of the model assumes that variation in juvenile abundance across sample sites follows a Poisson/log-normal mixture. That is, abundance at-a-site is Poisson-distributed based on a mean density drawn from a lognormal distribution. The observation component of the model assumes that variation in the number of fish observed at index sites, and number of tagged fish observed at mark-recapture sites, follow binomial distributions, and that variation in detection probabilities across sites follows a beta distribution. Estimates of the total abundance across sampled sites within a reach are added to an estimate of the abundance in the unsampled shoreline in the reach to determine the total abundance in the reach. Reach-specific estimates are summed to determine the total abundance in Brohm River and Cheakamus River. Reach Hyper-parameters for detection probability estimates are gear-specific. Only a single set of hyper-parameters are estimated for density, thus we assume that mean density does not vary across reaches or habitat types sampled by different gears.

Beginning with the detection model, the number of marked fish observed at mark-recapture site *i* on the second pass was assumed to be binomially distributed and to depend on the detection probability and number of marks released on the first pass (Table 3.3, eqn. 3.1 from Table 3.2). The between-site variation in detection probability at mark-recapture sites was assumed to follow a beta hyper-distribution (eqn. 3.2). The number of fish observed at single-pass index site *j* was assumed to be binomially distributed and to depend on abundance at the site and a randomly selected detection probability taken from the hyper-distribution of detection probability for the appropriate gear type (eqn.'s 3.3 and 3.4). Abundance was assumed to be Poisson-distributed with a mean equal to the product of the density at each site and the shoreline length that was sampled (eqn. 3.5). The log of density across index sites was assumed to be normally distributed (eqn. 3.6).

The total fish population in reach *r* (eqn. 3.9) was computed as the sum of the population estimates from sampled sites in the reach (eqn. 3.7) and the estimate of population in the unsampled shoreline length (eqn. 3.8). The latter value was computed as the product of the transformed mean density from the lognormal density hyper distribution (μ_λ) with lognormal bias correction ($0.5\tau_\lambda$), and the length of the unsampled shoreline in the reach. The estimate of abundance for the entire river was computed as the sum of reach-specific estimates (eqn. 3.10).

Posterior distributions of parameters and population estimates from the hierarchical model were estimated using WinBUGS (Spiegelhalter et al. 1999) called from the R2WinBUGS library (Sturtz et al. 2005) from the 'R' statistical package (R Development Core Team 2009). Uninformative prior distributions for hyper-parameters were used in almost all river-, year-season-, and age-specific strata. An uninformative uniform prior was used for both the mean and standard deviation of the hyper-distribution for detection probability (eqn. 3.11 and 3.12 from Table 3.4). An uninformative normal prior was used for the mean of the hyper-distribution for log fish density, and an uninformative half-Cauchy distribution was used as a prior for the standard deviation of log fish density (eqn. 3.13). The half-Cauchy prior, also referred to as a 'folded *t* distribution', is useful in cases where it is difficult to estimate the variance of hyper-distributions in hierarchical Bayesian models due to limited information in the data (Gelman 2006). In total, abundance was estimated for 24 strata (two rivers, two seasons, two years for each season, and three ages). Abundance for each of these strata was subdivided into reach-specific estimates. Posterior distributions were estimated by taking every second sample from a total of 10000 simulations after excluding the first 1000 'burn in' samples. This sample size and sampling strategy was sufficient to achieve adequate model convergence in all cases.

We compared estimates of age 1 and 2 steelhead abundance in the Cheakamus River in spring 2009-2012 determined from the HBM with the estimated number of smolts passing the Rotary Screw Trap (RST) at ages 2 and 3 years, respectively. Recall that an age 1 parr sampled in early April would be considered a 2-year old fish by the time the winter is complete by May when most of the steelhead at the RST are caught. Similarly, age 2 parr sampled in early April would be 3 year smolts in May. A number of manipulations and assumptions were required for this comparison of the abundance of parr and smolt estimates. It is important to note that not all age 1 parr (which have essentially spent two winters in freshwater at the time of juvenile surveys) will leave as two years smolts, as some will reside in the river an additional year, and if they survive, will depart as 3 year smolts. As we can assume that the vast majority of smolts depart no later than age 3 (see results below), the easiest comparison to make is between the number of age 2 parr and the number of age 3 smolts because it is very likely that very few age 2 parr will remain in the river an additional year (owing to the virtual absence of 4 year smolts at the RST). We therefore focus our assessment on this age 2 parr – 3 year smolt comparison. The estimates for age 1 and 2 steelhead abundance used in this comparison were derived from the HBM using revised habitat and juvenile index site data files that only included habitat and sites located above the RST, respectively. The comparison inherently assumes minimal mortality between the time of our juvenile surveys (early April) and when most smolts pass the RST (May).

3.3 Results and Discussion

3.3.1 Data Summary and Supporting Analyses

The sum of the shoreline length from index sites that were sampled covered 11% and 6% of the useable shoreline length of the Brohm and Cheakamus Rivers during the fall 2011 surveys, respectively (Table 3.1a). We sampled 44% and 18% of the useablelshoreline length during the spring 2012 surveys in the Brohm and Cheakamus Rivers, respectively. Discharge and water temperature in the Cheakamus River spanning the period when juvenile surveys were conducted are shown in Fig. 3.2. Flows were generally very near winter base flow levels of 15-20 m^3/sec during both surveys. Water temperature during the fall survey averaged about 10 ^oC in the Cheakamus River and 10-11 ^oC in Brohm River. Water temperatures in the Cheakamus and Brohm Rivers during the spring surveys ranged from 5- 7 ^oC.

Results from scale ageing (Table 3.4) were used to assign maximum lengths for age 0, and 1 year old steelhead. Scales from Brohm River have not been analyzed yet, so maximum lengths-at-age for other years were used to assign ages in fall 2011 and spring 2012. In the Cheakamus River, maximum lengths for age 0 and 1 year old steelhead in fall 2011 were 70 and 135 mm, and 95 and 135 mm in spring 2012. We used a maximum length of 180 mm for age 2 steelhead for all strata which was based on very limited length-at-age data for the upper limit for this age class. Generally, there has been relatively little variation in size-at-age across years within rivers in fall (typically ± 5-10 mm). There appears to be larger variation in size-at-age for age 0 fish in the Cheakamus River in the spring sample.

Length frequency distributions (unadjusted for size-dependent detection probability) for juvenile steelhead based on electrofishing in the fall were dominated by smaller, mostly age 0 fish (Fig. 3.3 a, c). Length frequency distributions reflect patterns in abundance among size classes as well as size-specific differences in vulnerability to sampling gear. Larger and older fish were more prevalent in the spring when snorkeling was also conducted (Fig. 3.3 b, d). Note that electrofishing and snorkeling were used to sample Brohm River in spring 2010 and 2011, but only snorkeling was used in 2009. The absence of a small mode in the spring 2009 Brohm length frequency distribution is the result of not using electrofishing in this year, which is more efficient at capturing smaller individuals (Korman et al. 2010b).

A total of 614 and 7,067juvenile steelhead were enumerated at index sites in Brohm and Cheakamus Rivers in fall 2011, and 772 and 6,084 in spring 2012, respectively (Table 3.5). Trends in catch-per-effort (CPE) are shown in Table 3.6. As detection probability is considered exchangeable among years within –rivers (and across rivers for snorkeling), relative differences in CPE will be similar to relative differences based on population estimates. The most obvious patterns that emerge from the CPE are:

1. Consistent CPE of age-0 + fish in Brohm River in fall across years, which is not the case in the Cheakamus River;
2. Very low CPE for age-1+ and -2+ parr in the fall in the Cheakamus River, owing to poor detection probability associated with electrofishing
3. The presence of a large cohort form the 2011 brood year in the Cheakamus River, as indicated by high age-0+ CPE in fall 2011 and spring 2012.
4. A sequence of low-high-low-high snorkelling CPE for age-1+ parr in the Cheakamus River in spring, indicative of large interannual variation and possible inter-cohort density effects (i.e., reduced survival of age-0+ fish with higher abundance of age- 1+ from the previous years brood).

Mark-recapture experiments conducted in spring 2012 provided a few additional experiments to estimate hyper distributions of detection probability in the HBM (Table 3.7). Aggregating data from all years, detection probability for age-0 steelhead based on electrofishing was relatively consistent among experiments and was almost twice as high in the Cheakamus River compared to Brohm River (Table 3.8), likely due to the more porous nature of the substrate in Brohm. For 1+ steelhead, detection probability for electrofishing was higher in Brohm River than in the Cheakamus River, likely due to reduced channel width and shallower depths in Brohm. Electrofishing-based detection probability estimates for age 1+ steelhead in the Cheakamus River were highly uncertain because few fish are marked due to low capture probability. High variability among sites for this stratum partially reflects the large uncertainty in detection probability estimates within sites due to the sampling error induced by low numbers of marked fish. Detection probability for snorkeling was lower for age 0 steelhead than for 1+ fish due to increased concealment behavior of smaller fish. Detection probability for age 1+ fish based on snorkeling was generally high and consistent among sites.

3.3.3 Estimates of Juvenile Steelhead Abundance from the Hierarchical Bayesian Model

An intense and successful sampling effort was implemented in fall 2011 and spring 2012 in both the Brohm and Cheakamus Rivers, resulting in catch data from a large number of index sites (Table 3.9). In addition, the multi-year mark-recapture datasets expanded based on experiments conducted in spring 2012. These characteristics led to good precision (Coefficient of Variation (CV)) for estimates of juvenile steelhead abundance for the majority of strata. An example of output from the HBM for one strata (Cheakamus River age-1+ steelhead in spring 2012) is shown in Figure 3.4. In this example, electrofishing-based detection probability is low, and experiment-specific estimates are uncertain, resulting in considerable shrinkage of HBM-estimated values compared to the independent estimates (r/R) (Fig. 3.4a and b). Detection probability for snorkeling is approximately 3-fold higher (Fig. 3.4c and d) and there is less uncertainty in the estimates because the number of marked fish is greater, resulting in less shrinkage. Fish densities at index sites were highly variable and generally low (Fig. 3.4e), resulting in a fish density distribution with a long right-hand tail (Fig. 3.4f). Due to the large number of index sites, the total estimate of abundance across the sampled sites was relatively precise (Fig. 3.4g) even though site-specific densities were highly variable. The majority of uncertainty in the estimate for the entire river was driven by uncertainty in the estimate of abundance for the portion of river that was not sampled (Fig. 3.4h), which depends on uncertainty in the hyper-distribution of fish density (Fig. 3.4f).

Total abundance estimates in fall 2011 and spring 2012 were less precise (average CV across 12 strata = 0.34, Table 3.10) compared to those in fall 2010 and spring 2011 (average CV = 0.13). This occurred largely due to higher uncertainty in Brohm River owing to large variation in densities across sites. Estimates for the Cheakamus River were precise for all seasons and age classes (average CV=0.16) but we suspect age-1+ and 2+ parr abundance estimates for fall underestimate the true abundance (see discussion below). Abundance estimates for age-1+ parr in the Cheakamus River in spring, perhaps the most important metric we measure as a surrogate for smolt production, had CVs of 0.17, 0.12, 0.09, and 0.10 in 2009, 2010, 2011, and 2012, respectively. The improving precision is the result of increasing the number of index sites beginning in 2010. Note that in spring 2009, the Brohm age 0 estimate was greater than the age 1 estimate, which was not the case in spring 2010 and 2011. This occurred because both electrofishing and snorkeling were used in the latter years, but not in 2009. It is very likely that the abundance of age 0 steelhead in spring 2009 was underestimated due to a positive bias in detection probability for small fish when snorkeling (Korman et al. 2010b). Abundance estimates for Brohm River in fall 2008 were very imprecise, owing to the very limited number of index sites that were sampled (making it difficult to estimate variation in fish density across sites).

Trends in reliable abundance estimates for the Cheakamus River (age-0+ in fall and spring, age-1+ in spring only) are presented in Figure 3.5. They show relatively high abundance of age-0+ in fall and spring in 2008 and especially 2011, compared to 2009 and 2010. The spring age-1+ abundance estimate was highly variable across years and showed high abundance in 2010 and 2012.

We tracked the change in the abundance of the 2008-2011 steelhead cohorts (fish from the spawn in 2008-2011) by combining estimates across strata (Table 3.11, Fig. 3.6). As an example, the 2008 cohort from the Cheakamus River declined from an estimated egg deposition of 573 thousand to 241 thousand age-0+ fish in fall 2008 to 18 thousand age-1+ fish by spring 2010. The net apparent survival rates from egg deposition to fall age-0+, fall age-0+ to spring age-1+, and from spring age-0+ to -1+, was 42%, 8%, and 37%, respectively. We use the term apparent survival because the estimate is potentially affected by immigrants from Brohm River as well as emigration out of the sampled area. Survival from fall age-0+ to spring age-1+ ranged from 4-28% and 5-12% for cohorts from Cheakamus and Brohm Rivers. These survival estimates were reasonably precise, with CVs ranging from 16-30%.

Some life-stage specific survival estimates are likely inaccurate (and therefore not presented) due to biases in population estimates (Table 3.11, Fig. 3.6). The estimate of age-1+ abundance in fall in the Cheakamus is likely biased low because the estimates for the same cohort the following spring are often larger. This would results in a nonsensical survival rate between sample periods of greater than one. The bias in estimates of abundance for age-1+ steelhead in fall is not surprising, and is likely caused by an overestimation of river-wide detection probability for this age class. This occurs because few informative mark-recapture experiments for parr in deeper habitats are achieved due to low detection probability, so the ones from shallow habitats, where detection probability is higher, dominate the estimated hyper distribution and population estimates. For Brohm River, the age-0+ estimate in spring 2009 is very likely biased low (due to snorkeling only), resulting in a nonsensical survival estimate between spring 2009 and fall 2009. The survival estimate between fall 2008 and spring 2009 is also likely biased low for the same reason. Such biases in Brohm River did not occur after spring 2009 because electrofishing was introduced as an additional sampling method. The overall fall age-0+ to spring age-1+ survival rate in Brohm River is likely unbiased because these two abundance samples are likely unbiased (electrofishing adequate to sample age 0 fish in fall, and snorkeling and electrofishing used for age 1 in spring 2010 sample).

Estimates of age 2 parr abundance above the RST in the spring of 2009-2012 were compared to estimates of 3 year smolt abundance at the RST. Juvenile survey-based estimates ranged from about 0.5 to 1.8-fold values from the RST (Table 3.12). However, except for differences in 2012, due to the uncertainty in both types of estimates, these differences could be solely due to sampling error (Fig. 3.7).

3.4 Conclusions

Juvenile steelhead population estimates in the Cheakamus and Brohm Rivers are generally quite precise due to increases in the number of index sites and the accumulation of mark-recapture data across years. The former provided better information on mean fish densities and variation in fish densities across sites, while the latter provided additional data on detection probability. In the Cheakamus River, most population estimates had CVs that were less than 0.2. At the currently level of effort, estimates for age-1+ parr in the spring, which may be our best proxy of potential smolt production, are very precise (CV ~0.1). Estimates of steelhead 2+ parr abundance derived from juvenile surveys in spring 2008-2011 were not statistically different than RST-derived estimates (but were in 2012). However, this evaluation is a relatively insensitive test when one considers the uncertainty in both juvenile survey- and especially RST-based estimates.

The most significant finding from the analysis is the demonstration that it is possible to estimate survival rates of juvenile steelhead after 2 winters in freshwater. Survival from age-0+ in the fall to age-1+ in the spring (i.e., 2 winters in freshwater) was 4-28% and 5-12% in the Cheakamus and Brohm Rivers, respectively with CVs between

0.14 and 0.3. This precision will likely allow evaluation of the effects of major changes in flow and other abiotic and biotic factors on juvenile survival rates.

Given reasonably accurate escapement estimates and information on the size of returning spawners, we have shown that it is possible to compute egg-fall fry survival rates to evaluate effects of flow during the incubation and emergence period. Estimates of egg-fall fry survival in the Cheakamus River ranged from 4-43% for 2008-2011 spawning cohorts. Some of this variation could be due to higher mortality resulting from greater densities, as egg deposition in 2010 was 3-fold greater than in 2008. However, egg-fry survival in 2011 was 3-fold higher than in 2010 even though egg deposition in this 2011was 2-fold higher. Some of the differences egg-fry survival rates could be caused by changes in flow (e.g., Fig. 1.3). High survival in 2008 and 2009 compared to 2010 and 2011 could be due to lower flows during the emergence period, however differences among these groups of years could also be due to density dependent mortality (higher densities in 2010 and 2011 could have caused lower survival). The lower survival in 2010 compared to 2011 could be due to the sudden reductions in flow in 2010 compared to 2011. Survival rates were much higher in 2011 in spite of higher densities, suggesting a possible strong flow effect in this year. See Korman et al. (2012) for a more detailed synthesis of escapement and juvenile data collected over the five year study period.

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5.0 Tables and Figures

Table 2.1. Equations used in the model to estimate steelhead escapement from swim survey, radio telemetry, and angler catch data. See Table 2.3 for definition of model variables.

Eqn. #	Description	Equation
Process Model		
2.1	Arrival Timing	a) beta model: $PA_{o,i} = \phi_i^{\tau_o - 1}(1-\phi_i)^{\beta_o - 1}$ b) deviate model: $PA_{o,i} = \omega_i$
2.2	Transformation of arrival timing parameters	$\beta_o = \frac{\tau_o - 1}{\frac{\mu_o}{T}} + 2 - \tau_o$
2.3	Survey life – date of entry	$SL_t = \lambda_m (1 - \frac{i^{\lambda_s}}{\lambda_h^{\lambda_s} + i^{\lambda_s}})$
2.4	Departure day	$d_i = i + SL_i$
2.5	Proportion arriving on day 'i' that depart on day 'j'	$PAD_{i,j} = Normal(j, d_i, \sigma_{sl})$
2.6	Departure timing	$PD_{o,j} = \sum_i PA_{o,i} * PAD_{i,j}$
2.7	Number present by model day	$U_{o,i} = \varepsilon_o \left\lfloor \int_1^i PA_o - \int_1^i PD_o \right\rfloor$
2.8	Proportion of wild-origin fish that have arrived by model day	$P_{w,i} = \frac{E_W \int_1^i PA_W}{E_W \int_1^i PA_W + E_H \int_1^i PA_H}$
Observation Model		
2.9	Likelihood for marked fish observed (L_r)	$r_i \sim Poisson(q_i R_i)$
2.10	Likelihood for unmarked fish observed (L_u)	$u_i \sim Poisson(q_i (U_{W,i} + U_{H,i} - R_i))$
2.11	Conditional MLE of detection probability	$q_i = \frac{r_i + u_i}{U_{W,i} + U_{H,i}}$
2.12	Detection probability based on physical conditions	$p_i = \frac{\frac{HV_i}{Q_i}^{\rho_s}}{\rho_h^{\rho_s} + \frac{HV_i}{Q_i}^{\rho_s}}$
2.13	Likelihood for marked fish observed in current year based on	$r_i \sim Poisson(p_i R_i)$

p from eqn. 2.12 (L_{pr})

Table 2.1. Con't.

Eqn. #	Description	Equation
2.14	Likelihood for unmarked fish observed in current year based on p from eqn. 2.12 (L_{pu})	$u_i \sim Poisson(p_i(U_{W,i} + U_{H,i} - R_i))$
2.15	Likelihood for marked fish observed from other years based on p from eqn. 2.12 (L_p)	$r_i \sim Poisson(p_i R_i)$
2.16	Likelihood for survey life (L_{sl})	$slobs_i \sim Normal(i, SL_i, \sigma_{sl})$
2.17	Conditional MLE for the standard deviation in survey life – date of entry relationship	$s_{sl} = \sqrt{\frac{\sum (slobs_i - SL_i)^2}{n-1}}$
2.18	Likelihood for departure timing (L_{dW} and L_{dH})	$Nexit_{o,i} \sim Multinom(\sum_i Nexit_{o,i}, PD_{o,i})$
2.19	Likelihood of stock composition given catch data (L_f)	$C_{W,i} \sim Poisson(P_{W,i,}(C_{W,i} + C_{H,i}))$
2.20	Total Likelihood (L_T)	$L_T(data \mid \theta) = \frac{L_r + L_{pr}}{2} + \frac{L_u + L_{pu}}{2} +$ $L_p + L_s + L_{dW} + L_{dH} + L_f - Hpen$

Table 2.2. Definition of variables used in the steelhead escapement model.

Symbol	Definition
State Variables	
$PA_{o,i}$	Proportion of stock 'o' arriving on day 'i'
$PAD_{i,j}$	Proportion arriving on day 'i' that depart on day 'j'
$PD_{o,j}$	Proportion departing for stock 'o' on day 'j'
$U_{o,i}$	Number present for stock 'o' on day 'i'
$P_{w,i}$	Cumulative proportion of wild-origin fish that have arrived by day 'i'
d_i	Mean departure day for fish arriving on day i
p_i	Predicted detection probability on day 'i' based on physical conditions
Parameters	
ε_o	Escapement for stock 'o'
μ_o	Model day where the maximum arrival rate of stock 'o' occurs
τ_o	Precision of arrival timing for stock 'o'
β_o	Transformed parameter for arrival timing model for stock 'o'
ω_i	The proportion of the run that has arrived between survey 'i-1' and 'i'
λ_m	Maximum mean survey life (days)
λ_h	Model day where survey life is ½ the maximum
λ_s	Slope of the survey life – date of entry relationship
ρ_h	HV/Q ratio at which detection probability is 0.5
ρ_s	Slope of the qP-HV/Q relationship
Conditional Parameter (calculated)	
q_i	Detection probability on day 'i'
σ_{sl}	Standard deviation (error) in survey life – date of entry relationship
Data	
R_i	Number of tags in survey area on day 'i'
r_i	Number of tags observed on day 'i'
u_i	Number of untagged fish observed on day 'i'
HV_i/Q_i	Ratio of horizontal visibility to discharge on day 'i'
$slobs_i$	Observed survey life on day 'i'
n	# of observations of survey life
$Nexit_{o,i}$	# of fish of origin 'o' departing on day 'i'
$C_{o,i}$	Cumulative landed catch of fish of origin 'o' by day 'i'
Constants	
i, j	Indices for model day
T	Maximum model day (T=181)
o	Stock origin (wild: o=W, hatchery: o=H)
ϕ_i	Proportional model day (i/T ranging from 0-1)

Table 2.3 Physical conditions and counts of adult steelhead (SH), resident rainbow trout (RB), and bull trout (BT) during adult surveys in 2012.

Survey Date	Discharge (Q in m3/sec)	Horizontal Visibility (HV in m)	HV/Q	Count SH	Count RB	Count BT
08-Mar	21.1	6.6	0.31	34	49	128
14-Mar	20.3	5.3	0.26	31	24	57
21-Mar	15.5	6.4	0.41	58	59	169
05-Apr	23.3	6.7	0.29	86	47	178
12-Apr	23.5	5.5	0.23	58	51	89
19-Apr	19.8	4.9	0.25	69	74	185

Table 2.4. Number of rainbow trout (steelhead and resident trout) that were sampled for size, sex, age, and origin in 2012.

Origin	Female	Male	Unknown	Total
# Sampled				
Hatchery	1	0	0	1
Wild	9	4	0	13
Total	10	4	0	14
Average Fork Length (mm)				
Hatchery	550			550
Wild	671	808		713
Total	659	808		702

Table 2.5. Proportions of freshwater, ocean, and total ages for Cheakamus River wild (W) and hatchery (H)-origin adult steelhead from scale samples collected over all years when telemetry was conducted. Note that ocean age and total age proportions are based on maiden spawners only. The proportion of repeat spawners is also shown. 'n' denotes the sample size for each strata.

		Freshwater Age				
Year	**Origin**	**1**	**2**	**3**	**4**	**n**
2000	W	0.00	0.85	0.15	0.00	13
2001	W	0.00	0.85	0.15	0.00	26
2003	W	0.00	0.72	0.24	0.03	29
2004	W	0.00	0.74	0.26	0.00	19
2005	W	0.00	0.52	0.48	0.00	23
2009	H	1.00	0.00	0.00	0.00	12
	W	0.00	0.60	0.40	0.00	10
2010	H	1.00	0.00	0.00	0.00	23
	W	0.00	0.78	0.22	0.00	23
2011	H	0.95	0.05	0.00	0.00	21
	W	0.00	0.35	0.63	0.02	52
2012	W	0.00	0.40	0.60	0.00	5
Avg	H	0.98	0.02	0.00	0.00	56
	W	0.00	0.62	0.37	0.01	200

		Ocean Age				
Year	**Origin**	**1**	**2**	**3**	**Repeat**	**n**
2000	W	0.00	0.63	0.38	0.00	16
2001	W	0.00	0.73	0.27	0.00	30
2003	W	0.03	0.41	0.56	0.00	32
2004	W	0.00	0.63	0.37	0.00	35
2005	W	0.08	0.38	0.51	0.03	39
2009	H	0.23	0.77	0.00	0.00	13
	W	0.00	0.57	0.43	0.00	14
2010	H	0.08	0.75	0.17	0.00	24
	W	0.07	0.89	0.04	0.00	28
2011	H	0.00	0.04	0.96	0.00	26
	W	0.00	0.26	0.74	0.00	76
2012	W	0.00	0.11	0.89	0.00	9
Avg	H	0.08	0.46	0.46	0.00	63
	W	0.02	0.49	0.49	0.00	279

Table 2.5. Con`t.

		Total Age					
Year	**Origin**	**2**	**3**	**4**	**5**	**6**	**n**
2000	W	0.00	0.00	0.62	0.23	0.15	13
2001	W	0.00	0.00	0.64	0.36	0.00	25
2003	W	0.00	0.05	0.40	0.40	0.15	20
2004	W	0.00	0.00	0.50	0.38	0.13	16
2005	W	0.00	0.00	0.44	0.56	0.00	18
2009	H	0.25	0.75	0.00	0.00	0.00	12
	W	0.00	0.00	0.67	0.00	0.33	9
2010	H	0.09	0.73	0.18	0.00	0.00	22
	W	0.00	0.05	0.71	0.24	0.00	21
2011	H	0.00	0.00	1.00	0.00	0.00	16
	W	0.00	0.00	0.07	0.61	0.32	41
2012	W	0.00	0.00	0.00	0.75	0.25	4
Avg	H	0.11	0.49	0.39	0.00	0.00	50
	W	0.00	0.01	0.51	0.35	0.13	167

Table 2.6. Number of resident rainbow trout aged by year and origin in the Cheakamus River and their average fork lengths. 'H' and 'W' denote hatchery- and wild-origin fish and the former groups represents hatchery smolts that residualized in freshwater.

		Total Freshwater Age					
Year	**Origin**	**3**	**4**	**5**	**6**	**7**	**Total**
Number of Fish							
2010	H	3	7				10
2011	H			1			1
	W		1	5	3	1	10
2012	W			2	1		3
Average Fork length (mm)							
2010	H	393	414				408
2011	H			380			380
	W		305	374	390	370	372
2012	W			438	500		458

Table 2.7. Calculations used to estimate annual egg deposition for steelhead in the Cheakamus River in years when information on sex ratio and size is available from angling surveys. Egg deposition is computed as the product of escapement, the proportion females, and fecundity. The latter estimates are computed based on mean female fork length and a fecundity-fork length relationship from the Keogh River (Ward and Slaney 1993).

Year	Fork length & Sex Sample Size	Average Female Fork Length (mm)	Average Fecundity	Proportion Females	Total Escapement	Total Eggs ('000s)	Egg ('000s) / Escapement Ratio
2000	18	700	3,329	0.50	103	171	1.7
2001	27	756	4,219	0.41	310	533	1.7
2003	33	801	5,016	0.52	311	804	2.6
2004	36	769	4,431	0.44	330	650	2.0
2005	38	776	4,552	0.50	332	756	2.3
2009	27	735	3,864	0.59	204	467	2.3
2010	57	691	3,206	0.44	1,144	1,609	1.4
2011	107	794	4,885	0.61	1,071	3,178	3.0
2012	9	836	5,733	0.63	568	2,035	3.6
Average or Total	351	762	4,313	0.51			2.3

Table 2.8. Summary of steelhead escapement estimates to Brohm River based on the resistivity counter, redd counts, and calculations that depend on escapement in the Cheakamus River and the immigration rate into Brohm River based on radio tags. Problems with the resistivity counter in 2012 precluded developing a reliable estimate in this year.

	2010	2011	2012
Brohm Escapement			
Resistivity Counter	65	54	NA[1]
Redd Counts	70	70	40
Derived Brohm Escapement			
Cheakamus Escapement			
Wild	708	724	568
Total	1144	1071	568
Brohm Immigration Rate	5.9%	6.5%	6.2%[2]
Escapement to Brohm River			
based on Wild	42	47	35
based on Total	67	70	35

[1] Problems were encountered with the resistivity counter in 2012.

[2] Telemetry was not conducted in 2012, so the estimate of the proportion of fish from the Cheakamus that immigrated to Brohm was calculated as the average from 2010 and 2011 estimates.

Table 3.1. Summary of juvenile steelhead sampling effort in Fall 2011 and Spring 2012 in Brohm and Cheakamus Rivers. 'EF' and 'SN' denote electrofishing and snorkelling sampling gear types, respectively. Index sites were sampled using one pass, while Mark Recapture (MR) sites were sampled using two passes.

a) Index Sites

		# Index Sites			Sampled Length (m)	Useable Length (m)	Proportion Sampled
		EF	SN	Total			
Fall 2011	Brohm	10		10	298	2,675	0.11
	Cheakamus	100		100	2955	46,197	0.06
Spring 2012	Brohm	10	11	21	1172	2,675	0.44
	Cheakamus	81	119	200	8170	46,197	0.18

b) Mark-Recapture

		# Mark Recapture Sites		
		EF	SN	Total
Fall 2011	Brohm	0		0
	Cheakamus	6		6
Spring 2012	Brohm	0	0	0
	Cheakamus	0	0	0

Table 3.2. Definition of variables of the hierarchical Bayesian model used to estimate juvenile steelhead abundance in the Cheakamus and Brohm Rivers.

Variable	Description
Data	
$r_{i,g}$	Marks detected at mark-recapture site i for gear type g
$m_{i,g}$	Marks released at mark-recapture site i for gear type g
$c_{j,g}$	Fish detected at index site j for gear type g
l_j	Shoreline length for index site j
h_r	Total shoreline length in reach r
Site-Specific Parameters	
$\theta_{i,g}$	Estimated detection probability at mark-recapture site i for gear type g
$\theta_{j,g}$	Simulated detection probability for index site j for gear type g
λ_j	Estimated density (fish/m) at index site j
Hyper-Parameters	
$\mu_{\theta,g}$	Mean of beta hyper-distribution for detection probability for gear type g
$\tau_{\theta,g}$	Precision of beta hyper-distribution for detection probability for gear type g
μ_{λ}	Mean of normal hyper-distribution for log fish density
τ_{λ}	Precision of normal hyper-distribution for log fish density
Derived Variables	
$\alpha_{i,g}$	Parameter for beta hyper distribution of detection probability
$\beta_{i,g}$	Parameter for beta hyper distribution of detection probability
$N_{j,g}$	Abundance at index site j sampled by gear type g
Ns_r	Total abundance across all index sites in reach r
Nus_r	Total abundance in unsampled shoreline in reach r
Nt_r	Total abundance in reach r
Nt	Total abundance across all reaches
Indices and Constants	
i	Index for mark-recapture site
j	Index for single-pass index site
g	Index for gear type (SN or EF)
r	Index for reach

Table 3.3. Equations of the hierarchical Bayesian model used to estimate juvenile steelhead abundance in the Brohm and Cheakamus Rivers. See Table 3.2 for definition of model parameters, constants, and subscripts. Lower case Arabic letters denote data or indices (if subscripts). Capital Arabic letters denoted derived variables, which are computed as a function of estimated parameters. Greek letters denote estimated parameters. Parameters with Greek letter subscripts are hyper-parameters.

Detection Model

(3.1) $r_{i,g} \sim dbin(\theta_{i,g}, m_{i,g})$

(3.2) $\theta_{i,g} \sim dbeta(\alpha_g, \beta_g)$

Population Model

(3.3) $\theta_{j,g} \sim dbeta(\alpha_g, \beta_g)$

(3.4) $c_{j,g} \sim dbin(\theta_{j,g}, N_{j,g})$

(3.5) $N_{j,g} \sim dpois(\lambda_j l_j)$

(3.6) $\log(\lambda_j) \sim dnorm(\mu_\lambda, \tau_\lambda)$

(3.7) $Ns_r = \sum_g \sum_{j \in r} n_{j,g}$

(3.8) $Nus_r = \exp[\mu_\lambda + 0.5\tau_\lambda^{-1}](h_r - \sum_{j \in r} l_j)$

(3.9) $Nt_r = Ns_r + Nus_r$

(3.10) $Nt = \sum_r Nt_r$

Table 3.3. Con't.

1.

2.

Priors and Transformation

$$\begin{aligned} \mu_{\theta,g} &\sim dunif\,(0,1) \\ \sigma_{\theta,g} &\sim dunif\,(0.05,10) \end{aligned} \tag{3.11}$$

$$\begin{aligned} \tau_{\theta,g} &= \sigma_{\theta,g}^{-2} \\ \alpha_g &= \mu_{\theta,g}\tau_{\theta,g} \\ \beta_g &= (1-\mu_{\theta,g})\tau_{\theta,g} \end{aligned} \tag{3.12}$$

$$\begin{aligned} \mu_{\lambda} &\sim dnorm(0,0.01) \\ \sigma_{\lambda} &\sim dhcauchy(0,0.5) \end{aligned} \tag{3.13}$$

$$\tau_{\lambda} = \sigma_{\lambda}^{-2} \tag{3.14}$$

Table 3.4. Number of juvenile steelhead captured in Brohm and Cheakamus Rivers assigned to each age-class by 5 mm fork length bin determined from scales in Brohm River in fall (a) and spring (b), and the Cheakamus River in fall (c) and spring (d). Yellow-shaded cells indicate the maximum size cut-offs used to assign ages based on fork length for fish that were not aged. Brohm – Fall and – Spring samples for 2011 and 2012, respectively have not been aged yet. Size cutoffs were based on the average from previous years.

a) Brohm - Fall

Fork Length		**2008**			**2009**			**2010**			**2011**	
(mm)	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**
<45							2					
45-49							6					
50-54							8					
55-59							3					
60-64							1					
65-69							2	1				
70-74					1		1	3				
75-79	2				2		1	3				
80-84		1			3			4				
85-89		2			6			2				
90-94		4			4			5				
95-99		3			4			3				
100-104		1			4			3				
105-109					4			3	1			
110-114						2		1				
115-119									1			
120-124						1			1			
125-129			1			2			2			
130-134			1			3			6			
135-139												
140-144									1			
145-149			1									
150-154						1						
155-159						1						
160-164												
165-169												
170-174									1			
175-179												
180-184												
185-190			1									
>190												
Total	2	11	4		28	10	24	28	13			

Table 3.4. Con’t.

b) Brohm - Spring

Fork												
Length	**2009**			**2010**			**2011**			**2012**		
(mm)	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**
<45												
45-49							5					
50-54				2			4					
55-59	1			1			4					
60-64				9			4					
65-69				4			2					
70-74	1			3				1				
75-79		1		1								
80-84					2		1	1				
85-89		3			1		1	6				
90-94		2			2			6				
95-99		4			2			4				
100-104					3			3	1			
105-109		1			4			6				
110-114		1			1				1			
115-119					1			5	1			
120-124		2						2	8			
125-129					3	1			1			
130-134									4			
135-139		1							7			
140-144									6			
145-149			2						3			
150-154			1						1			
155-159		1	1						2			
160-164			1						2			
165-169			1									
170-174												
175-179												
180-184												
185-190												
>190												
Total	2	16	6	20	19	1	21	34	37			

Table 3.4. Con’t.

c) Cheakamus - Fall

Fork												
Length		**2008**			**2009**			**2010**			**2011**	
(mm)	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**	**0+**	**1+**	**2+**
<45												
45-49				1						1		
50-54				1			4			1		
55-59				6			8			6		
60-64				6			10			6		
65-69	1			11			3			3		
70-74	1	1		6	1		3					
75-79				3	2		6	1			1	
80-84		1		4	2		1	2			1	
85-89					1						5	
90-94		3			5						5	
95-99		5			2						5	
100-104		3			3			3			8	
105-109		7			4			2			1	
110-114					6	1		4			5	
115-119		2			4	1		2			2	1
120-124		2			6	1		3	2		1	1
125-129		4			5	1		2	1		5	3
130-134		2	2		3				3			
135-139		1	2		1	1			1			6
140-144		1	3			2			4		1	4
145-149			2			2						3
150-154									1			3
155-159									2			
160-164			3						1			1
165-169												
170-174			2									1
175-179			2						1			
180-184												
185-190												
>190									1			
Total	2	32	16	38	45	9	35	19	17	17	40	23

Table 3.4. Con’t.

d) Cheakamus - Spring

Fork Length (mm)	2008			2009			2010			2011			2012		
	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+
<45										1					
45-49				1						1					
50-54				5			2			3			6		
55-59				3			6			4			9		
60-64				6			3	1		7			6		
65-69				2			6	1		6			1		
70-74				6			6	2		6			6		
75-79				3			6	4		7	1		7		
80-84		1		6	1		1	5		6	1		3		
85-89	1			3			2	11		5	1		9	1	
90-94		7		7	2			10		6	1		4	1	
95-99		3		1	2		1	11		5	3		1	2	1
100-104		1			1			7		1	4		3	3	
105-109		1			3			12		2	6		2	2	
110-114					2			5			6		1	4	
115-119					6			5			4	1		1	
120-124					1			4	1		5	3		8	
125-129					7	1		1	1		2	1			
130-134		3			4			1			2	2		1	3
135-139		3	1		7	2			1		3	2		1	
140-144		4			1	2		1	2			2		2	1
145-149		3	4		1	1			4			1		2	2
150-154		1	2			1			2			4	1		2
155-159			4			3			4						2
160-164		1	1			1						1			1
165-169		1	1			1			1			5			1
170-174												1			1
175-179						1			1			1			
180-184			2			1									1
185-190						1									
>190															
Total	1	29	15	43	38	15	33	81	17	60	39	24	59	28	15

Table 3.5. Total number of juvenile steelhead captured by electrofishing (EF) or observed by snorkelling (SN) in fall 2011 and spring 2012 sample sessions.

Season Year	Gear	River	Age			
			0+	1+	2+	0+ - 2+
Fall	EF	Brohm	461	102	51	614
2011	EF	Cheakamus	6,932	115	20	7,067
Spring	EF	Brohm	65	38	5	108
2012	SN		33	520	111	664
	EF	Cheakamus	1,391	175	12	1,578
	SN		2,794	1,357	355	4,506

Table 3.6. Summary of effort (KM of shoreline sampled for electrofishing (EF) and snorkeling (SN)) and catch per effort in the Brohm and Cheakamus Rivers, fall 2008 to spring 2012.

					Catch Per KM					
			KM Sampled			EF			SN	
River	Season	Year	EF	SN	0+	1+	2+	0+	1+	2+
Brohm	Fall	2008	0.13		1,488	512	291			
		2009	0.39		1,646	510	249			
		2010	0.55		1,501	385	339			
		2011	0.30		1,547	342	171			
	Spring	2009		0.40				73	590	125
		2010	0.30	0.50	292	193	23	277	836	311
		2011	0.33	0.50	317	178	86	50	182	288
		2012	0.37	0.81	178	104	14	41	644	138
Cheakamus	Fall	2008	1.13		1,550	85	32			
		2009	2.55		642	38	9			
		2010	3.00		483	20	8			
		2011	2.96		2,346	39	7			
	Spring	2009	0.98	2.92	520	17	3	126	50	20
		2010	1.78	5.59	180	74	3	106	217	53
		2011	2.32	6.17	299	12	7	172	49	33
		2012	2.39	5.78	581	73	5	484	235	61

Table 3.7. Summary of data from individual mark-recapture experiments for juvenile steelhead in Brohm and Cheakamus Rivers since the project was initiated in fall 2007. Detection probability (θ) is the ratio of recaptured (electrofishing) or resighted (snorkeling) fish to the total that were marked (Marked).

Brohm Age-0 Electrofishing				
Year	**Season**	**Marks**	**Recaps**	**θ**
2008	Fall	131	16	0.12
2008	Fall	101	12	0.12
2009	Fall	98	24	0.24
2009	Fall	111	27	0.24
2010	Spring	54	11	0.20
2010	Spring	72	14	0.19
2010	Fall	160	36	0.23
2010	Fall	93	21	0.23
2011	Spring	52	5	0.10
2011	Spring	44	6	0.14
2011	Spring	45	8	0.18
2011	Spring	51	7	0.14
2011	Spring	37	9	0.24
2011	Spring	53	7	0.13
Brohm Age-1+ Electrofishing				
Year	**Season**	**Marks**	**Recaps**	**θ**
2008	Fall	74	18	0.24
2008	Fall	69	27	0.39
2009	Fall	46	10	0.22
2009	Fall	20	11	0.55
2010	Spring	26	6	0.23
2010	Spring	41	5	0.12
2010	Fall	43	14	0.33
2010	Fall	58	24	0.41
2011	Spring	41	10	0.24
2011	Spring	50	6	0.12
2011	Spring	32	8	0.25
2011	Spring	37	4	0.11
2011	Spring	40	10	0.25
2011	Spring	43	10	0.23

Table 3.7. Con't.

Cheakamus Age-0 Electrofishing							Cheakamus Age-1+ Electrofishing					
Year	**Season**	**Marks**	**Recaps**	**θ**	**CV θ**		**Year**	**Season**	**Marks**	**Recaps**	**θ**	**CV θ**
2007	Fall	105	40	0.38	0.12		2007	Fall	11	1	0.09	0.95
2007	Fall	62	24	0.39	0.16		2007	Fall	13	0	0.00	
2007	Fall	104	35	0.34	0.14		2007	Fall	4	0	0.00	
2007	Fall	439	137	0.31	0.07		2007	Fall	52	6	0.12	0.38
2007	Fall	231	117	0.51	0.06		2007	Fall	20	2	0.10	0.67
2007	Fall	141	74	0.52	0.08		2007	Fall	17	3	0.18	0.52
2008	Fall	122	49	0.40	0.11		2008	Fall	2	0	0.00	
2008	Fall	212	60	0.28	0.11		2008	Fall	4	0	0.00	
2008	Fall	155	46	0.30	0.12		2008	Spring	19	5	0.26	0.38
2008	Spring	13	6	0.46	0.30		2008	Spring	13	1	0.08	0.96
2008	Spring	17	7	0.41	0.29		2008	Spring	18	3	0.17	0.53
2008	Spring	40	23	0.58	0.14		2008	Spring	1	0	0.00	
2008	Spring	98	29	0.30	0.16		2008	Spring	34	10	0.29	0.27
2008	Spring	32	12	0.38	0.23		2008	Spring	9	1	0.11	0.94
2008	Spring	142	46	0.32	0.12		2008	Spring	12	1	0.08	0.96
2008	Spring	139	40	0.29	0.13		2008	Spring	15	0	0.00	
2008	Spring	136	57	0.42	0.10		2009	Fall	2	2	1.00	0.00
2009	Fall	74	21	0.28	0.18		2009	Fall	3	0	0.00	
2009	Fall	118	41	0.35	0.13		2009	Fall	1	0	0.00	
2009	Fall	81	36	0.44	0.12		2009	Fall	3	1	0.33	0.82
2009	Fall	123	46	0.37	0.12		2009	Fall	1	0	0.00	
2009	Fall	118	48	0.41	0.11		2009	Fall	5	0	0.00	
2009	Fall	41	15	0.37	0.21		2009	Fall	2	2	1.00	0.00
2009	Fall	82	21	0.26	0.19		2009	Fall	9	2	0.22	0.62
2009	Fall	43	20	0.47	0.16		2009	Fall	10	4	0.40	0.39
2009	Fall	74	28	0.38	0.15		2009	Fall	7	0	0.00	
2009	Fall	106	33	0.31	0.14		2009	Spring	2	1	0.50	0.71
2009	Fall	71	19	0.27	0.20		2010	Spring	40	6	0.15	0.38
2009	Spring	84	9	0.11	0.31		2010	Spring	39	4	0.10	0.47
2009	Spring	79	21	0.27	0.19		2010	Spring	15	4	0.27	0.43
2009	Spring	83	20	0.24	0.19		2010	Spring	19	3	0.16	0.53
2009	Spring	102	23	0.23	0.18		2010	Fall	11	1	0.09	0.95
2009	Spring	73	12	0.16	0.26		2010	Fall	5	0	0.00	
2009	Spring	105	27	0.26	0.17		2010	Fall	16	7	0.44	0.28
2010	Spring	45	11	0.24	0.26		2010	Fall	16	1	0.06	0.97
2010	Spring	28	9	0.32	0.27		2011	Fall	8	1	0.13	0.94
2010	Spring	58	13	0.22	0.24		2011	Fall	6	0	0.00	
2010	Spring	20	4	0.20	0.45		2011	Fall	3	0	0.00	
2010	Fall	64	9	0.14	0.31		2011	Fall	1	0	0.00	
2010	Fall	98	13	0.13	0.26							
2010	Fall	136	34	0.25	0.15							
2010	Fall	25	0	0.00								
2010	Fall	129	22	0.17	0.19							
2011	Fall	186	59	0.32	0.11							
2011	Fall	120	54	0.45	0.10							
2011	Fall	66	8	0.12	0.33							
2011	Fall	128	40	0.31	0.13							
2011	Fall	212	29	0.14	0.17							
2011	Fall	209	54	0.26	0.12							

Table 3.7. Con't.

Cheakamus-Brohm Age-0 Snorkelling

River	Year	Season	Marks	Recaps	θ
Brohm	2009	Spring	1	0	0.00
Brohm	2009	Spring	6	1	0.17
Brohm	2010	Spring	6	2	0.33
Brohm	2010	Spring	18	4	0.22
Brohm	2011	Spring	13	3	0.23
Cheakamus	2008	Spring	10	2	0.20
Cheakamus	2008	Spring	16	8	0.50
Cheakamus	2008	Spring	5	2	0.40
Cheakamus	2008	Spring	23	11	0.48
Cheakamus	2008	Spring	16	3	0.19
Cheakamus	2008	Spring	18	6	0.33
Cheakamus	2008	Spring	41	29	0.71
Cheakamus	2008	Spring	18	5	0.28
Cheakamus	2009	Spring	19	10	0.53
Cheakamus	2009	Spring	21	8	0.38
Cheakamus	2009	Spring	23	14	0.61
Cheakamus	2010	Spring	19	19	1.00
Cheakamus	2010	Spring	1	0	0.00
Cheakamus	2010	Spring	8	6	0.75
Cheakamus	2010	Spring	13	7	0.54

Cheakamus-Brohm Age-1+ Snorkelling

River	Year	Season	Marks	Recaps	θ
Brohm	2009	Spring	34	28	0.82
Brohm	2009	Spring	33	15	0.45
Brohm	2010	Spring	37	19	0.51
Brohm	2010	Spring	37	21	0.57
Brohm	2011	Spring	60	24	0.40
Cheakamus	2008	Spring	24	14	0.58
Cheakamus	2008	Spring	25	15	0.60
Cheakamus	2008	Spring	27	16	0.59
Cheakamus	2008	Spring	22	18	0.82
Cheakamus	2008	Spring	23	22	0.96
Cheakamus	2008	Spring	22	14	0.64
Cheakamus	2008	Spring	12	9	0.75
Cheakamus	2008	Spring	19	14	0.74
Cheakamus	2009	Spring	20	12	0.60
Cheakamus	2009	Spring	40	21	0.53
Cheakamus	2009	Spring	25	17	0.68
Cheakamus	2010	Spring	13	8	0.62
Cheakamus	2010	Spring	54	10	0.19
Cheakamus	2010	Spring	11	8	0.73
Cheakamus	2010	Spring	26	11	0.42

Table 3.8. Summary statistics of detection probability from mark-recapture experiemets in Brohm and Cheakamus Rivers since the project was initiated in fall 2007 based on electrofishing (EF) and snorkeling (SN). ‘N’, ‘Mean’, and ‘CV’ denote the sample size (# of experiments), mean detection probability, and coefficient of variation in detection probability across experiments within each strata.

Strata	**N**	**Mean**	**CV**
Brohm Age-0 EF	14	0.18	0.30
Brohm Age-1+ EF	14	0.26	0.46
Cheakamus Age-0 EF	49	0.31	0.38
Cheakamus Age-1+ EF	39	0.16	1.47
Both Rivers, Age-0 SN	20	0.39	0.64
Both Rivers, Age-1+ SN	20	0.61	0.28

Table 3.9. Sample sizes used in hierarchical Bayesian model to estimate juvenile steelhead abundance in Brohm and Cheakamus Rivers. Note index sites used in the estimation are specific to river, year, and season, while mark-recapture data is aggregated across years and seasons for both gear types and among rivers in the case of snorkeling only.

				Index Sites			Mark Recapture		
River	**Year**	**Season**	**Age**	**EF**	**SN**	**Total**	**EF**	**SN**	**Total**
Brohm	2011	Fall	0	10		10	14		14
			1-2	10		10	14		14
Cheakamus			0	101		101	49		49
			1-2	101		101	39		39
Brohm	2012	Spring	0	10	0	10	14		14
			1-2	10	11	21	14	20	34
Cheakamus			0	81	69	150	49	20	69
			1-2	81	118	199	39	20	59

Table 3.10. Statistics of total population estimates (in thousands) for juvenile steelhead in the Cheakamus and Brohm Rivers. CV denotes coefficient of variation, while LCL and UCL denote the lower and upper bound of the 95% credible interval, respectively. All estimates were based on uninformative prior distributions.

River	Year	Season	Age	Mean	Median	CV	LCL	UCL
Cheakamus	2008	Fall	0	249.87	241.3	0.22	171.89	375.1
			1	27.58	25.7	0.33	15.85	50.37
			2	8.88	8.37	0.34	4.58	16.48
	2009	Spring	0	51.31	49.86	0.23	33.45	78.01
			1	5.8	5.68	0.17	4.25	8.22
			2	2.11	2.08	0.14	1.6	2.77
Brohm	2008	Fall	0	26.76	22.69	1.96	14.15	53.64
			1	10.5	5.44	14.12	3.18	14.08
			2	Did not converge due to low density and sample size				
	2009	Spring	0	0.49	0.45	0.51	0.26	0.91
			1	2.74	2.68	0.17	2.07	3.78
			2	0.58	0.57	0.21	0.4	0.86
Cheakamus	2009	Fall	0	100.93	97.54	0.21	68.65	151.11
			1	10.15	9.82	0.23	6.6	15.87
			2	2.68	2.59	0.24	1.65	4.1
	2010	Spring	0	22.63	21.96	0.19	16.16	32.46
			1	18.67	18.41	0.12	14.98	23.75
			2	3.37	3.35	0.11	2.7	4.16
Brohm	2009	Fall	0	25	24.28	0.2	17.84	36.38
			1	5.22	5.12	0.15	4.01	6.91
			2	2.56	2.49	0.19	1.8	3.8
	2010	Spring	0	5.14	4.86	0.28	3.36	8.74
			1	2.77	2.76	0.1	2.26	3.38
			2	1.05	1.04	0.14	0.8	1.34

Table 3.10. Con't.

River	Year	Season	Age	Mean	Median	CV	LCL	UCL
Cheakamus	2010	Fall	0	72.39	70.97	0.14	55.9	96.92
			1	5.51	5.36	0.2	3.72	8.05
			2	2.46	2.4	0.22	1.54	3.62
	2011	Spring	0	32.49	32.13	0.1	27.17	39.7
			1	3.58	3.56	0.09	3.01	4.23
			2	2.39	2.37	0.1	2	2.89
Brohm	2010	Fall	0	22.45	22.42	0.09	18.88	26.43
			1	3.93	3.9	0.12	3.07	5.01
			2	3.6	3.58	0.12	2.81	4.51
	2011	Spring	0	4.62	4.6	0.13	3.47	5.94
			1	1.19	1.17	0.15	0.92	1.64
			2	1.19	1.18	0.15	0.94	1.51
Cheakamus	2011	Fall	0	403.68	392.75	0.18	290.45	577.15
			1	12.18	11.73	0.22	8.11	18.76
			2	1.98	1.93	0.22	1.24	2.95
	2012	Spring	0	89.54	87.77	0.14	69.26	120.49
			1	19.83	19.66	0.1	16.27	24.44
			2	3.78	3.75	0.1	3.11	4.63
Brohm	2011	Fall	0	31.17	26.6	0.66	16.26	66.55
			1	21.25	18.31	0.81	10.68	45.77
			2	0.94	0.94	0.1	0.76	1.13
	2012	Spring	0	1.79	1.43	1.32	0.86	4.35
			1	2.38	2.35	0.11	1.94	2.94
			2	0.53	0.52	0.15	0.39	0.71

Table 3.11. Juvenile survival statistics for Cheakamus (a) and Brohm (b) River steelhead cohorts (year of spawning). Abundance for each age calss and sampling period is the median of the posterior distribution of the total abundance estimates from the HBM. See Table 2.7 for estimated annual egg deposition. Survival between periods is the ratio of abundances across adjacent rows. Survival rates are not calculated in cases where abundance estimates in the calculation are not reliable.

a) Cheakamus

Brood Year	Age (Yr. from Emergence)	Sampling Period	Abundance ('000s)	Survival between Periods	Survival Fall Age-0 Spring Age-1	Survival Spring Age-0 Spring Age-1
2008	Eggs	Spring-08	573			
	0+	Fall-08	241.3	42%		
	0+	Spring-09	49.9	21%		
	1+	Fall-09	9.8			
	1+	Spring-10	18.4		8%	37%
2009	Eggs	Spring-09	467			
	0+	Fall-09	97.5	21%		
	0+	Spring-10	22.0	23%		
	1+	Fall-10	5.4			
	1+	Spring-11	3.6		4%	16%
2010	Eggs	Spring-10	1,609			
	0+	Fall-10	71.0	4%		
	0+	Spring-11	32.1	45%		
	1+	Fall-11	11.7			
	1+	Spring-12	19.7		28%	61%
2011	Eggs	Spring-11	3,178			
	0+	Fall-11	392.8	12%		
	0+	Spring-12	87.8	22%	NA	NA

Table 3.11. Con't.

b) Brohm

Brood Year	Age (Yr. from Emergence)	Sampling Period	Abundance ('000s)	Survival between Periods	Survival Fall Age-0 Spring Age-1	Survival Spring Age-0 Spring Age-1
2008	0+	Fall-08	22.7			
	0+	Spring-09	0.5			
	1+	Fall-09	5.1			
	1+	Spring-10	2.8	54%	12%	NA
2009	0+	Fall-09	24.3			
	0+	Spring-10	4.9	20%		
	1+	Fall-10	3.9	80%		
	1+	Spring-11	1.2	30%	5%	24%
2010	0	Fall-10	22.42			
	0+	Spring-11	4.6	21%		
	1+	Fall-11	18.31			
	1+	Spring-12	2.35		10%	51%
2011	0+	Fall-11	26.6			
	0+	Spring-12	1.43	5%	NA	NA

Table 3.12. Comparison of steelhead smolt production estimates for the Cheakamus River from 2009-2011 based on the Rotary Screw Trap program (Melville and McCubbing, 2011) with those derived from juvenile surveys. Juvenile parr abundance estimates are the medians of the posterior distributions from the HBM. Estimates of smolt numbers from the RST exclude side channel production and are based on the Bayesian Spline model (non-diagonal version). Shaded cells show the key comparison (age 2 parr vs. 3 Yr smolts).

	Year of Outmigration			
	2009	**2010**	**2011**	**2012**
Juvenile Survey Parr Abundance				
Age 1 Parr (--> 2 Yr Smolt)	4,900	14,180	2,390	10,720
Age 2 Parr (--> 3 Yr Smolt)	1,520	2,610	1,580	2,730
RST Estimates of Smolts				
Total Smolts	11,088	4,974	5,518	2,208
% 2 Yr Smolts	75%	49%	56%	44%
2 Yr Smolts	8,272	2,452	3,085	978
3 Yr Smolts	2,816	2,522	2,433	1,230
RST 3 Yr Smolt / Juvenile Survey 2+ Parr Ratio	1.85	0.97	1.54	0.45

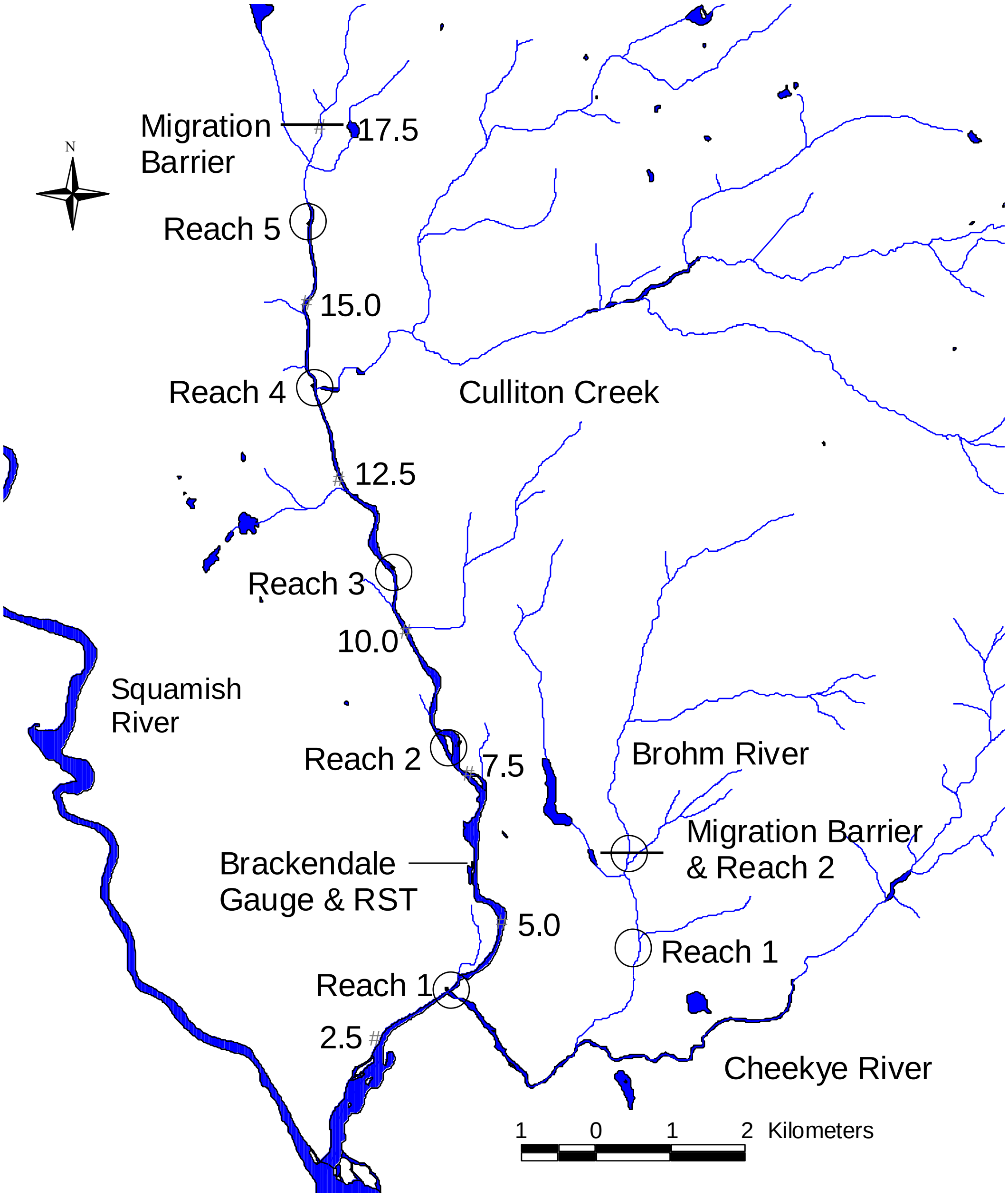


Figure 1.1. Map of the Cheakamus River study area showing the locations of the upstream limit of reach breaks used for habitat and juvenile surveys (open circles), distance (km) from the Squamish River confluence (gray points), migration barriers for anadromous fish in the Cheakamus and Brohm Rivers, and the Water Survey of Canada discharge gauge at Brackendale and rotary screw trap (RST).

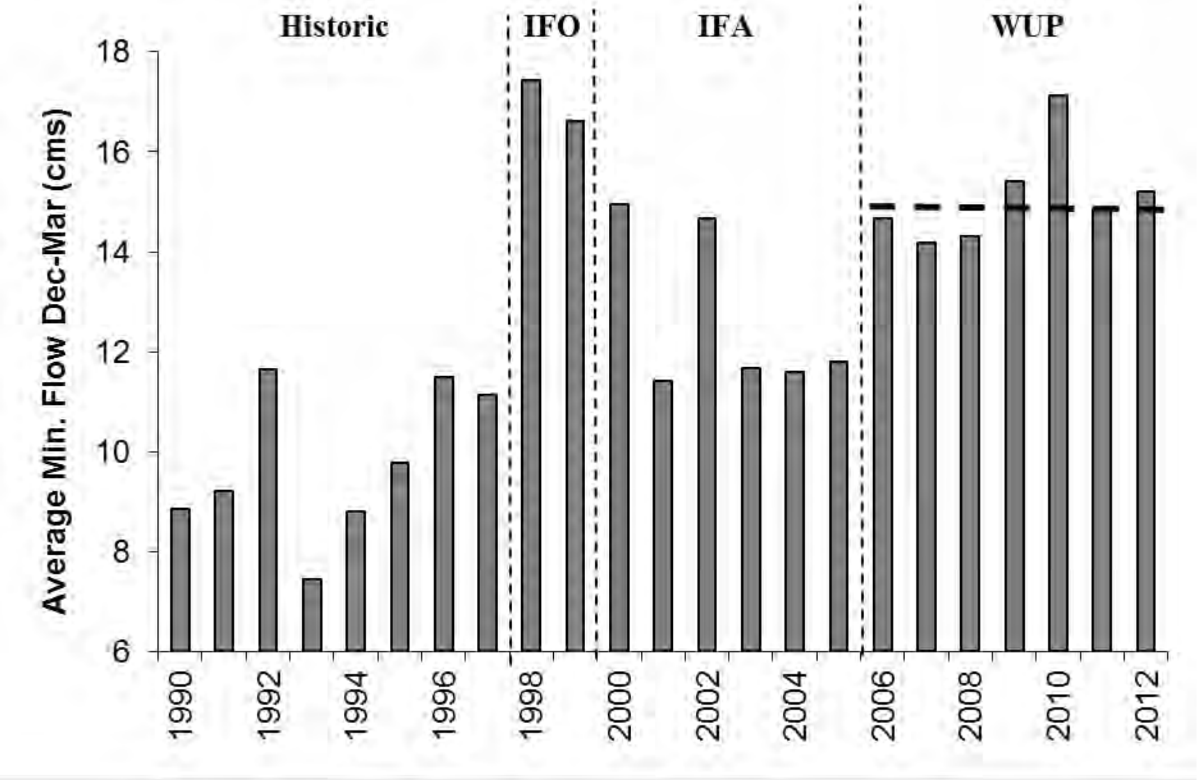
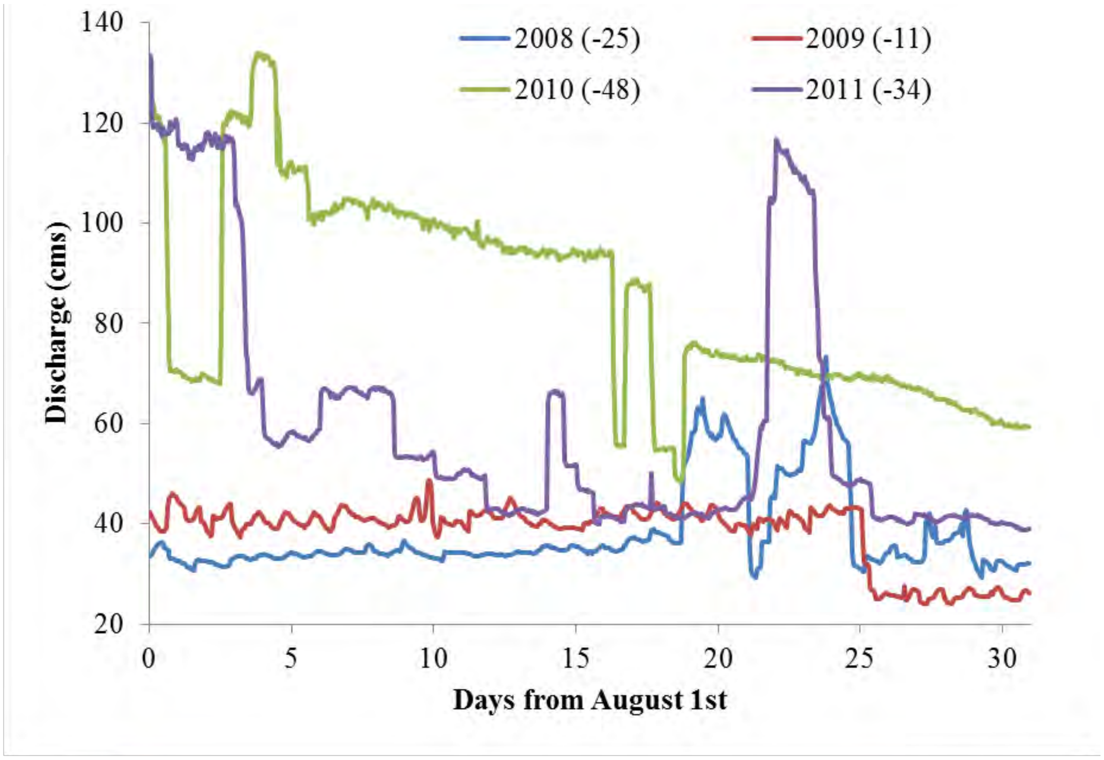


Figure 1.2. The average minimum flows during winter at the Brackendale gauge on the Cheakamus River, 1990-2012. The average minimum flow between December and March was computed as the average of the minimum flow in December from the previous year (based on average daily flows), and the minimum flows in January, February, and March for the current year (specified on x-axis). Labels at the top of the graph denote historic operations, and operations under the Instream Flow Order (IFO), Instream Flow Agreement (IFA), and the current Water Use Plan (WUP). The dashed horizontal thick line shows the WUP 15 $m^3 \cdot sec^{-1}$ minimum flow target during winter at the Brackendale gauge.



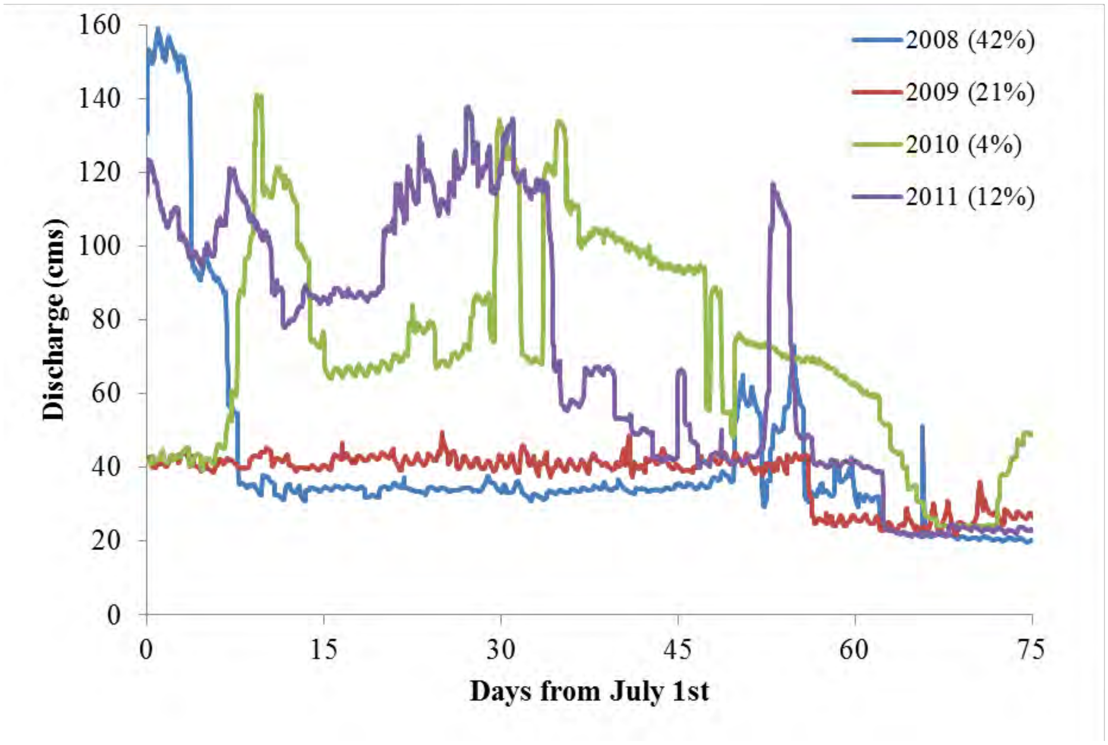


Figure 1.3. Hourly discharge at the Brackendale gauge over August (top) and between July 1st and August 15th (bottom) 2008-2011. Values in parentheses in the legend of top graph are the maximum reductions in discharge over all 6 hour periods in August, while values in parentheses in the legend of the bottom graph are the steelhead egg-fry survival rates.

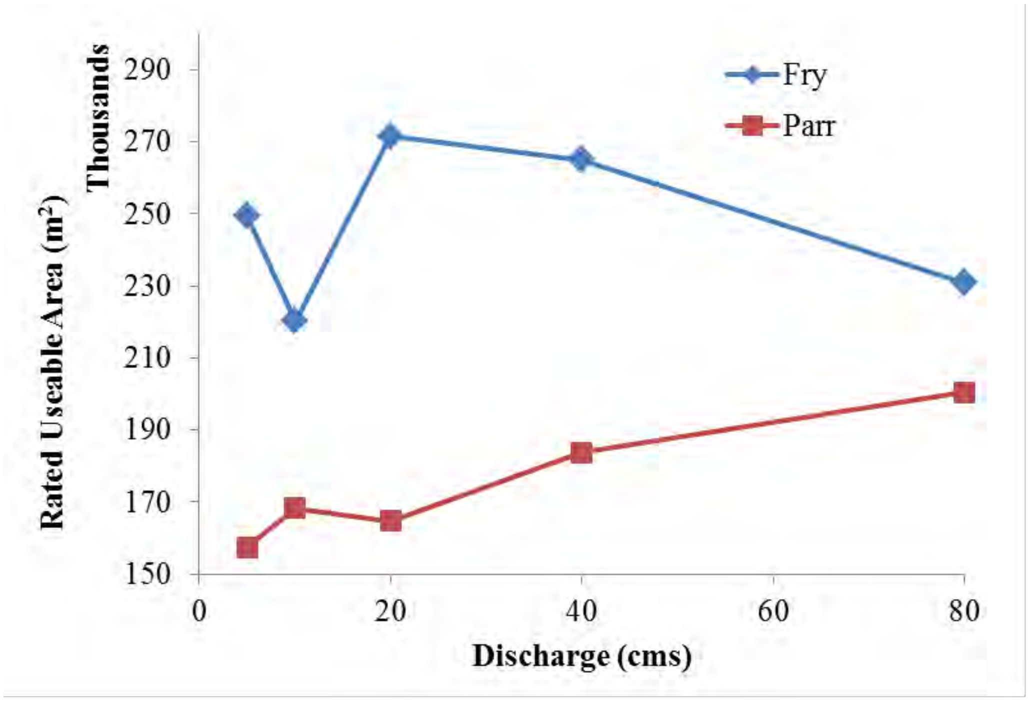


Figure 1.4. Changes in predictions of rated useable steelhead habitat in the Cheakamus River (summed across reaches) as a function of discharge. This habitat model was used in the initial WUP assessment.

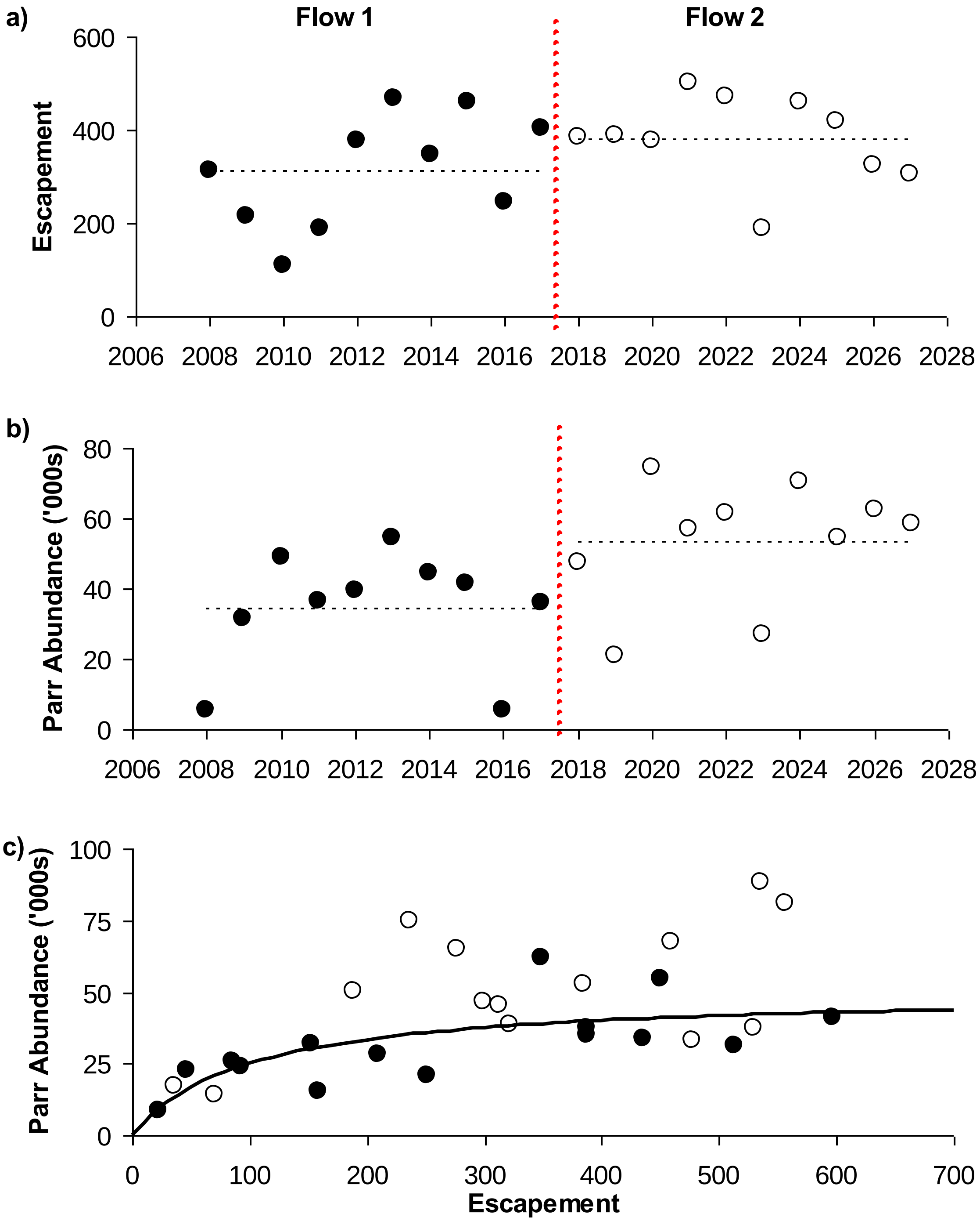
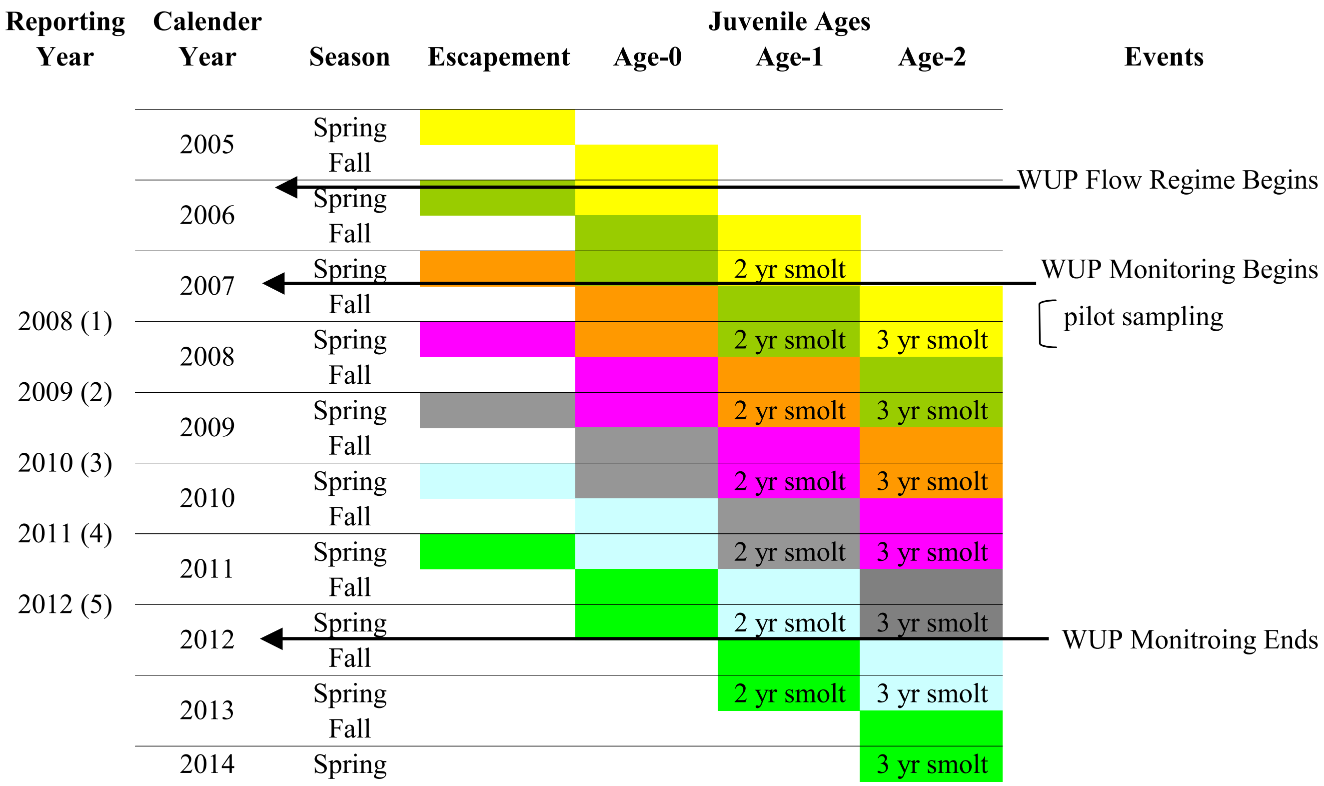


Figure 1.5. Theoretical responses of escapement (a) and parr abundance (b) under two flow regimes, with 10 years of data collected under each regime, and the stock-recruit relationship between these life stages over the two periods (c). Solid and open circles represent data collected under flow regimes 1 and 2, respectively. Dashed horizontal lines in a) and b) represent the mean abundances over these periods. The solid line in c) represents the best-fit stock-recruitment curve under flow regime 1. Evidence for the effect of flow increases from a) to c) by reducing the confounding effects of marine survival (b) and the effects of both marine survival and density dependence (c).



Reporting Year	Calender Year	Season	Escapement	Juvenile Ages			Events
				Age-0	Age-1	Age-2	
	2005	Spring					
		Fall					
	2006	Spring					WUP Flow Regime Begins
		Fall					
	2007	Spring			2 yr smolt		WUP Monitoring Begins
2008 (1)		Fall					pilot sampling
	2008	Spring			2 yr smolt	3 yr smolt	
2009 (2)		Fall					
	2009	Spring			2 yr smolt	3 yr smolt	
2010 (3)		Fall					
	2010	Spring			2 yr smolt	3 yr smolt	
2011 (4)		Fall					
	2011	Spring			2 yr smolt	3 yr smolt	
2012 (5)		Fall					
	2012	Spring			2 yr smolt	3 yr smolt	WUP Monitroing Ends
		Fall					
	2013	Spring			2 yr smolt	3 yr smolt	
		Fall					
	2014	Spring				3 yr smolt	

Figure 1.6. Life history table for the freshwater life stages of steelhead in the Cheakamus River in relation to annual-seasonal monitoring periods, the five-year WUP assessment and reporting periods, and implementation of the WUP flow regime. Each color tracks the cohort from individual broods (year of spawning). Note that an age-0 fish sampled in spring (mid-March to mid-April) is just less than one year old from the date of fertilization. An age-1 parr enumerated in early spring during the surveys (e.g., March) can potentially smolt in the same calendar year in late spring (e.g., May) as an age-2 smolt. Juvenile sampling began in fall 2007 and will end in spring 2012. Pilot juvenile sampling was conducted in year 1 (both fall 2007 and spring 2008) to evaluate alternate sampling approaches. Reliable juvenile abundance estimates are available beginning fall 2008. Reliable escapement and smolt production (via the Rotary Screw Trap) estimates are available back to 1996 and 2008, respectively.

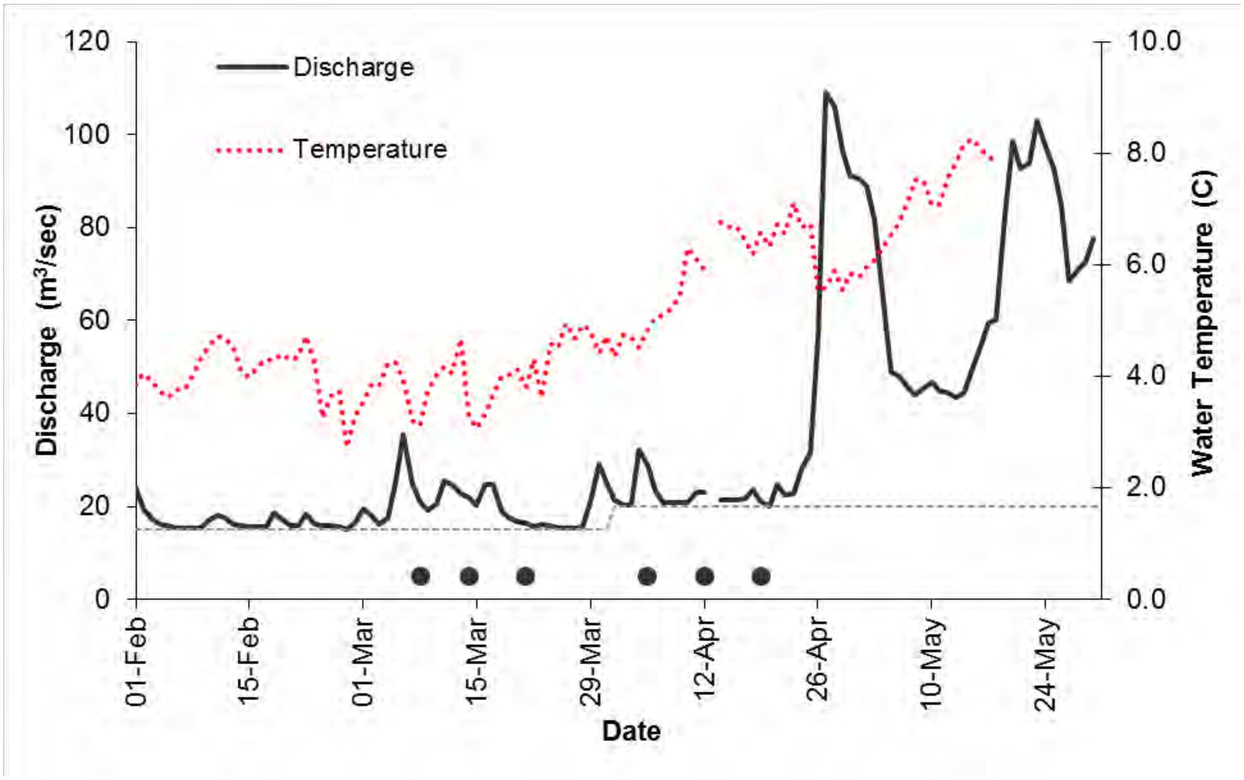


Figure 2.1. Discharge (black solid line) and water temperature (red dashed line) at the Brackendale gauge locations on the Cheakamus River in winter and spring of 2012. The gray dashed line shows minimum discharge requirements at the Brackendale gauge before and after March 31st. The points denote the dates that adult swim surveys were conducted.

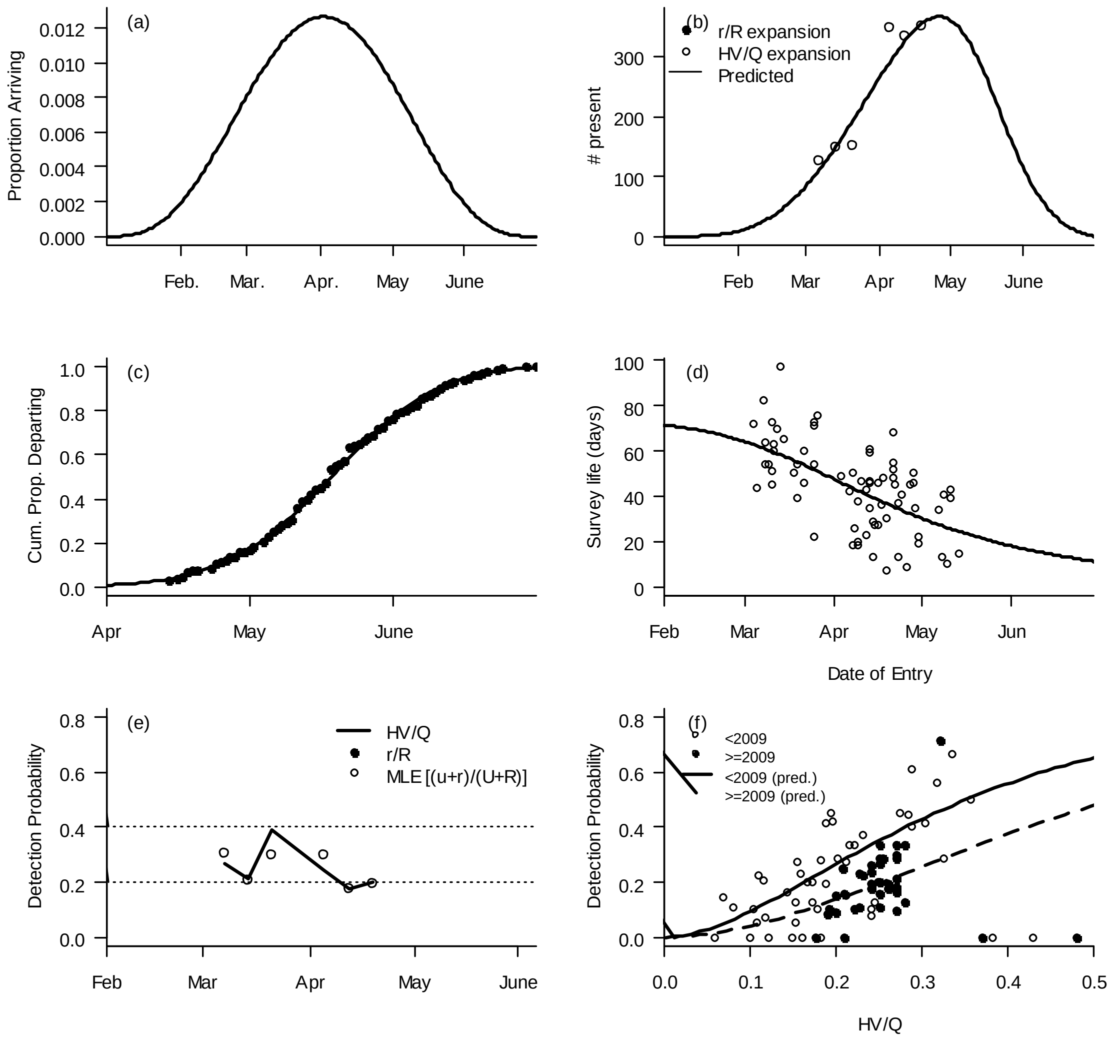


Figure 2.2. Fit of the steelhead escapement model to the 2012 data. a) shows the predicted proportion of the run arriving by day. b) shows the predicted number present (line) through the run, and the expected numbers present on individual surveys based on expanding counts by the ratio of tags observed to tags present (r/R) and based on detection probability predicted from the ratio of horizontal visibility to discharge (HV/Q). c) shows the predicted (line) and observed (points) departure schedule (data from 2001-2011). d) shows the predicted and observed survey life – date of entry relationship (data from 2001-2011). e) shows the predicted detection probability by survey date based on the p-HV/Q model (lines), and estimates of detection probability based on tagging data (r/R) or the conditional estimate (MLE). f) shows the predicted detection probability – HV/Q relationships (lines) and estimates of detection probability from tagging data only based on data from 2000-2011 (r/R, points).

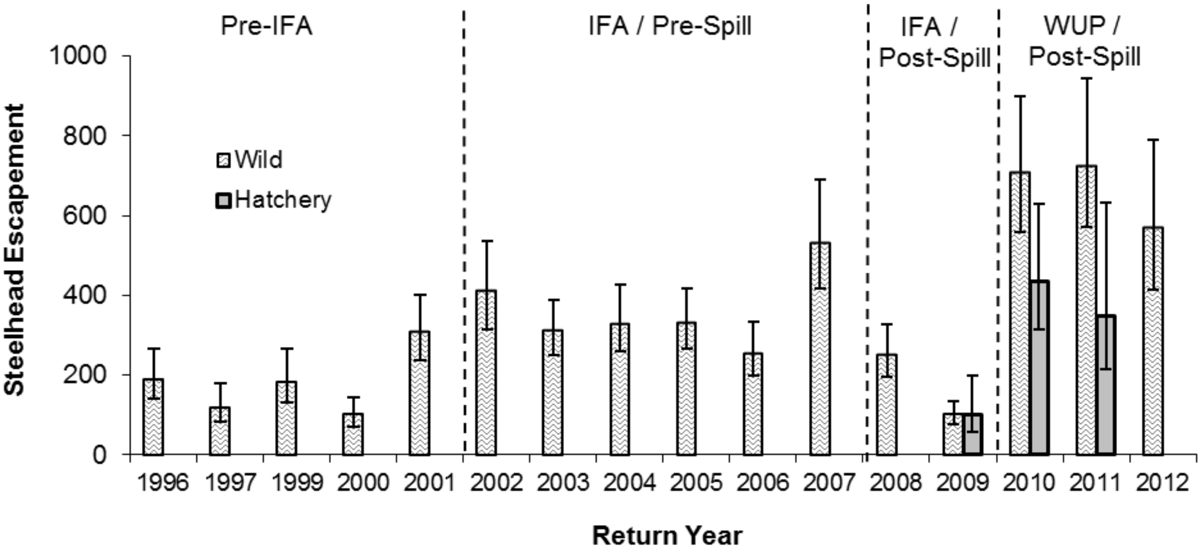


Figure 2.3. The steelhead escapement trend in the Cheakamus River, 1996-2012 showing abundance of returns that reared as juveniles in the river before and after the Instream Flow Agreement (IFA) and Water Use Plans (WUP) were implemented and the year that the sodium hydroxide spill occurred (Pre- and Post-Spill). The height of the bars and error bars show the average and 95% credible intervals from the posterior distribution of escapement estimates for each year, respectively.

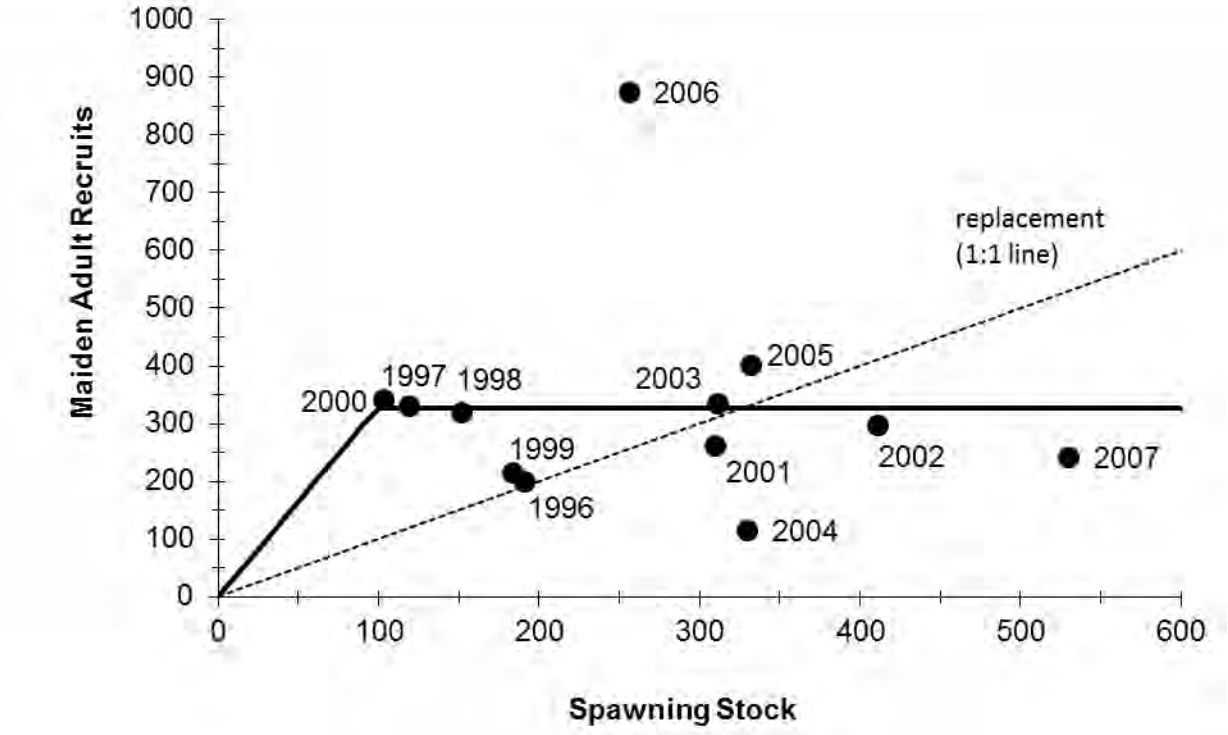


Figure 2.4. The relationship between the number of steelhead spawners in the Cheakamus River and the resulting maiden adult returns (total returns less repeat spawners). The year beside each point represents the brood year. The solid line represents the average recruitment over the period of record and the dashed line represents the 1:1 relationship. Note that the recruitment estimate for the 2007 brood year is incomplete as it does not yet include 6 year old fish that will return in 2013.

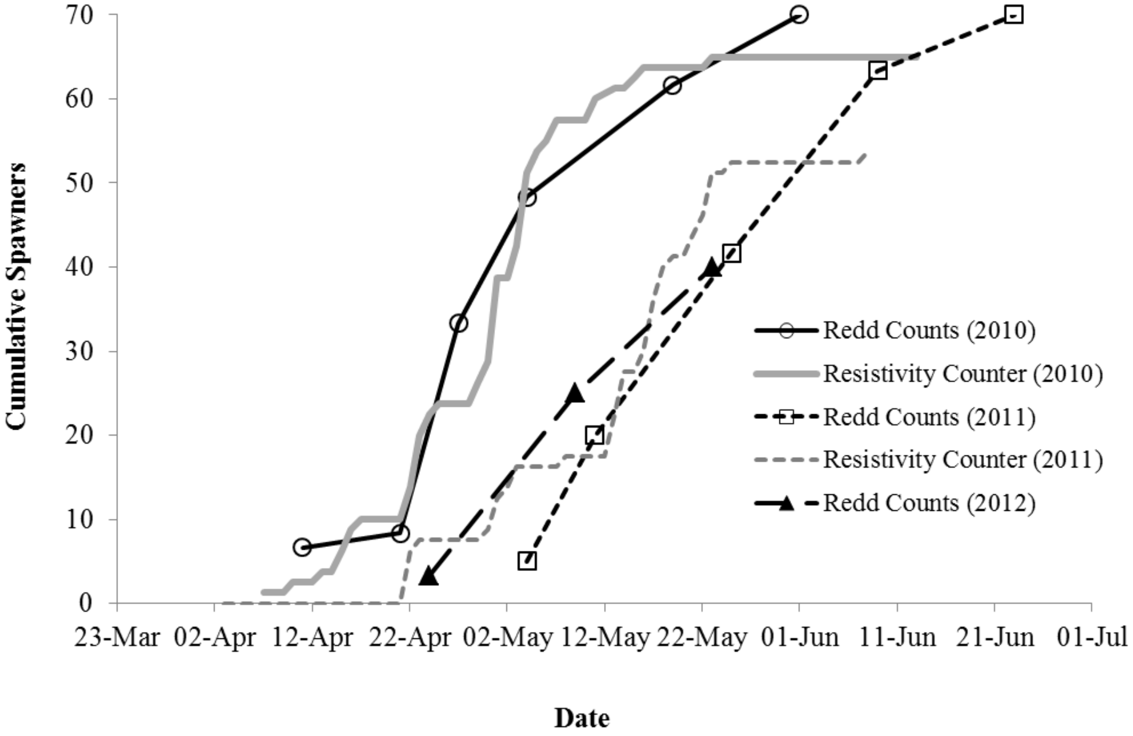


Figure 2.5. Comparison of steelhead run-timing in Brohm River based on redd counts (expanded to spawners) and net cumulative arrivals based on a resistivity counter near the mouth. Resistivity counter data from 2012 were not available.

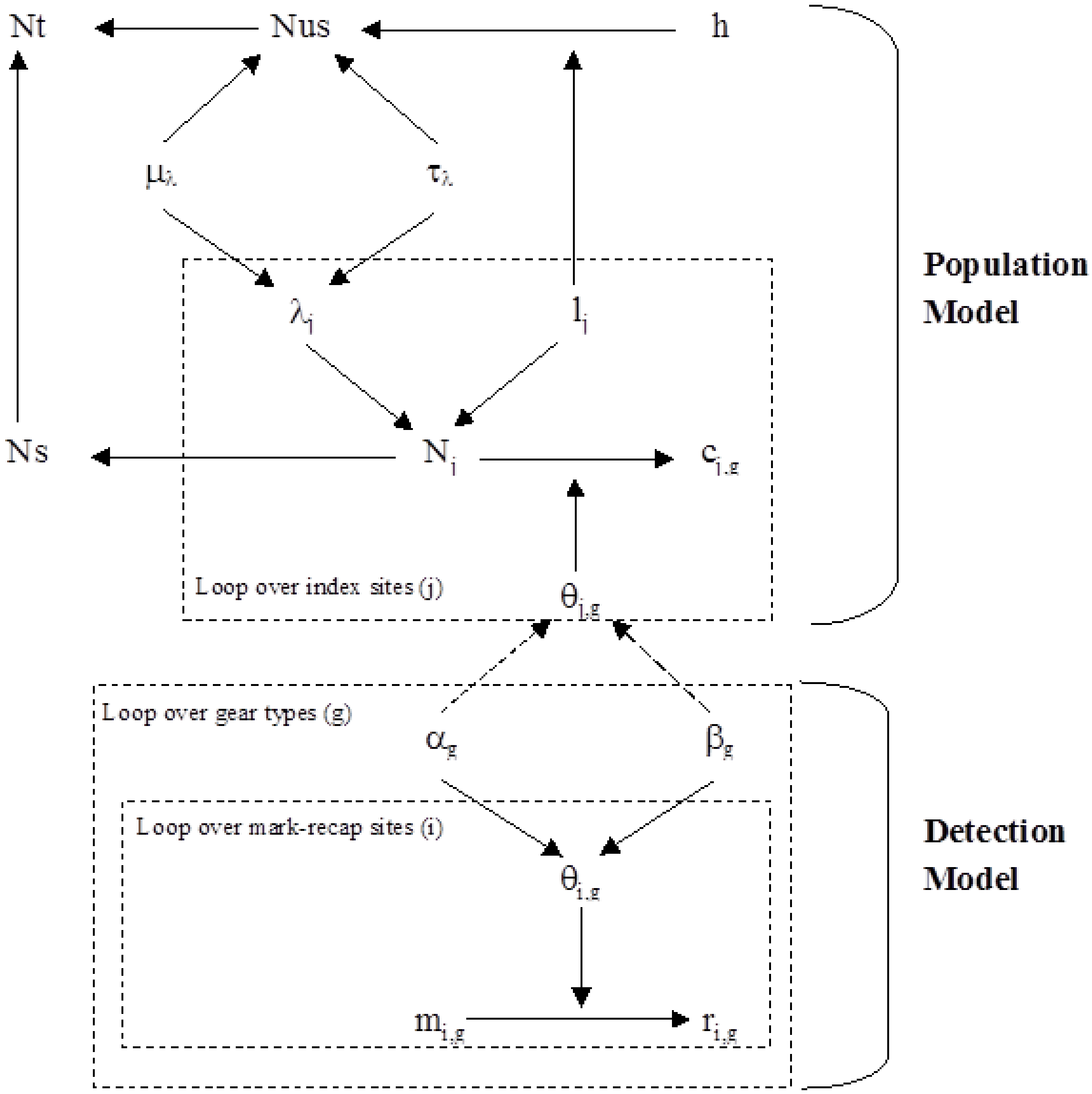


Figure 3.1. Graphical representation of the two-phase hierarchical Bayesian model to estimate juvenile steelhead abundance in the Cheakamus River. See Table 3.2 for definition of model variables. Arrows indicate conditional dependencies between the variables. The dashed arrows indicate that the hyper-parameters of the detection model effect detection probabilities in the population model but that there is no feedback from the population model to the detection model, which reflects the two-phased structure of the sampling design. The dashed boxes represent repetition of structure over units.

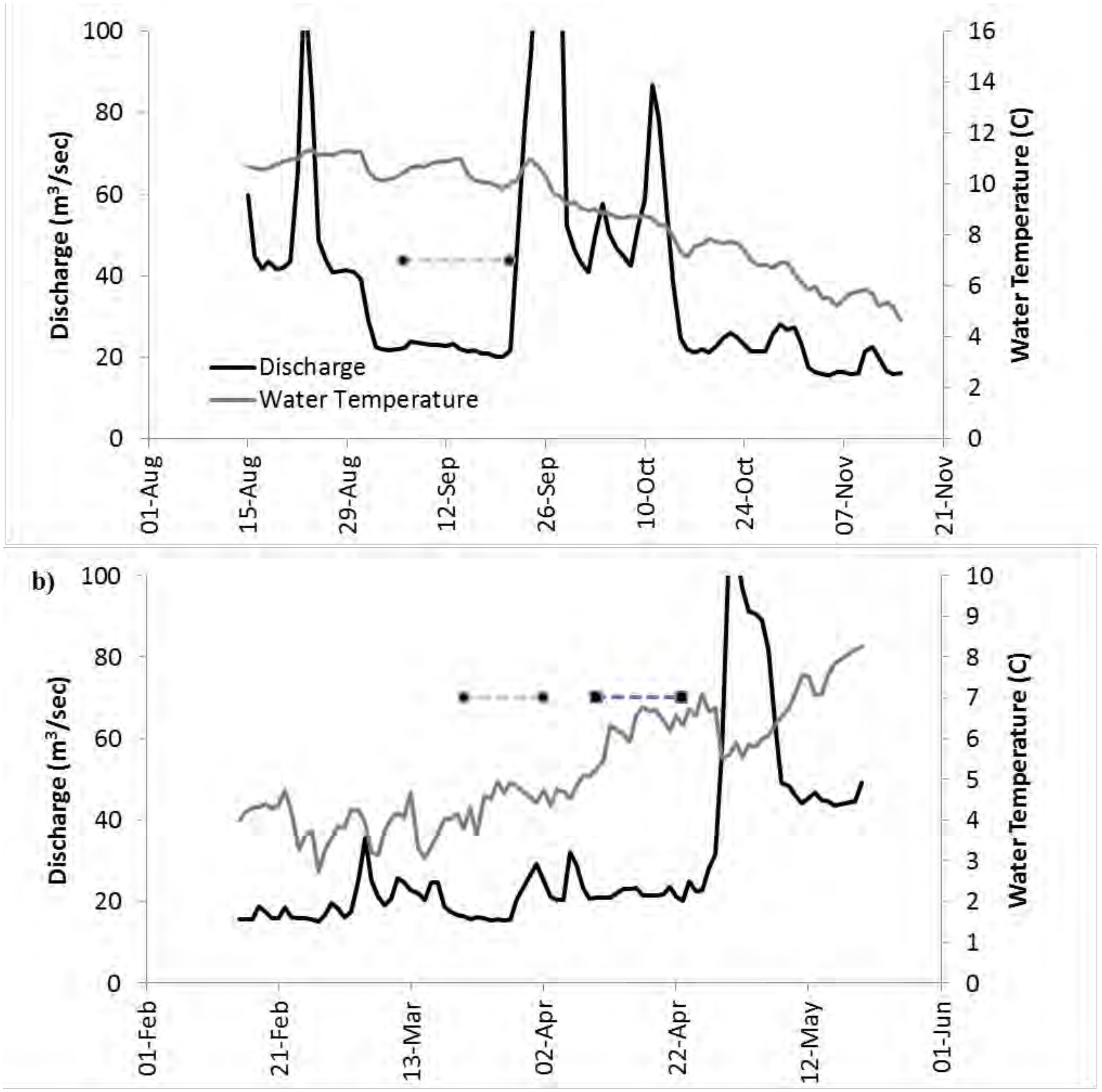


Figure 3.2. Discharge and water temperature at the Brackendale gauge (near Rotary Screw Trap) in the Cheakamus River during the fall 2011 (a) and spring 2012 (b). The horizontal lines show the fish sampling periods. In b), horizontal lines with circles and squares denote snorkeling and electrofishing sampling periods, respectively.

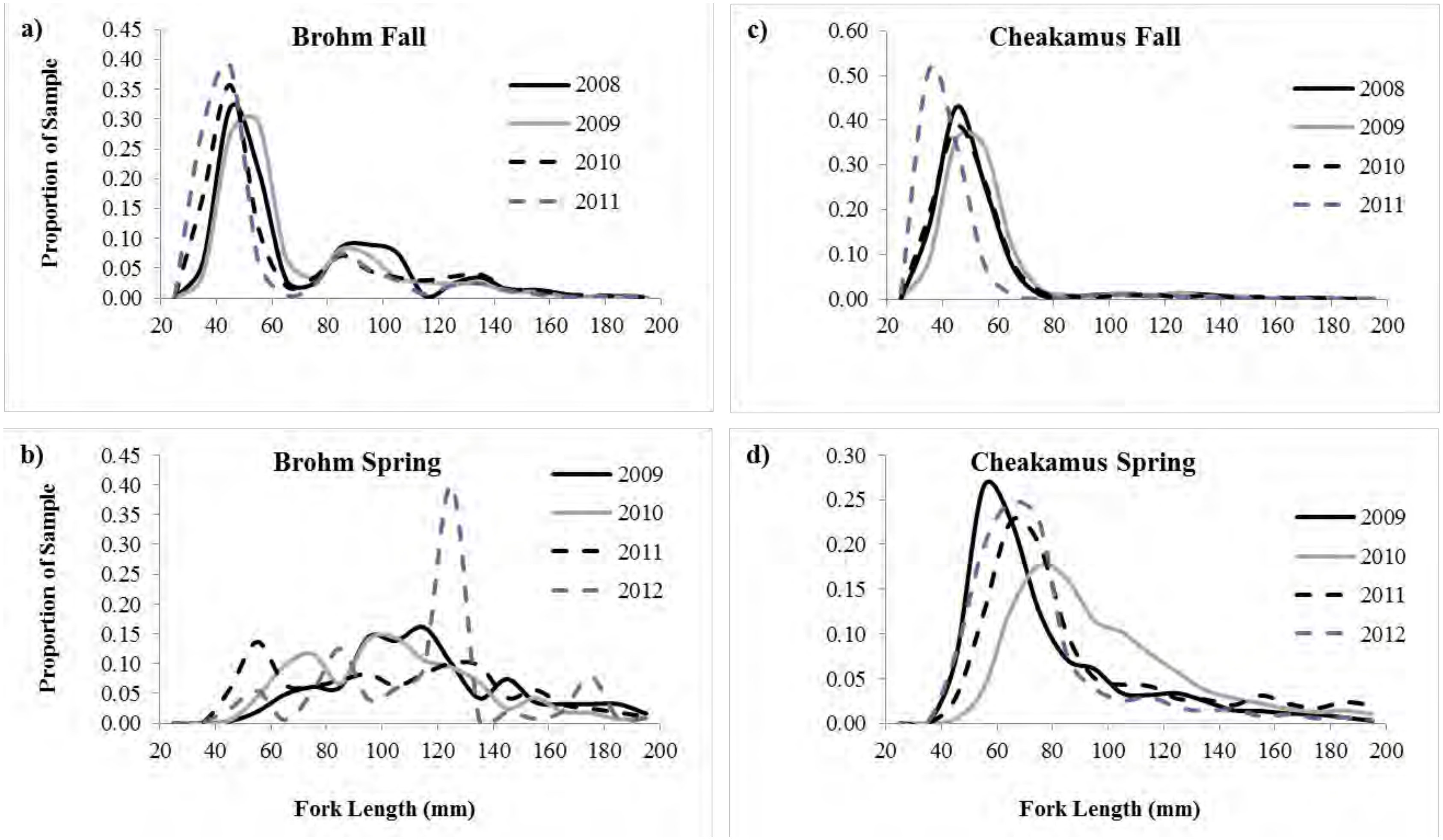


Figure 3.3. Interannual comparisons of length frequency distributions for juvenile steelhead between years within rivers and seasons. Distributions from fall samples are based on electrofishing only while distributions for spring samples are based on electrofishing and snorkelling for all Cheakamus River samples and most Brohm samples only (Brohm 2009 sample based on snorkeling only).

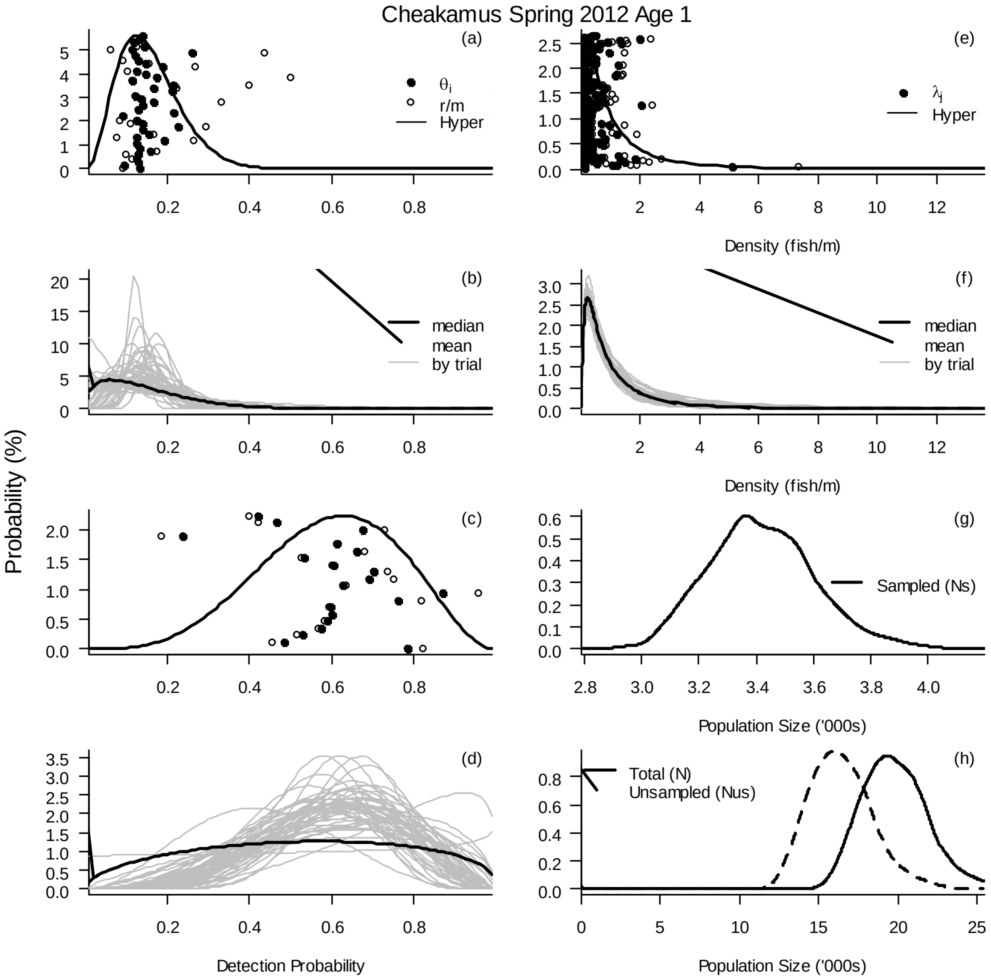


Figure 3.4. Graphical representation of output from the hierarchical Bayesian model that estimates juvenile steelhead abundance showing results for age 1+ fish in the Cheakamus River in spring 2012. a) and c) show the median hyper-distribution for detection probability, the median estimates of site-specific detection probability at mark-recapture sites (θ_i), and expected values (recaptures/marks or r/m) for electrofishing and snorkelling, respectively. The vertical order of site-specific estimates in b) is from earliest (lowest points on y-axis) to latest (see Table 3.6). b) and d) show the median and mean detection probability hyper-distribution and 50 randomly selected hyper-distributions from the posterior sample for these two gear types. e) shows the hyper-distribution for fish density and average site-specific estimates (λ_j), with the vertical order of site-specific estimates going from downstream (lowest y-axis value) to upstream. f) shows the median and mean hyper-distribution of fish density and 50 randomly selected hyper-distributions from the posterior sample. g) and h) show the posterior distribution of population size for the sampled shoreline, and the unsampled, and total shoreline, respectively.

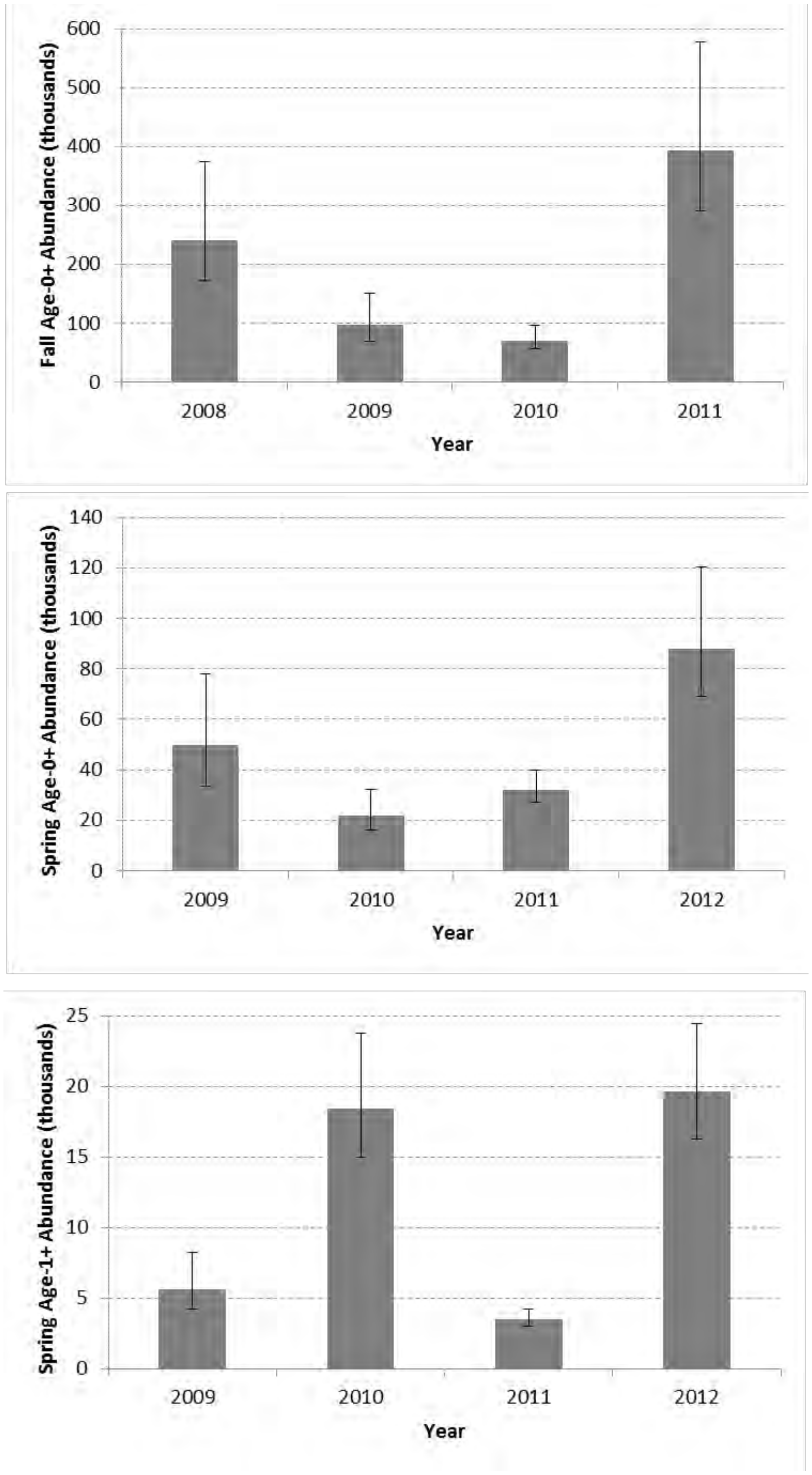


Figure 3.5. Juvenile steelhead abundance estimates in the Cheakamus River.
The height of bars and error bars represent median values and the 95% credible intervals from the HBM (see Table 3.10).

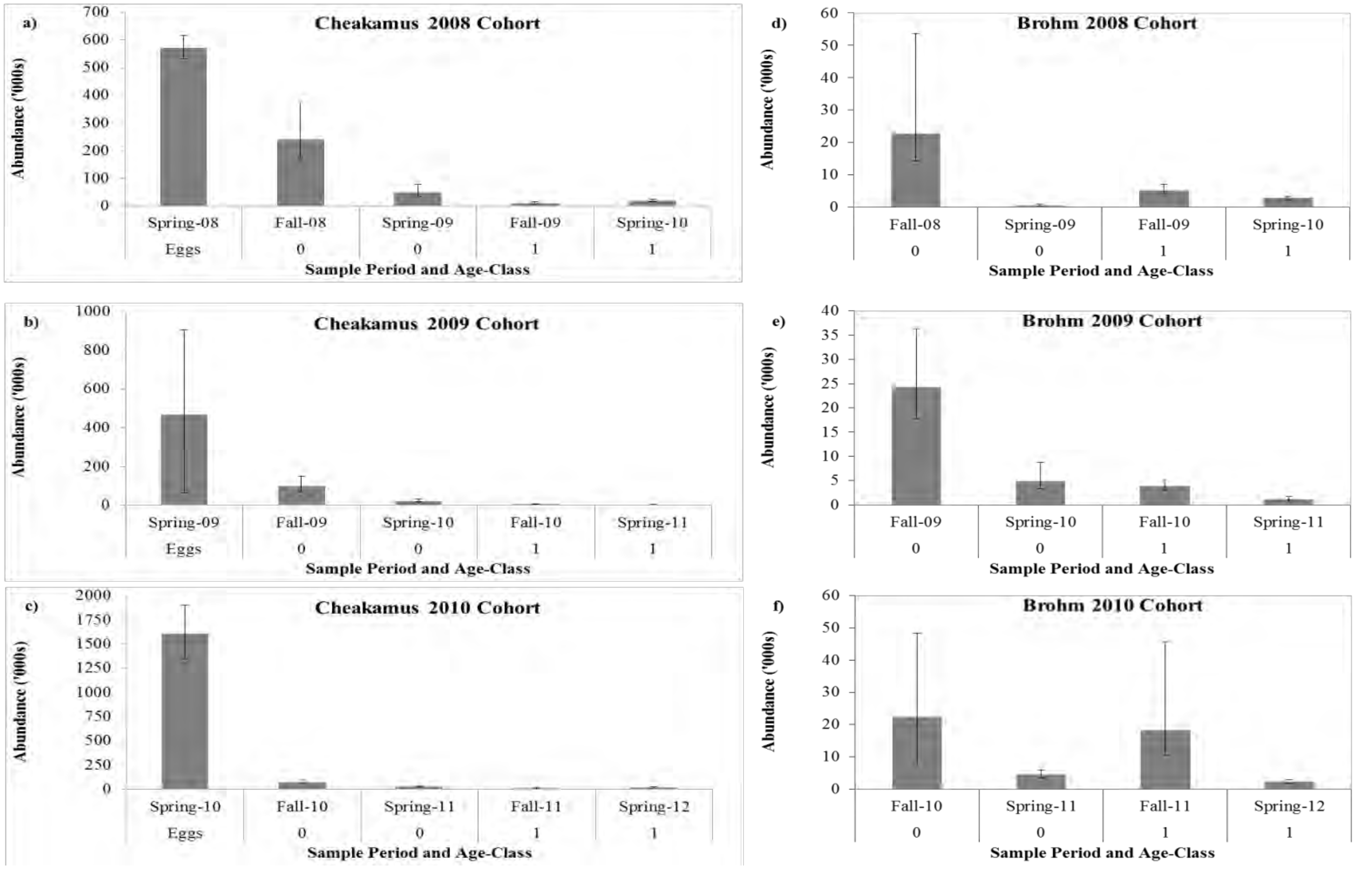


Figure 3.6. Change in abundance of steelhead cohorts (year of spawning) in Cheakamus (a-c) and Brohm (d-f) Rivers. Bar heights represent the medians from the posterior distributions of the total abundance estimates from the HBM and error bars denote the 95% credible intervals. Egg deposition estimates for Cheakamus are based on annual escapement and mean fork length of spawners for each year.

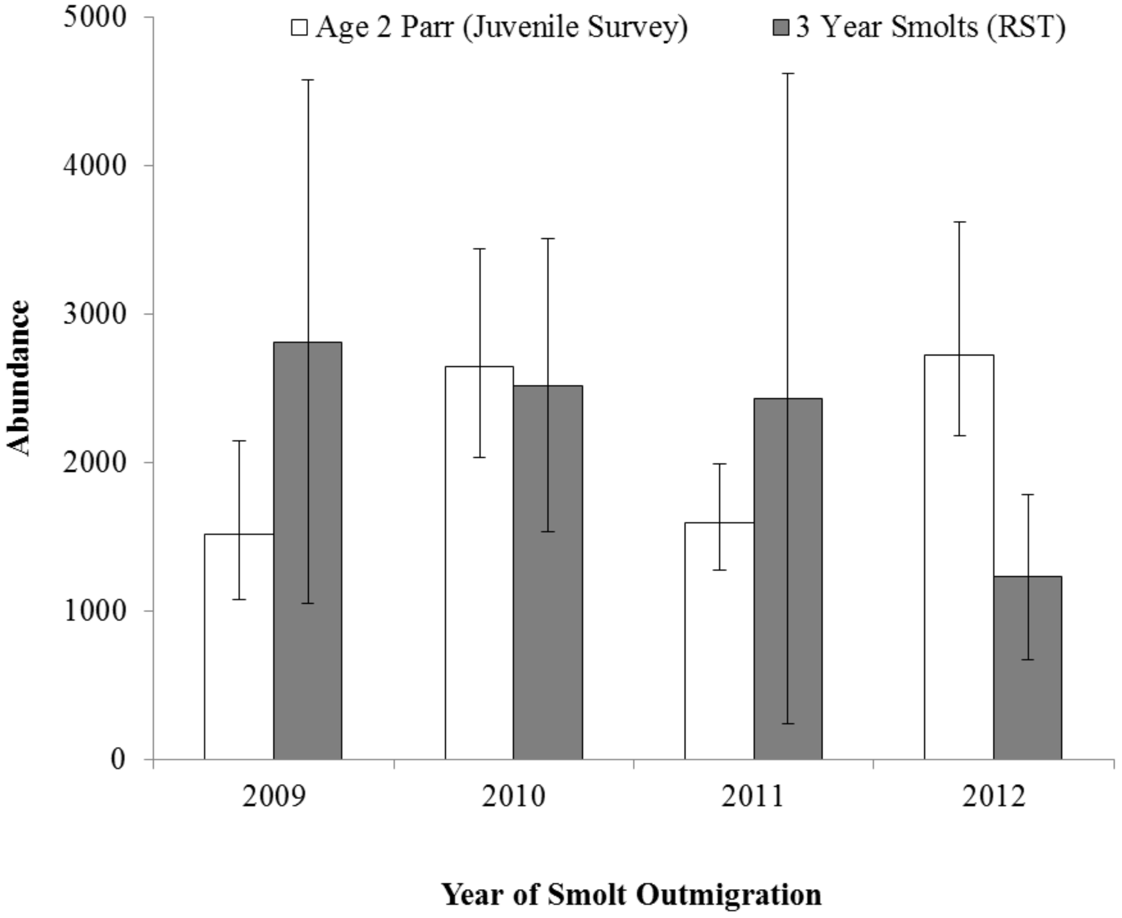


Figure 3.7. Comparison of abundance estimates of age 2 steelhead parr in the Cheakamus River above the Rotary Screw Trap (RST) in 2009-2012 based on juvenile surveys (based on HBM results developed in this report) with abundance of 3 year smolts at the RST in the same year (based on the Bayesian spline non-diagonal model). Error bars denote 95% confidence limits.