Cheakamus Project Water Use Plan

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

Implementation Year 7

Reference: CMSMON-03

Cheakamus River Steelhead Juvenile and Adult Abundance Monitoring

Study Period: 2013

Josh Korman and Jody Schick
Ecometric Research
3560 W 22nd Ave.
Vancouver, BC
V6S 1J3

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Executive Summary

The Cheakamus River supports a wild winter-run Steelhead population and a popular Steelhead (*Oncorhynchus mykiss*) 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 Cheakamus 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. This report summarizes results of year seven of the Cheakamus Steelhead monitoring project. It includes results on the 2014 escapement and on the juvenile abundance in fall 2013 and spring 2014. Results from year 7 are compared with estimates from previous years, and trends in survival rates between some juvenile life stages are compared to trends in discharge statistics.

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 2014, nine swim surveys were conducted. Counts of Steelhead were high and ranged from a low of 20 (March 13th) to a high of 96-98 (April 23rd and 28th, respectively). The estimated escapement in 2013 was 796 fish (CV=0.15) which was the 2nd highest on record.

The historical escapement trend for the Cheakamus River was segregated into four periods. Adult returns were low (average 176) 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 period but prior to the sodium hydroxide spill (357, escapement from 2002-2007). Wild-origin escapement declined over two consecutive years for returns produced from

surviving juveniles that were present in the river during the spill (179, escapement in 2008, 2009). The escapement since 2010, which was produced from juveniles which have reared in the river under WUP flows, has an average two-fold higher that the IFA/pre-spill period (858).

It is possible that the doubling in escapement pre-IFA and IFA periods was in part caused by higher minimum flows during the latter period. Unfortunately, no reliable juvenile monitoring data are available for this period, so it is uncertain whether this change was caused by improvements in freshwater rearing conditions, higher marine survival, or reduced by-catch in First Nations net fisheries on the Squamish River. However, Steelhead marine survival rates measured in other systems on the South Coast did not increase over these periods, suggesting that increased escapement was due to better freshwater survival or reduced in-river harvest. The sodium hydroxide spill resulted in a halving of escapement for broods that were in the river at the time of the spill (2008-2009). However, spill effects were short-lived, as escapements since 2009 have been more than double values produced under the IFA regime (pre-spill). Escapements have been more than two-fold higher under the WUP relative to those produced from IFA flows (pre-spill). Unfortunately, reliable estimates of juvenile Steelhead abundance (this project) or smolt production (from the rotary screw trap) only began in 2008. Thus, it is uncertain whether the much higher escapements under the WUP period are due to changes in freshwater or marine survival.

Juvenile Abundance

Estimates of juvenile Steelhead abundance were derived for fall and spring periods in Brohm (control stream) 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 to estimate river-wide abundance using a hierarchical Bayesian model (HBM).

Index sampling sites covered 17% and 8% of the total useable shoreline length in Brohm and Cheakamus Rivers in fall 2013, and 44% and 18% of shoreline length in spring 2014, respectively. Median abundance of age-0+ Steelhead in the Cheakamus River in fall 2013 and spring 2014 was 246,700 (CV=0.19) and 52,500 (CV=0.16), respectively. Median abundance of age-1+ and -2+ Steelhead in the Cheakamus River in spring 2014 were 45,600 (CV=0.11) and 3,900 (CV=0.10), respectively. The age-1+ estimate in the spring of 2014 was more than 2.5-fold greater than estimates from previous years, and was caused by exceptional survival in 2013, perhaps due to very high pink salmon abundance. In Brohm River, median abundance estimates of age-0+ Steelhead in fall 2013 and spring 2014 were 15,500 (CV=0.17) and 3,800 (CV=0.19), respectively. Median abundance estimates of age-1+ Steelhead in Brohm River in fall 2013 and spring 2014 were 5,100 (CV=0.13) and 2,300 (CV=0.10), respectively. Inter annual variation in juvenile abundance in Brohm River has been relatively low compared to the Cheakamus River and estimates from fall 2013 and spring 2014 are consistent with the stable trend.

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 41% for the 2008 spawning Cohort, to a low of 3% for the 2009 cohort. Survival from fall fry to the spring two winters later (when fish were age 1+) ranged from 3-30% in the Cheakamus River, and 5-14% in Brohm River. Coefficient of variation in these survival rates and those for other life stages ranged from 0.19-0.35. There are a wide range of juvenile Steelhead and Atlantic salmon survival rates (a good surrogate for Steelhead) measured in other systems, and estimates in the Cheakamus fall within these reported ranges.

The most significant finding from the juvenile Steelhead surveys conducted to date is that reasonable precision in estimates of juvenile abundance, and survival rates across various juvenile life stages, can be achieved. These estimates will help evaluate effects of major changes in flow and other abiotic and biotic variables on freshwater Steelhead production. For example, based on a limited sample size, egg-fry survival rates in the Cheakamus River appear to be negatively correlated with egg deposition, average flows in August (a critical period for emergence), and the maximum rate of discharge decline over short periods (6 hrs.) in August. Additional years of data collection are required to determine if such correlations are spurious or represent meaningful effects.

Conclusions Regarding Key Uncertainties

The key uncertainties for Steelhead identified during the Cheakamus WUP, and preliminary conclusions from this project, are summarized here.

1. Do high flows in July and August negatively affect Steelhead fry that have recently emerged?

   There is some indication that high flows during summer and/or rapid reductions in flow during this period limited egg-fry survival rates. However, as sample size (number of replicate years) is extremely limited, this conclusion should be considered very preliminary. Additional observations of egg-fry survival rates under high flows with and without rapid reductions in flow in coming years will resolve this uncertainty.

2. Does flow effect juvenile production, as indexed by the number of fry, parr, smolts, and returning adults?

Escapement produced from juveniles that reared under the IFA regime (pre-spill, 2002-2007) was over two-fold higher than escapement produced under pre-IFA conditions (1996-2001). 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. Unfortunately, no reliable juvenile monitoring data are available for this period, so it is uncertain whether this change was caused by improvements in freshwater rearing conditions, higher marine survival, or reduced by-catch in First Nations net fisheries on the Squamish River. However, Steelhead and Coho marine survival rates measured in other systems on the South Coast did not *increase over these periods, suggesting that increased escapement was due to better freshwater survival or reduced in-river harvest.*

3. Has the current WUP flow regime led to changes in Steelhead production, as indexed by adult returns, juvenile abundance, and smolt production?

Escapements produced from juveniles that reared in the Cheakumus River under WUP flows have been more than two-fold higher relative to those produced from IFA flows (pre-caustic soda spill). Unfortunately, reliable estimates of juvenile Steelhead abundance (this project) or smolt production (from the rotary screw trap) only began in 2008. Thus, it is uncertain whether the much higher escapements under the WUP period are due to changes in freshwater or marine survival. This uncertainty could be resolved over time with continued monitoring of juvenile abundance/production and escapement combined with changes to the flow regime following the current WUP period.

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 Akaike Information Criterion 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-referenced data.

HV: Horizontal visibility used in this study to measure the clarity of water which affects detection probability.

Lognormal Distribution: Statistical distribution for which the log of the random variable is distributed normally.

HBM: A Hierarchical Bayesian Model assumes that parameters for a series of replicates (e.g. fish density from a series of sampling sites) are exchangeable. This assumption leads to more reliable site-specific estimates as well as a more accurate description of the overall behavior of the mean and the variance across replicates.

IFA/IFO: Instream Flow Agreements and Instream Flow Orders are operating rules used to regulate discharge in rivers.

Iteroparous: A species is considered iteroparous if it is characterized by multiple reproductive cycles over the course of its lifetime.

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 calculating 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 stream 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: An egg nest formed in the gravel by salmon and other fish.

Repeat Spawner: A Steelhead adult returning to freshwater that has spawned before.

Semaloparous: A species is considered semalparous if it is characterized by a single reproductive episode before death.

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 to 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: (Terrain Resource Information Management). 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 (*Oncorhynchus mykiss*), Chinook (*Oncorhynchus tshawytscha*), Coho (*Oncorhynchus kisutch*), Pink (*Oncorhynchus gorbuscha*), and Chum (*Oncorhynchus keta*) salmon, as well as resident populations of Rainbow Trout (*Oncorhynchus mykiss*), Bull Trout (*Salvelinus confluentus*), 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 one of the more productive wild Steelhead populations 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 affects 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 (BC Hydro 2005), flows from the dam must now exceed 3 $m^3 \cdot sec^{-1}$ (November 1-December 31st), 5 $m^3 \cdot sec^{-1}$ (January 1st – March 31st), or 7 $m^3 \cdot sec^{-1}$ (April 1st-Octber 31st), and additional water must be released to maintain minimum flows at the Brackendale gauge (08GA043) 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) 20 $m^3 \cdot sec^{-1}$ (August 16th – August 31st , unless otherwise directed by the Comptroller to increase flows to 38 m3/s for the benefit of recreation.) and 20 $m^3 \cdot sec^{-1}$ (September 1st-October 31st).

Dam-induced changes to the flow regime during winter and summer have the potential to affect 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 (65 $m^3 \cdot sec^{-1}$) which divert water to the Squamish River. Occasional maintenance on Daisy Lake Dam and at the Cheakamus Powerhouse temporarily reduces reservoir storage and diversion capacity, which affects flows below the dam, sometimes during peak inflow periods (Fig. 1.3). Flows into the Cheakamus River downstream of the dam have been greater in years when maintenance has occurred at the Powerhouse and 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.

The key uncertainties for Steelhead identified during the Cheakamus WUP and addressed by this project are:

1. Do high flows in July and August negatively affect Steelhead fry that have recently emerged?
2. Does flow effect juvenile production, as indexed by the number of fry, parr, smolts, and returning adults?
3. Has the current WUP flow regime led to changes in Steelhead production, as indexed by adult returns, juvenile abundance, and smolt production?

The first question is based on the concern that high flows during and shortly after the Steelhead fry emergence period (July and August) could displace fry from preferred shallow edge habitats and reduce the availability of this habitat, ultimately leading to a reduction in egg-fry survival rate which would in turn lead to reduced smolt production and adult returns. The second question is more general and can be evaluated by comparing various statistics of the flow regime (minimum winter flows, average flow or flow fluctuations during summer) to abundance and survival estimates. The third question focuses on whether abundance estimates for various Steelhead life stages have changed due to the current WUP operation. This can be addressed by comparing abundance estimates obtained prior to implementation of the WUP regime with estimates obtained under the regime.

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). CMSMON#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. CMSMON#3 (this report) 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 address the 3 critical uncertainties summarized above, and more broadly to determine if the number of adult returns, juvenile abundance, and smolt production are affected by flows and the WUP flow regime. The overall approach to addressing these questions is 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 the parental escapement and the resulting parr abundance, or escapement and smolt abundance. These relationships control for the effect of escapement on juvenile production, and remove 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. 1.5c).

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 affect 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 seventh year of the Cheakamus River WUP Steelhead monitoring project, covering the fall 2013 and spring 2014 surveys (Fig. 1.6). This report is divided into two main chapters. Chapter two summarizes the adult escapement program conducted in winter and spring of 2014, and chapter three summarizes the results from the juvenile abundance program conducted in fall 2013 and spring 2014.

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 surveys 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 2014. A synthesis of relevant physical data, other supporting information required to generate the 2014 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 2014 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 are an aggregate measure which includes the escapement to the Cheakamus proper as well as some 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 could be attributed to differences in trends in freshwater productivity between systems. However, Brohm River may only act as a pseudo-control, since some juveniles that were spawned there may migrate into the Cheakamus River and be affected 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 2013, seven surveys were conducted between March 4th and April 30th. Discharge was low and stable for the majority of this entire period and provided ideal counting conditions (Fig. 2.1). As in many other years, a large and prolonged freshet beginning in early May (shortly after the last survey) precluded our ability to conduct surveys in mid- to late-May and quantify the abundance of late run-Steelhead that entered after the last survey date.

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 (approximately >50 cm, purple-silver hue, few black spots, fusiform shape), resident Rainbow Trout approximately 20-50 cm, darker coloration, black spots common and large, more 'blocky' shape), and bull trout observed in each section was recorded. Horizontal visibility (HV) was estimated by measuring the maximum distance from which a diver could detect the silhouette of another diver's leg. 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

Adult 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, sex, and age structure of the 2013 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. Sex was determined based on external characteristics. Samples were placed in coin envelopes marked with appropriate data for cross-reference. After a period of air-drying, scales were 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. Scales are read or checked by at least one reader that has aged Cheakamus Steelhead every year since the inception of the program.

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 (discharge and horizontal visibility). 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 marked fish 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 eight (2000, 2001, 2003-2005, 2009-2011) of 17 years that the swim surveys have been conducted (1996-2013, 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 negative binomial distribution with a common estimate of overdispersion (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). Separate estimates of the constant of p-HV/Q relationship are estimated from 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, 10 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 1996-2014 and hatchery-origin fish from 2009-2011, a total of 189 parameters are estimated (39 for the 3 years when hatchery returns occurred (2009-2011), and 150 parameters in non-hatchery return years (1996-2014 with 1998 excluded as no surveys were conducted in that year)).

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 95% credible intervals (2.5 and 97.5 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 a sufficient scale sample was available (2000, 2001, 2003-2005, 2009-2011, 2013, 2014). Age proportions in other years 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 semelparous species, or to immature stages of iteroparous species. In the case of Steelhead, which are iteroparous, the number of repeat spawners (as determined from scales) 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 and fitted a Beverton-Holt stock-recruit model to the estimates.

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. A stock-recruit plot based on annual egg deposition was plotted. The multi-year average egg-deposition to escapement ratio was used to compute total egg deposition (based on the product of the ratio and escapement) in years when year-specific egg deposition estimates were not available.

2.2.6 Redd Counts in 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 2014, we conducted six surveys of the entire 2.4 km of Brohm River that is accessible to Steelhead at roughly two-week intervals between April 8th and June 3rd. 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).

2.3 Results

2.3.1 Swim Counts and Creel Survey

Discharge in the Cheakamus River was low and steady from mid-March to early-May (Fig. 2.1). Due to high flows and turbidity, there were no opportunities to conduct surveys after our last survey on April 30th. Counting conditions were relatively poor in 2014 compared to other years under the same level of discharge. Observer efficiency is correlated with the ratio of horizontal visibility to discharge, with higher efficiency when the river is clear and discharge is low. Although discharges during swim surveys were similar to other years, horizontal visibility at those discharges was lower than normal (Fig. 2.2), likely because elevated levels of phytoplankton in the water. Counts of Steelhead and to some extent Rainbow Trout, were good in 2014 in spite of lower than normal visibility, indicative of a larger run.

2.3.2 Age structure

Volunteers sampled a total of 148 adult resident rainbow trout or steelhead for length, sex, and age in 2014 (Table 2.4). Based on the scale patterns, 57 and 91 of these fish were designated as resident rainbow trout and steelhead, respectively. The sex-ratio of steelhead was close to 1:1, but the ratio for resident rainbow trout was 1.6 males for every female. The average size of resident rainbow trout was larger for males than females, but both sexes were considerably smaller than the average size of steelhead. However, there were some large resident rainbow trout, and the maximum size of males exceeded the minimum size of both female and male steelhead. The overlap in the size distributions of resident rainbow trout and steelhead leads to some uncertainty in their classification during surveys.

Freshwater and ocean ages could be determined for 71 and 69 Steelhead sampled in 2014, respectively (Table 2.5). 80% of returning Steelhead were comprised of fish that resided in freshwater for 3 years, considerably higher than the long term average of 49%. Ocean ages in 2014 were similar to other years, with about 60% and 40% of fish returning after 2 and 3 winters at sea, respectively. The total age of Steelhead in 2014 was older than in most other years owing to the higher proportion of fish that spent 3 years in freshwater. 23 and 38 of the 72 steelhead that had a total age estimate came from the spawn in 2008 and 2009, respectively. Thirty three resident Rainbow Trout could be reliably aged in 2014 and most fish were 5 and 6 years old. Mean size of rainbow trout increased from 400 mm at age 4 to 479 mm at age 6. The majority of resident rainbow trout that were aged were derived from the spawn in 2008 and 2009.

2.3.3 Escapement Estimates

The expected value for wild escapement to the Cheakamus River in 2014 was 796 (CV=0.15, Table 2.7), the second highest estimate over the 18-year record. Peak arrival occurred in early-mid April (Fig. 2.3a) similar to other years, and expanded counts continued to rise through the survey period (Fig. 2.3b). Due to this latter pattern, the 2014 estimate was more dependent on the assumed end date of the run and telemetry data on survey life and departure timing from other years. The model provided good fits to telemetry-based patterns in departure timing (Fig. 2.3c) and survey life (Fig. 2.3d). Detection probability across surveys, as estimated from the ratio of horizontal visibility to discharge (HV/Q) was approximately 0.2 (Fig. 2.3e). A common constant but separate slopes of the relationship predicting observer efficiency as a function of horizontal discharge were fit to telemetry data before and during/after 2009 (Fig. 2.3f).

The historical escapement trend for the Cheakamus River can be segregated into four periods (Fig. 2.4, Table 2.7). Adult returns were low (average 176) 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 (357, escapement from 2002-2007). This difference was statistically significant (p=0.003). Wild-origin escapement declined over two consecutive years for returns produced from juveniles that were present in the river during the spill (179, escapement in 2008, 2009). This decline was statistically significant (p=0.026). The average escapement since 2010, which was produced from juveniles which have reared in the river under WUP flows, has been very high (858). The increase in escapement produced under WUP flows relative to the IFA pre-spill period was statistically significant (p=0.006).

2.3.4 Stock-Recruit Analysis

Beverton-Holt models fit to the escapement and maiden recruit estimates indicate that the carrying capacity for Steelhead in the Cheakamus River is approximately 450 spawners (Fig. 2.5 top, intersection of curve and 1:1 line). The initial slope of the stock-recruit relationship (i.e. maximum recruits/spawner or productivity is poorly defined due to the absence of very low escapement values. However, there are a number of relatively low escapement estimates from early years (1997-2000) and in 2009 which indicate that the stock is relatively productive. Recruitment from 2006-2009 brood years has been exceptionally high. The 2006 brood was the first to spawn following the sodium hydroxide spill. Over 14,000 Steelhead smolts were estimated to have passed the Rotary Screw trap in 2008, and most of these fish were produced from the 2006 escapement (Melville and McCubbing 2012). This estimate was substantially higher than most other estimates but was uncertain due to low sample size (CV=0.55). Thus, there was too much uncertainty in Steelhead smolt size estimates in 2008 to determine if smolt production in 2008 was higher than normal, 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 cause for the high survival of the 2008 brood is also likely due to good marine survival, as smolt production in 2010 and 2011 was not exceptional (~5,000 smolts). The 2004 negative stock-recruit outlier was likely caused by the sodium hydroxide spill which severely limited freshwater production for this brood year. The 2005 brood year was not a negative outlier, which is surprising as these returns were produced from incubating and recently emerged fry 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 2.8). 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 0.61 (2011). Egg deposition varied from a low of 166,000 (2000) to a high of 1,524,000 (2013). The ratio of egg deposition (in '000s) to total escapement varied from a low of 1.4 (2010) to a high of 3.2 (2012, but note low sample size) with an average of 2.3.

The egg deposition-recruit relationship (Fig. 2.5 bottom) was similar to the one based on escapement (Fig. 2.5 top) as far as indicating Cheakamus Steelhead are relatively productive and in the identification of unusually poor or good survival for particular brood years. The egg deposition- and escapement-recruitment relationships were similar because there was a strong linear correlation between escapement and egg deposition ($r^2 = 0.87$), and because inter-annual variation in fecundity (female size) and the proportion of females was relatively modest (Table 2.8). As well, sex- and size-structure information was only available for about ½ of the years used in the stock-recruit analysis. In other years, an average multiplier of 2.3 was applied to translate spawning stock to egg deposition on the x-axis of the stock-recruit curve, resulting in an equal shift along the x-axis for most points.

2.3.5 Steelhead Redd Counts in Brohm River

A total of only 16 unique redds were enumerated over six surveys in 2014, which translated to 27 spawners based on the 1.7 spawner-per-redd conversion (Table 2.9). The 2014 escapement estimate was the lowest over the five-year period of record (Fig. 2.6). The estimated number of spawners in Brohm River in 2014, based on the product of the total escapement to the Cheakamus River (796, which can include fish destined to spawn in Brohm River) and the 2010-2011 average Brohm migration rate (6.2%), was 49 fish, almost twice the value estimated by redd surveys (Table 2.9). However, since Cheakamus-Brohm immigration rates were not estimated in 2014 (no telemetry conducted) the extrapolated Brohm escapement is highly uncertain.

2.3.6 Resident Rainbow Trout and Bull Trout Abundance Trends

The average counts of resident rainbow across swim surveys has been well above average in 4 of the last 5 years since 2010 (Fig. 2.7). The majority of resident trout we enumerate are 4 years old or older (Table 2.6). We used a telemetry-based model to estimate bull trout abundance in the survey area for each year swim surveys have been conducted (Ladell et al. 2010). Bull trout increased in abundance between 1996 and 2005, then declined through 2009, and has been relatively stable at about 300 fish since that time (Fig. 2.8).

2.4 Discussion

Steelhead escapement to the Cheakamus River in 2014 was the second highest on record since 1996, and the estimate was quite reliable (CV=0.15). Smolt production in 2011 (ocean age 3 fish) and 2012 (ocean age 2 fish), which produced the 2014 escapement, was not unusually large (Melville and McCubbing, 2013) indicating that the large return was likely caused by better-than-average marine survival. High returns since 2010, and relatively average smolt production since 2008 indicate that the cause of the larger return is due to improved marine survival. This assertion is supported by elevated trends in escapement or angler catch in other rivers on the BC south coast in recent years (R. Ptolemy, BC Ministry of Environment, unpublished data).

There were substantive differences in average escapements across groups of years with different flow regimes. Escapement produced from juveniles that reared under the IFA regime (pre-spill, 2002-2007) was over two-fold higher than escapement produced under pre-IFA conditions (1996-2001). 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. Unfortunately, no reliable juvenile monitoring data are available for this period, so it is uncertain whether this change was caused by improvements in freshwater rearing conditions, higher marine survival, or by possible undocumented reductions in catch in First Nations net fisheries on the Squamish River (S. Rochetta, BC Ministry of Environment, pers. comm.). However, Steelhead and Coho marine survival rates measured in other systems on the South Coast did not increase over these periods, suggesting that increased escapement was due to better freshwater survival or reduced in-river harvest.

The sodium hydroxide spill resulted in a halving of escapement for broods that were in the river at the time of the spill (2008-2009). However, spill effects were short-lived, as escapements since 2009 have been more than double values produce under the IFA regime (pre-spill). Patterns in stock-recruit residuals indicate a clear negative effect of the spill on the 2004 brood, a surprisingly limited effect on the 2005 brood (fry that were still in the gravel or recently emerged in the summer of the spill), and exceptional survival for the 2006 brood. Production from broods after 2006 has been considerably higher than average, and given the relatively flat trend in steelhead smolt production, was likely caused by higher than average marine survival.

There was no evidence of a decline in Steelhead escapement based on fish that reared in the river after February 2006 when the WUP was implemented. Escapements have been more than two-fold higher under the WUP relative to those produced from IFA flows (pre-spill). Unfortunately, reliable estimates of juvenile Steelhead abundance (this project) or smolt production (from the rotary screw trap) only began in 2008. Thus, it is uncertain whether the much higher escapements under the WUP period are due to changes in freshwater or marine survival. However, this uncertainty could be resolved over time with continued monitoring of juvenile abundance/production and escapement. This uncertainty will not be resolved within the remaining 3 yr. timeframe of the study.

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 recruitment from 1997, 2000, and 2006 brood years, when escapement was relatively low, indicate that it has a minimum range of 3-6 maiden recruits/spawner with an average of 4.2. This productivity indicates that harvest rates up to 50-60% are sustainable.

The cause for elevated resident rainbow trout abundance in the Cheakamus River beginning in 2010 is uncertain. One possibility is that improved conditions for growth result in a higher proportion of O. mykiss juveniles adopting a resident life history strategy. Typically, the proportion of males to females for resident rainbow trout in steelhead systems is much greater than 1:1 (e.g., Thompson River). The higher ratio of males in these systems is believed to occur because young males derived from steelhead parents are more likely to remain resident than females. This was evidence for a higher ratio of male resident rainbow trout in the Cheakamus in 2014 (M:F=1.6:1, n=39, sex identified in the field but morph determined from scale patterns), but not in 2013 (M:F=0.9, n=17). Sample sizes for other years were insufficient to evaluate sex ratios, but the ratio based on 14 fish combined sampled from 2011 and 2012 for resident trout has a M:F sex ratio of 0.6:1. It is possible that increasing escapements of pink salmon in the Cheakamus River, beginning in 2009 have contributed to the higher abundance of resident rainbow trout since 2010, be they from steelhead or resident parents. However, it is uncertain whether the rainbow trout enumerated during Cheakamus surveys are truly resident and were spawned in the Cheakamus River. It is possible that these fish were spawned in the Squamish River or its other tributaries, or at least make extensive use of these other systems for part of their life. Counts of resident rainbow trout increase over the survey period each year. This pattern could indicate that these fish are entering the Cheakamus River to spawn, or that they are always present but only become visible to divers when they change their behavior due to higher water temperature and spawning. Bull trout abundance has been relatively stable since 2010 and the majority of fish we enumerate reside in the Squamish/Elaho mainstem from late-spring through fall (Ladell et al. 2010). The fact that migratory bull trout abundance in the Cheakamus River has remained stable while resident rainbow trout abundance has increased could be indicative of a productivity gain in the Cheakamus River.

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 2013 and spring 2014 (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-wintering 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 affected 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 with a pilot study to decide on the optimal sampling approach for fall and spring sessions (Korman 2008). Reliable river-wide abundance estimates, beginning in fall 2008 and spring 2009 (six years) are now 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 (due to limited catch) (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 this chapter, we report on the results from surveys conducted in year 7. A key assumption in our methodology is that data on detection probability of juvenile Steelhead based on mark-recapture experiments are drawn from a common distribution and are therefore 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 2013 and spring 2014 mark-recapture data. Given the additional mark-recapture data, this chapter includes revised values for previously published estimates.

The abundance of juvenile steelhead in the Cheakamus River can be influenced by the magnitude of parental escapement, the quality and quantity of habitat, food availability, and predator abundance. Variation in steelhead densities among reaches can potentially provide insight into effects of geomorphology on habitat quality. For example, lower densities of juvenile steelhead downstream of Cheekeye and Culliton Rivers may indicate that the fine sediment supply from these tributaries is lowering habitat quality in parts of the Cheakamus River by reducing interstitial spaces in the river bottom. This information is potentially relevant to flow decisions, as reduced frequencies of small and intermediate floods due to flow regulation may affect the transport of fine sediment and the condition of the bed. From an abundance estimation perspective, failure to account for major differences in density among reaches could lead to substantial biases in population estimates or variance estimates that are unnecessarily high. In this year's report, we evaluate whether there are reach-specific differences in juvenile steelhead densities, and evaluate the effects of such differences on population estimates.

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 in spring, we used data from riffle and shallow sites sampled by electrofishing, and deep sites sampled by snorkeling. For estimates of age 1+ juvenile Steelhead in spring, we used data from riffle and shallow sites sampled by electrofishing, and shallow and deep sites sampled by snorkeling. Abundance estimates for all life stages in fall are based on electrofishing, however age 1+ estimates are unreliable as this gear is only effective at capturing parr in riffle habitats.

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 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 15 and 118 index sites were electrofished (EF) for the fall 2013 abundance estimates in the Brohm and Cheakamus Rivers, respectively (Table 3.1). Four and eight mark-recapture experiments were completed in fall 2013 in Brohm and Cheakamus Rivers, respectively. A total of 30 and 224 index sites were sampled in spring 2014 using either electrofishing and snorkeling (SN) 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 could not 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: 400-500 V, 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 Hagen et al. (2010) 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 Hagen et al. (2010) 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. 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. Immediately following marking, fish were returned to the original lie they had been holding in prior to capture.

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: 400-500 V, frequency and pulse I4-J5), traversed the site in an upstream direction. Electrofishing was very methodical, requiring 0.75-1.5 hours 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). Dyeing is a more efficient method for marking many small fish that are commonly captured in the fall, but the dye can result in behavioural changes or mortality at very low water temperatures in the spring. For dyeing, fish were placed in an aerated bucket with neutral red biological stain (0.5 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 used to collect scales for freshwater age determination. Age determinations were made for 137 and 85 juvenile Rainbow Trout from the Cheakamus River in fall 2013 and spring 2014, respectively. Age determinations were made for 88 and 65 juvenile Rainbow Trout from Brohm River in fall 2013 and spring 2014, respectively. 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+, 1+ and 2+ in the spring sample would be reported as one-, two-, or three-year old parr or smolts (i.e. 1-3 winters), respectively.

We computed mean size-at-age by river, season, and age class. As our age samples come from a size-stratified sample, mean size-at-age must be corrected for the proportion of a given size class in the total catch that is sampled for age. The correction or weighting procedure involves the following steps:

1. Compute the proportion of each age class per 5 mm size class from the sample of scales;
2. Multiply these proportions by the proportion of each size class in the total catch;
3. Multiply these weighted values by the mid-point of each size class, and sum those values by age class to get the mean size-at-age.

We computed the mean catch per meter of shoreline for each of the five major reaches in the Cheakamus River (Fig. 1.1) to evaluate whether there were differences in juvenile steelhead densities among reaches. In Brohm River, we compared catch densities among two reaches located below (reach 1) and above (reach 2) the canyon. In the Cheakamus River we expected that juvenile densities would be highest in reach 5 located upstream of Culliton Creek where the substrate is less embedded and where spawners are concentrated, and lowest in reach 1 located downstream of the Cheekeye River due to reduced substrate quality (from sediment inputs from the Cheekeye). In Brohm River, we expected that densities would be highest in reach 1 below the canyon where spawner densities may be higher owing to challenges in migrating through the canyon.

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 mean and variance of the lognormal density distribution can vary among reaches. 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.

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). Fish density distributions can vary among reaches, or a single distribution can used to represent density for all reaches.

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 3.3). 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 10 strata for each project year (two rivers, two seasons, and three ages, less age 1+ and 2+ fall Cheakamus strata). Estimates of abundance for age 1+ and 2+ steelhead from the Cheakamus River during the fall survey were not computed owing to large uncertainty about detection probability. Abundance for strata that were estimated was subdivided into reach-specific estimates. Posterior distributions were estimated by taking every 18th sample from a total of 20000 simulations after excluding the first 2000 'burn in' samples for each of 3 chains (total posterior sample size of 1,000 per chain or 3,000 across chains). This sample size and sampling strategy was sufficient to achieve adequate model convergence in all cases, which was evaluated using the Gelman Rubin convergence diagnostic. The Deviance Information Criteria (DIC) was used to compare models for the same river-year-season-age based on different reach stratifications for the parameters of the lognormal density distribution (unstratified vs. reach-stratified). For brevity and clarity of presentation, we restricted the analysis to groups where the number of index sites was a minimum of 15 per strata.

We compared estimates of age 1 and 2 Steelhead abundance in the Cheakamus River in spring 2009-2014 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 17% and 8% of the useable shoreline length of the Brohm and Cheakamus Rivers during the fall 2013 surveys, respectively (Table 3.1a). Owing to the extra effort associated with snorkeling in spring, we sampled 44% and 18% of the useable shoreline length during the spring 2014 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 20 m^3/sec during the spring survey, but ranged from approximately 20-40 m^3/sec during the fall survey. Water temperature during the fall and spring survey averaged 12.2 and 6.8 ^oC in the Cheakamus River, and temperatures were not measured in Brohm River.

Results from scale ageing (Table 3.4) were used to assign maximum lengths for age 0+, and 1+ year old Steelhead. In the Cheakamus River, maximum lengths for age 0+ and 1+ year old Steelhead in fall 2014 were 74 and 124 mm, and 89 and 134 mm in spring 2014. 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. Age-length cutoffs in Brohm River were similar.

Generally, mean length-at-age has been relatively consistent across years within rivers and sampling seasons (Table 3.5, Fig. 3.4). In fall, age 0+, 1+, and 2+ Steelhead averaged 60, 92, and 133 mm in Brohm River, and 57, 100, and 137 mm in Cheakamus River, respectively. On average in the Cheakamus River, age 0+ fish only grow about 13 mm from fall (average 57 mm) to the following spring (70 mm). There was also very little growth for age 0+ fish in Brohm River over this same period (about 5 mm on average). There is considerable growth in both rivers between age 0+ fish in spring through fall when they are reclassified as age 1+ fish (~ 30-40 mm). As for age 0+ fish, there is very limited growth between fall and spring survey periods for age 1+ fish in both rivers (5-10 mm). These growth patterns are caused by very cold temperatures in late fall through winter.

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 but are also affected by 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 876 and 4,806 juvenile Steelhead were enumerated at index sites in Brohm and Cheakamus Rivers in fall 2013, and 881 and 6,712in spring 2014, respectively (Table 3.6). Trends in catch-per-effort (CPE) are shown in Table 3.7. 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 in 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 where age-0 densities can vary by up to 5-fold;
2. Very low CPE for age-1+ and -2+ parr in the Cheakamus River based on electrofishing owing to poor detection probability;
3. The presence of a large cohort from the 2011 brood year in the Cheakamus River, as indicated by high age-0+ CPE in fall 2011 and spring 2012; and
4. Highly variable snorkelling CPEs 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 year's brood).
5. Exceptionally high abundance of age-1+ parr in the Cheakamus River on the spring 2014 survey seen in both electrofishing and snorkel surveys.

Four and eight mark-recapture electrofishing experiments were conducted in fall 2013 in Brohm and Cheakamus Rivers, respectively (Table 3.8). No snorkeling mark-recapture experiments were conducted owing to the already large sample size. Aggregating data from all years, detection probability for age-0 Steelhead based on electrofishing was relatively consistent among experiments and was 50% higher in the Cheakamus River (0.31) compared to Brohm River (0.21, Table 3.9), likely due to the more porous nature of the substrate and darker light condition in Brohm. For 1+ Steelhead, detection probability for electrofishing was higher in Brohm River (0.30) than in the Cheakamus River (0.16), 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 were 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 (note lowest CV compared to other strata).

Differences in juvenile steelhead density among reaches varied substantively among years, seasons, and age classes. Based on multi-year averages, density in reach 1 (downstream of Cheekeye River) was typically lower than for other reaches, and density in reach 5 (upstream of Culliton Creek) was typically highest (Fig. 3.5a). However, the confidence intervals for each reach often overlapped, and these intervals underestimate the true variation as they do not consider variation in capture probability or the overdispersed (long right hand tail) in fish distributions. Thus, we suspect these patterns are likely not significant, which was confirmed using the HBM as described below. There was considerable variability in across-reach density patterns between years. For example, in some cases for fall age-0 steelhead (2009, 2012), density was lowest in reach 1, intermediate in reaches 2-4, and highest in reach 5 (Fig. 3.5b). The pattern for this cohort persisted into the spring of the following year (Fig. 3.5c). In other years (2008, 2011), densities in reach 1 were still lower but densities in reach 5 were not higher than in reaches 2-4. Densities of age-1+ steelhead typically showed a declining density from upstream to downstream (Fig. 3.5d and e). Reach patterns suggest testing of 3 potential stratifications for the parameters of the lognormal distribution for fish density in the HBM: no stratification; two strata (reach 1 vs. 2-5); and three strata (reach 1, 2-4, and 5).

In Brohm River, steelhead densities were typically higher in reach 1 below the canyon than in reach 2, though there was considerable overlap in confidence intervals (Fig. 3.5f). As for the Cheakamus, differences varied by year, and were for example very apparent for fall age-0+ steelhead in 2011 and 2012, but not in other years (2010, 2013, Fig. 3.5g). Interestingly, strong reach-specific patters for fall age-0+ did not persist 6 months later when age-0+ fish were sampled in the spring (Fig. 3.5h), suggesting a redistribution of fish between sampling intervals. There was less evidence for reach-specific differences in density for parr (Fig. 3.5i and j), which is also suggestive of redistribution. We compare non stratification and a two-reach stratification for the lognormal fish density function in the HBM for Brohm River.

3.3.3 Estimates of Juvenile Steelhead Abundance from the Hierarchical Bayesian Model

An intense and successful sampling effort was implemented in fall 2013 and spring 2014 in both the Brohm and Cheakamus Rivers, resulting in catch data from a large number of index sites (Table 3.10). In conjunction with the relatively large sample of mark-recapture experiments, this 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 river-year-season-age estimation group (Cheakamus River age-1+ Steelhead in spring 2014) is shown in Figure 3.6. 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. 3.6a and b). Detection probability for snorkeling is approximately 3-fold higher (Fig. 3.6c 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. 3.6e), resulting in a fish density distribution with a long right-hand tail (Fig. 3.6f). Due to the large number of index sites, the total estimate of abundance across the sampled sites was relatively precise (Fig. 3.6g) 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. 3.6h).

The benefits of stratifying estimates of the lognormal fish density distribution by reach were highly variable among river-year-season-age groups (Table 3.11). Based on the deviance information criteria (DIC), there was little difference between alternate stratifications in 2011 and 2012 for fall age-0+ fish in the Cheakamus River, though the two- or three-strata models were better in 2013. The unstratified model was generally best for Cheakamus spring age-0+ and age-1+estimates, while the two-strata model (below vs. above Cheekeye River) was generally best for age-2+ fish. The number of index sites sampled in Brohm River is much smaller than in the Cheakamus, making stratified estimation more challenging. The model was unstable and did not produce reliable estimates in 3 of the 12 strata where we even attempted to use a stratified model for (note gray cells in Table 3.11). In the majority of other cases, there was little difference among the unstratified vs. two-strata models, though the latter was better for the majority of parr estimation groups in the spring. Differences in the mean and CV of population estimates among stratified and unstratified models were very small. After eliminating unreliable estimates from the two-strata model, the average absolute difference in the means of abundance between unstratified and stratified estimates was only 4%. The only exception was for fall age-0+ fish in the Cheakamus River in 2013, where the abundance estimates for the two- or three-strata models were about 25% lower than for the unstratified model. In this case the unstratified model was likely biased high due to undersampling of reach 1, resulting in application of a mean density to the unsampled area of this reach which was too high (Fig. 3.5b).

The results of the reach stratification analysis indicate that estimating separate lognormal fish density functions for different reaches in the Cheakamus and Brohm Rivers rarely leads to better estimates of abundance. Stratified estimates are unreliable for the first few years of sampling in Brohm and Cheakamus (2008-2010) Rivers when the number of index sites sampled was lower and some strata did not have enough samples to estimate density distributions reliably. Differences in DIC among alternate models were generally small, indicating that the statistical evidence for differences in fish density distributions among reaches was generally low. Finally, in the vast majority of cases, differences in estimates of abundance and uncertainty in abundance based on alternate stratifications were very small. This occurred because a large number of index sites are randomly selected in proportion to the availability of habitat in each reach. This in turn leads to estimates of the parameters of the lognormal fish density distribution which are representative of the entire river. Thus application of the simpler and more reliable unstratified model will be used for subsequent analyses.

Total abundance estimates in fall 2013 and spring 2014 were relatively precise with an average CV across rivers, seasons, and age classes of 0.15 (Table 3.12). The abundance estimate for age-1+ parr in the Cheakamus River in spring, perhaps the most important metric we measure as a surrogate for smolt production, was 46,000 with a CV of 0.11. This estimate was over 2-fold higher than the maximum estimate across all previous years. Abundance estimates for Brohm River in fall 2008 and spring 2009 were either not estimable or 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). We do not report abundance estimates for age 1+ and 2+ steelhead in the Cheakamus River in the fall as electrofishing does not provide a reliable means of capturing fish in deeper habitats, which compromise a large part of the total habitat. Catches or catch densities (Table 3.7) could provide a reliable index of relative differences in abundance of parr in fall among years. However, there is not much evidence for this in the data. For example, the age-1+ parr catch density in fall 2012 was almost two-fold higher than the maximum from other years, yet the abundance of 1+ parr the following spring was not exceptional (Table 3.12). The opposite pattern occurred in 2013, where catch densities of 1+ in fall were average or below-average, but 1+ parr abundance the following spring was exceptionally high.

There was relatively high abundance of age-0+ in fall and spring in 2008 and 2013 and especially in 2011 in the Cheakamus River (Fig. 3.7a). The spring age-1+ abundance estimate was highly variable across years and showed high abundance in 2010, 2012, and most notably 2014. Abundance by year was relatively consistent in Brohm River for age 0+ Steelhead in fall and spring but less so for age 1+ fish in spring. We tracked the change in the abundance of the 2008-2013 Steelhead cohorts (fish from the spawn in 2008-2013) by combining estimates across strata (Table 3.13). As an example, the 2008 Cohort from the Cheakamus River declined from an estimated egg deposition of 570 thousand to 237 thousand age-0+ fish in fall 2008 to 49 thousand age 0+ fish in spring 2009, to 18 thousand age-1+ fish in spring 2010. The net apparent survival rates from egg deposition to fall age-0+, fall age-0+ to spring age-0+, fall age-0+ to spring age-1+ (~1.5 yrs), and from spring age-0+ to -1+ (~ 1 yr), was 41%, 21%, 8%, and 38%, 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.

There are a wide range of life-specific survival rates reported for steelhead and Atlantic salmon (a good surrogate for steelhead owing to similarities in freshwater life history) and estimates for the Cheakamus and Brohm Rivers are within these reported ranges (Bley and Moring 1988). For example, egg-fry survival rates for Cheakamus steelhead ranged from 5-41% and were similar to reported ranges for Altantic salmon of 8-35%. Survival from fry release to 0+ parr for Atlantic salmon ranged from approximately 10-30%, compared to a 21-46% range for Cheakamus steelhead (note most reported estimates are based on hatchery stocking which may be a poor surrogate for wild fish). Annual survival rates from spring age 0+ to spring age 1+ parr ranged from

13-93% in the Cheakamus River. Spring age-0+ to 1+ survival rates were substantively higher for even brood years (2008, 2010, 2012), which could be related to large returns of pink salmon in the previous year (leading to better condition of fish prior to their first winter in freshwater). Spring age-0+ - 1+ survival rates in Brohm River were 26-63%. These values are close to the 30-50% survival rates reported for Altantic salmon and steelhead. Our overall survival rates from egg to 1+ parr in spring ranged from approximately 0.4-3% in the Cheakamus, compared to 0.5%-6% for Atlantic salmon and steelhead reported in the literature. Our egg-spring 1+ parr survival rates are slightly below steelhead emergent fry – smolt survival rates from Snow Creek (~ 8%), however those values do not include losses during incubation and emergence.

Estimates of age 2 parr abundance above the RST in the spring of 2009-2014 were compared to estimates of 3 year smolt abundance at the RST. Juvenile survey-based estimates were within 40% of RST-based estimates in five of 6 years (Table 3.14). Due to the uncertainty in both types of estimates, these differences could be solely due to sampling error for all years except 2012 where the juvenile survey-based estimates was double the estimate at the RST (Fig. 3.8). On average, the juvenile survey-based estimates of 2+ parr have been 13% lower than the estimate of 3 yr smolts from the RST.

Survival estimates between juvenile life stages and uncertainty in estimates are provided in Fig. 3.9. Egg-fry survival rate in the Cheakamus River has generally declined over the study period which could be related to increasing escapement resulting in higher density-dependent mortality during the emergence period. Over-winter survival of fry (fall age-0+ to spring age-0+) was generally consistent over time and between rivers, with higher survival in the Cheakamus River for the 2010 and to some extent 2012 brood years. Annual survival of parr (spring age-0+ to spring age-1+) in the Cheakamus River showed an increasing trend for even brood years (2008, 2010, 2012), and much lower values for odd brood years. Pink salmon return to the Cheakamus River in odd years, and escapements have been increasing beginning in 2007, and were especially high in 2013. As juvenile steelhead feed on salmon eggs and carcasses, it is possible that the condition of parr prior to winter in these odd years was better owing to the large increase in food supply, and this could have resulted in greater survival over the winter following the pink escapement.

We examined preliminary relationships between steelhead egg-to-fry survival rate in the Cheakamus River and discharge characteristics and egg deposition (Fig. 3.10). Egg-fry survival rate increased with reductions in the extent of sudden discharge declines in August, with declining average discharge in August, and with declining egg deposition (density-dependence). The latter relationship explained the most variability in egg-fry survival rates over time (37%). All these relationships are currently not statistically significant, perhaps due to low sample size. A multiple regression containing all 3 of these independent variables explained 60% of the interannual variation in egg-fry survival rate, but again was not statistically significant.

Some life-stage specific survival estimates are inaccurate due to biases in population estimates and were not presented. Estimates of age-1+ abundance in fall in the Cheakamus River are not reliable owing to low capture probability, especially in deeper habitats which are sampled poorly by electrofishing. For Brohm River, the age-0+ estimate in spring 2009 is very likely biased low (due to snorkeling only), resulting in undetermined survival estimates from fall 2008-spring 2009 (age-0+-0+) and spring 2009 to spring 2010 (age 0+-1+). This issue was corrected in later years by adding electrofishing to the spring sample. 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 provides an adequate sample for age-0+ fish in fall, and snorkeling and electrofishing used for age-1+ in spring 2010 sample).

3.4 General Conclusions

Juvenile Steelhead population estimates in the Cheakamus and Brohm Rivers are generally quite precise because a large number of index and mark-recapture sites are sampled. 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 current level of effort, estimates for age-1+ parr in the spring, which may be our best proxy of potential smolt production, are precise (CV ~0.1). Estimates of Steelhead 2+ parr abundance derived from juvenile surveys in spring 2009-2014 were not statistically different than RST-derived estimates except 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 two winters in freshwater. Survival from age-0+ in the fall to age-1+ in the spring (i.e., two winters in freshwater) was 3-30% and 5-14% in the Cheakamus and Brohm Rivers, respectively with CVs generally between 0.2 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. There is some indication that survival of parr is higher in years when pink salmon return to the Cheakamus River, especially when that escapement is large. Future years of data collection will provide additional replicates to confirm whether this relationship holds.

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 for steelhead in the Cheakamus River to evaluate effects of flow during the incubation and emergence period. Estimates of egg-fall fry survival ranged from 5-41% for 2008-2013 spawning cohorts. Some of this variation could be due to higher mortality resulting from greater densities. However, egg-fry survival in 2011 was more than two-fold higher than in 2010 even though egg deposition in this 2011was three-fold higher. High survival in 2008 and 2009 compared to 2010 and 2011 could be due to lower flows during the emergence period in the former years, and lower survival in 2010 compared to 2011 could be due to the sudden reductions in flow in 2010 compared to 2011 (Fig. 1.3). Egg-fry survival rates were much higher in 2011 in spite of higher egg deposition, suggesting a possible strong negative flow effect in 2010. Additional years of data will help reduce uncertainties in potential flow-survival relationships.

3.5 Conclusions Regarding Key Uncertainties

The key uncertainties for Steelhead identified during the Cheakamus WUP, and preliminary conclusions from this project, are summarized here:

1. Do high flows in July and August negatively affect Steelhead fry that have recently emerged?

There is some indication that high flows during summer and/or rapid reductions in flow during this period limited egg-fry survival rates. However, as sample size (number of replicate years) is extremely limited, this conclusion should be considered very preliminary. Additional observations of egg-fry survival rates under high flows with and without rapid reductions in flow in coming years will resolve this uncertainty.

2. Does flow effect juvenile production, as indexed by the number of fry, parr, smolts, and returning adults?

Escapement produced from juveniles that reared under the IFA regime (pre-spill, 2002-2007) was over two-fold higher than escapement produced under pre-IFA conditions (1996-2001). 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. Unfortunately, no reliable juvenile monitoring data are available for this period, so it is uncertain whether this change was caused by improvements in freshwater rearing conditions, higher marine survival, or reduced by-catch in First Nations net fisheries on the Squamish River. However, Steelhead and Coho marine survival rates measured in other systems on the South Coast did not increase over these periods, suggesting that increased escapement was due to better freshwater survival or reduced in-river harvest.

3. Has the current WUP flow regime led to changes in Steelhead production, as indexed by adult returns, juvenile abundance, and smolt production?

Escapements produced from juveniles that reared in the Cheakumus River under WUP flows have been more than two-fold higher relative to those produced from IFA flows (pre-caustic soda spill). Unfortunately, reliable estimates of juvenile Steelhead abundance (this project) or smolt production (from the rotary screw trap) only begin in 2008. Thus, it is uncertain whether the much higher escapements under the WUP period *are due to changes in freshwater or marine survival. This uncertainty could be resolved over time with continued monitoring of juvenile abundance/production and escapement combined with changes to the flow regime following the current WUP period.*

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5.0 Tables and Figures for Chapter 1

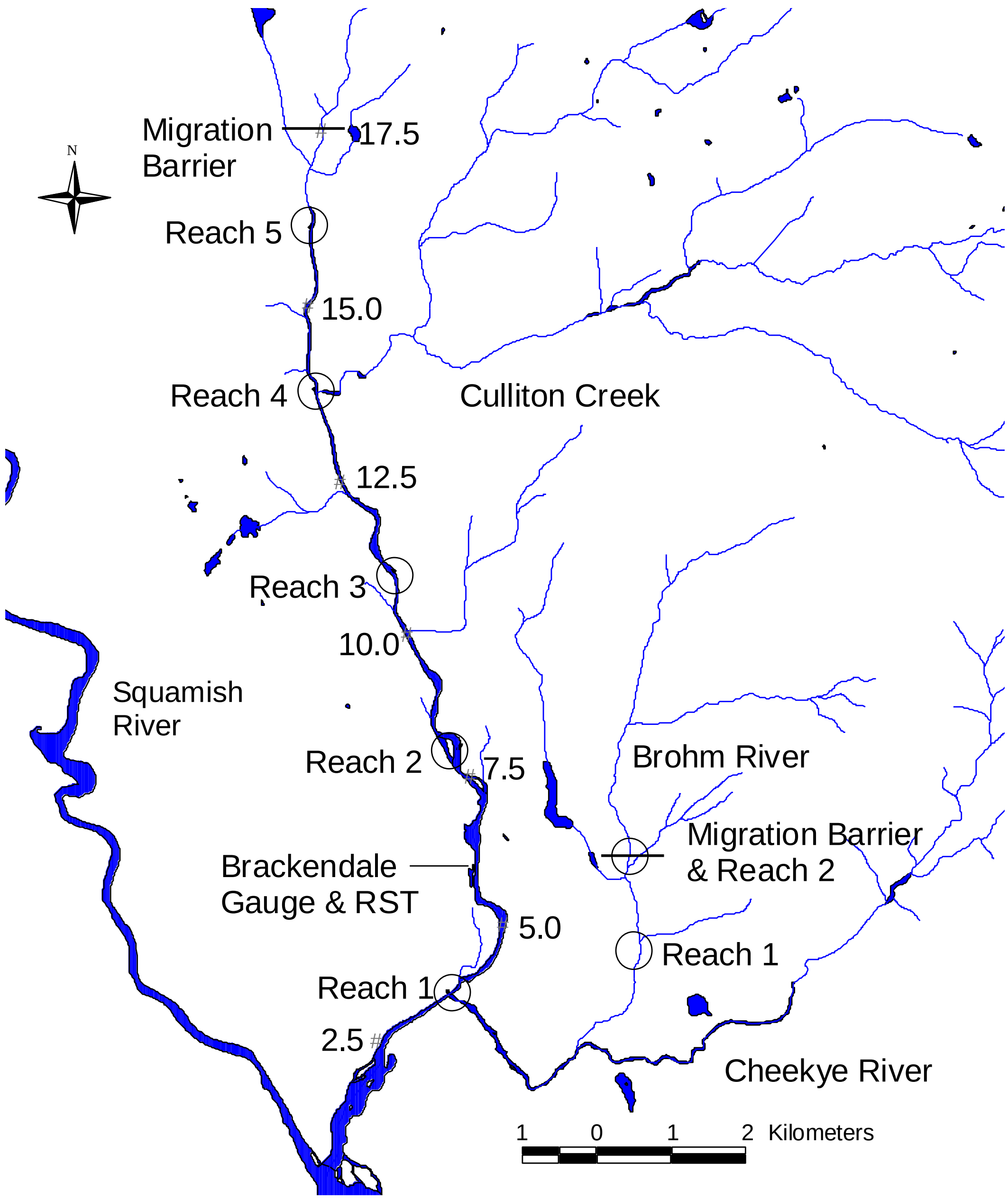


Figure 1.1. Map of the Cheakamus River study area showing the locations of the upstream limit of reach breaks used for habitat and juvenile surveys (open circles), distance (km) from the Squamish River confluence (gray points), migration barriers for anadromous fish in the Cheakamus and Brohm Rivers,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

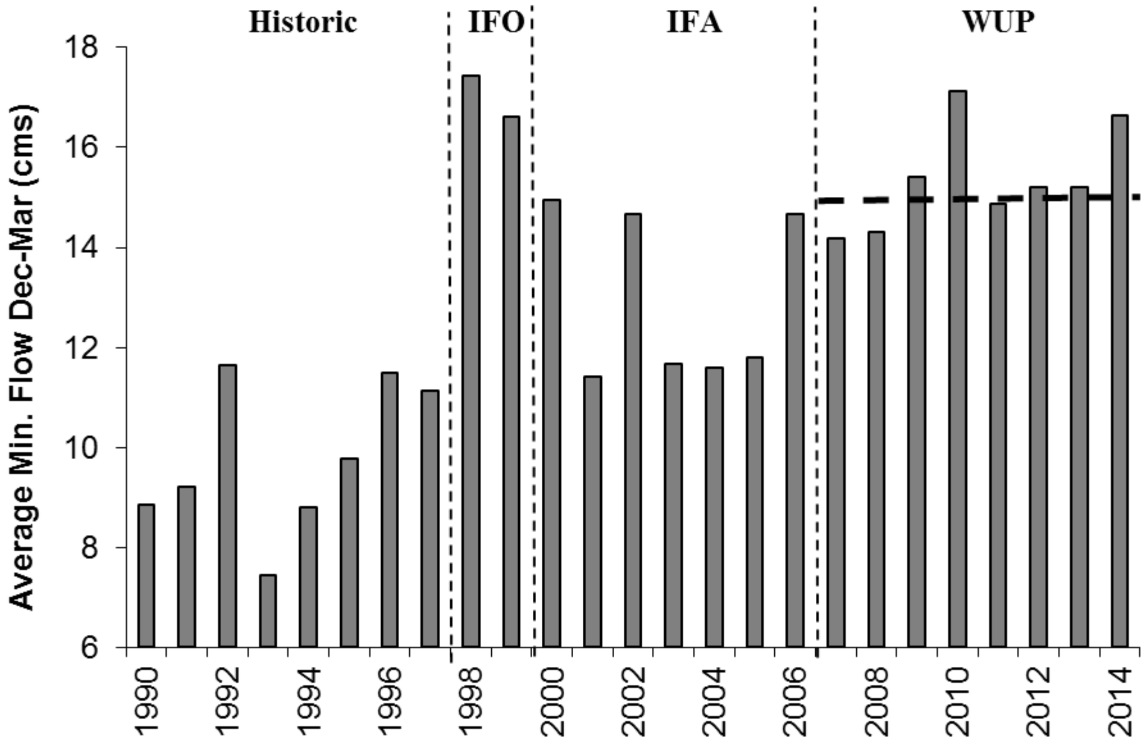


Figure 1.2. The average minimum flows during winter at the Brackendale gauge on the Cheakamus River, 1990-2014. The average minimum flow between December and March was computed as the average of the minimum flow in December from the previous year (based on average daily flows), and the minimum flows 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.

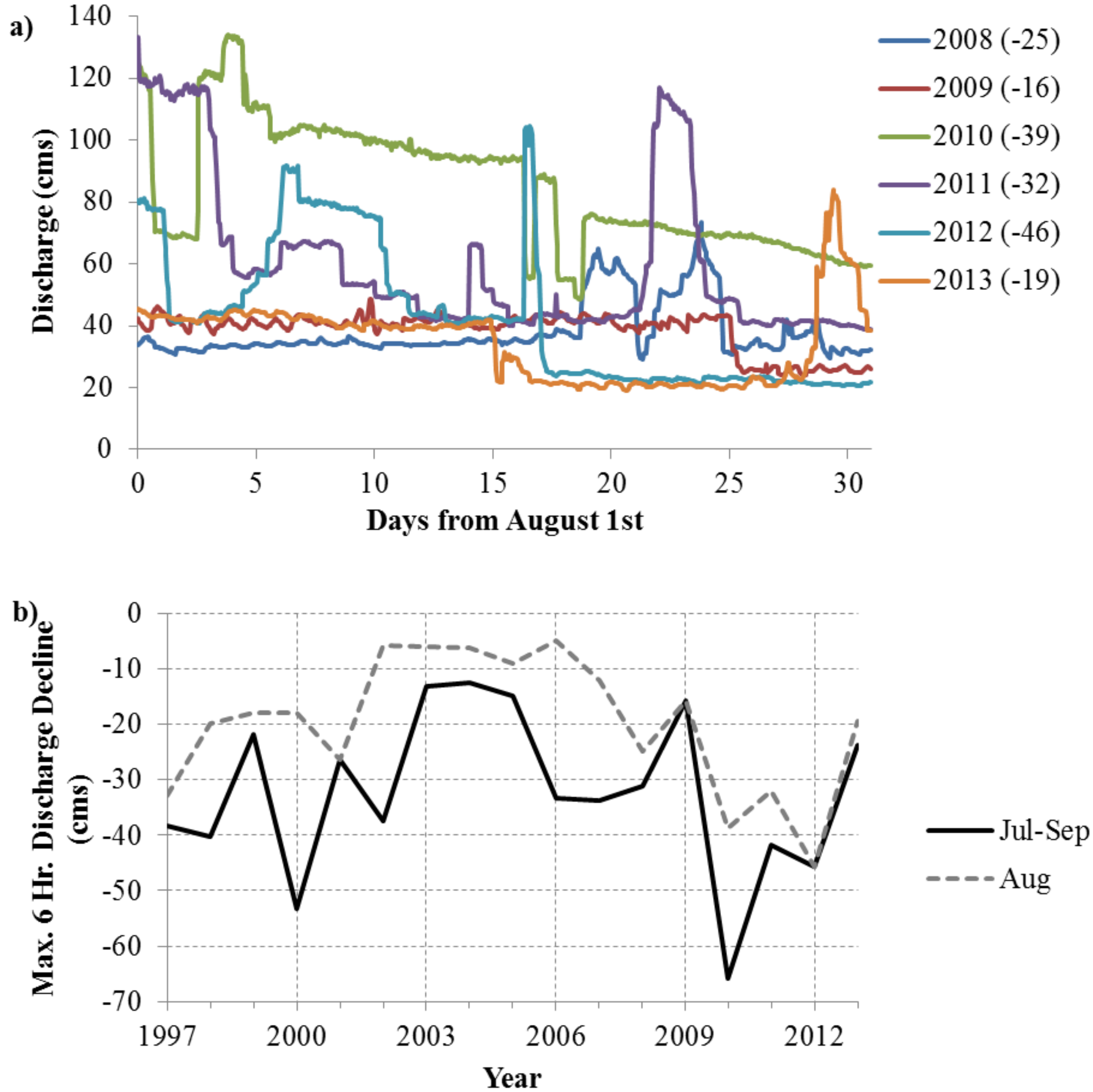


Figure 1.3. Hourly discharge at the Brackendale gauge on the Cheakamus River over August (a) from 2008-2012, and the maximum 6 hour discharge decline over August and from July 1st to September 30th by year (b). Values in parentheses in the legend in a) correspond to the August discharge declines shown in b) for those years.

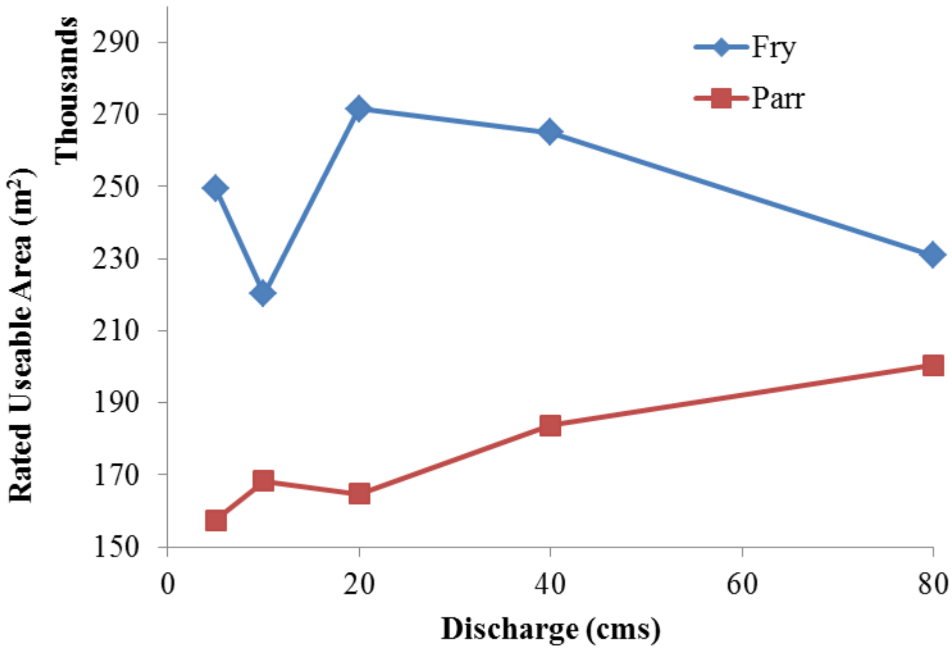


Figure 1.4. Changes in predictions of rated useable Steelhead habitat in the Cheakamus River (summed across reaches) as a function of discharge. This habitat model was used in the initial WUP assessment (BC Hydro 2007).

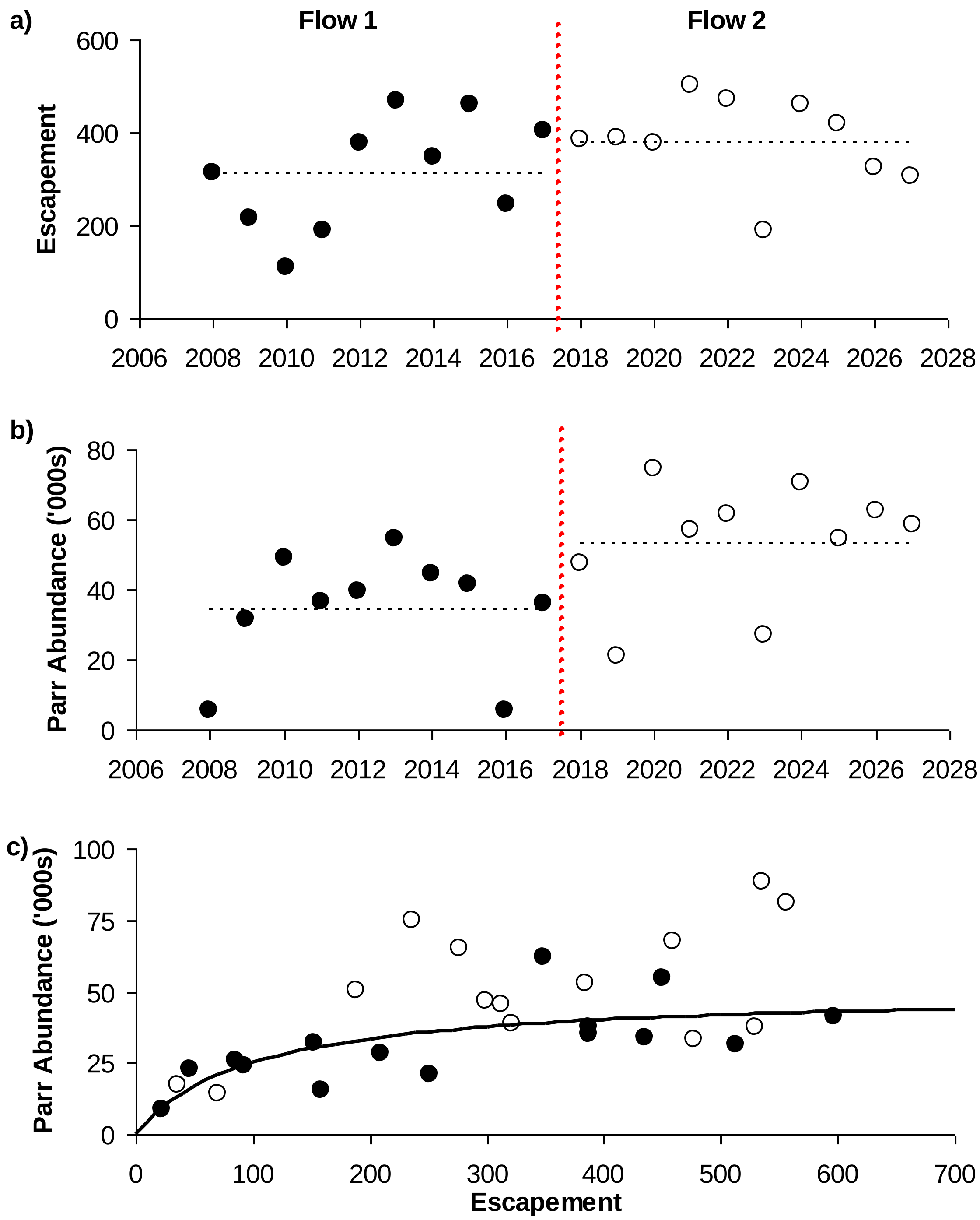


Figure 1.5. Theoretical responses of escapement (a) and parr abundance (b) under two flow regimes, with 10 years of data collected under each regime, and the stock-recruit relationship between these life stages over the two periods (c). Solid and open circles represent data collected under flow regimes 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 Age-0	Age-1	Age-2	Events
	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 Phase I Monitroing Ends
2013 (6)		Fall					
	2013	Spring			2 yr smolt	3 yr smolt	
2014 (7)		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 and seasonal monitoring periods, WUP assessments and reporting periods, and implementation of the WUP flow regime. Each color tracks the Cohort from individual broods (year of spawning) through the freshwater residency period. 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. Pilot juvenile sampling was conducted in year 1 (both fall 2007 and spring 2008) to evaluate alternate sampling approaches. Reliable escapement and smolt production (via the Rotary Screw Trap) estimates are available back to 1996 and 2008, respectively.

6.0 Tables and Figures for Chapter 2

Table 2.1. Equations used in the model to estimate Steelhead escapement from swim survey, radio telemetry, and angler catch data. See Table 2.2 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	$U_{o,i} = \varepsilon_o \left[\int_1^i PA_o - \int_1^i PD_o \right]$
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	$p_i = \frac{\frac{HV_i^{\rho_s}}{Q_i}}{\rho_h^{\rho_s} + \frac{HV_i^{\rho_s}}{Q_i}}$
2.13	Likelihood for marked fish observed in current year based on p from eqn. 2.12 (L_{pr})	$r_i \sim Poisson(p_i R_i)$

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})	$u_i \sim NegBin(p_i(U_{W,i} + U_{H,i} - R_i), \tau)$
2.15	Likelihood for marked fish observed from other years based on p from eqn. 2.12 (L_p)	$r_i \sim NegBin(p_i R_i, \tau)$
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)	$C_{W,i} \sim NegBin(P_{W,i,}(C_{W,i} + C_{H,i}), \tau)$
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
τ	Overdispersion of negative binomial likelihoods for count data
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 2014.

Survey Date	Discharge (Q in m3/sec)	Horizontal Visibility (HV in m)	HV/Q	Count SH	RB	BT
04-Mar	18.5	6.1	0.33	34	46	102
13-Mar	19.9	3.6	0.18	20	5	16
24-Mar	16.0	3.55	0.22	32	31	79
03-Apr	21.2	3.2	0.15	59	25	56
11-Apr	21.4	4.5	0.21	81	45	116
16-Apr	22.0	4.8	0.22	51	40	85
23-Apr	19.6	4.8	0.24	96	78	138
28-Apr	20.3	4	0.20	98	51	57
30-Apr	20.2	4.2	0.21	79	49	84

Table 2.4. Number of resident rainbow trout and steelhead sampled for size, sex, and age in 2014, and average, minimum, and maximum fork lengths.

Origin	Female	Male	Unknown	Total
# Sampled				
Resident	14	22	21	57
Steelhead	45	44	2	91
Total	59	66	23	148
Fork Length (mm)				
Average				
Resident	438	501	439	
Steelhead	769	774	645	
Minimum				
Resident	318	356	305	
Steelhead	584	510	560	
Maximum				
Resident	559	630	580	
Steelhead	920	970	730	

Table 2.5. Proportions of freshwater, ocean, and total ages for Cheakamus River wild (W) and hatchery (H)-origin adult steelhead. 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
2013	W	0.00	0.47	0.53	0.00	15
2014	W	0.00	0.20	0.80	0.00	71
Avg	H	0.98	0.02	0.00	0.00	56
	W	0.00	0.51	0.49	0.01	286

Table 2.5. Con't.

Year	Origin	Ocean Age 1	Ocean Age 2	Ocean Age 3	Repeat Spawners	n
2000	W	0.00	0.63	0.38	0.00	16
2001	W	0.00	0.79	0.21	0.06	28
2003	W	0.05	0.55	0.41	0.30	22
2004	W	0.00	0.71	0.29	0.11	31
2005	W	0.10	0.50	0.40	0.23	30
2009	H	0.23	0.77	0.00	0.00	13
	W	0.00	0.73	0.27	0.20	11
2010	H	0.09	0.74	0.17	0.03	23
	W	0.08	0.88	0.04	0.07	26
2011	H	0.00	0.00	1.00	0.27	19
	W	0.00	0.32	0.68	0.21	60
2012	W	0.00	0.13	0.88	0.11	8
2013	W	0.00	0.41	0.59	0.00	22
2014	W	0.00	0.62	0.38	0.14	69
Avg	H	0.11	0.50	0.39	0.10	55
	W	0.02	0.57	0.41	0.13	323

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
2013	W	0.00	0.00	0.20	0.53	0.27	15
2014	W	0.00	0.00	0.15	0.56	0.30	61
Avg	H	0.11	0.49	0.39	0.00	0.00	50
	W	0.00	0.01	0.40	0.42	0.17	243

Table 2.6. Number of resident Rainbow Trout by year, age and origin in the Cheakamus River and their average fork lengths. 'H' and 'W' denote hatchery- and wild-origin fish.

		Total Freshwater Age					
Year	**Origin**	**3**	**4**	**5**	**6**	**7**	
Number of Fish							**Total**
2010	H	3	7				10
2011	H			1			1
	W		1	5	3	1	10
2012	W			2	1		3
2013	W		2	8	2		12
2014	W		3	6	13		33
Average Fork length (mm)							**Avg**
2010	H	393	414				408
2011	H			380			380
	W		305	374	390	370	372
2012	W			438	500		458
2013	W		510	516	535		518
2014	W		383	426	492	525	453
Avg. Wild			399	439	479	448	

Table 2.7. Steelhead escapement estimates to the Cheakamus River, 1996-2014. Mean and CV denote the mean and coefficient of the posterior distribution of escapement estimates. Average values by period are shown at the bottom of the table.

	Wild		Hatchery		Wild+Hatchery	
Year	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1996	189	0.18				
1997	115	0.19				
1999	178	0.18				
2000	100	0.22				
2001	300	0.15				
2002	393	0.14				
2003	311	0.12				
2004	336	0.14				
2005	336	0.12				
2006	254	0.14				
2007	513	0.14				
2008	249	0.14				
2009	108	0.17	105	0.32	213	0.2
2010	672	0.14	424	0.21	1096	0.15
2011	730	0.13	357	0.29	1087	0.15
2012	570	0.17				
2013	1,524	0.15				
2014	796	0.15				
Pre-IFA ('96-01)	176	0.18				
IFA Pre-Spill ('02-07)	357	0.13				
IFA Post-Spill ('08-09)	179	0.16				
WUP ('10-14)	858	0.15				

Table 2.8. 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	100	166	1.7
2001	27	756	4,219	0.41	300	516	1.7
2003	33	801	5,016	0.52	311	804	2.6
2004	36	769	4,431	0.44	336	662	2.0
2005	38	776	4,552	0.50	336	765	2.3
2009	27	735	3,864	0.59	213	488	2.3
2010	57	691	3,206	0.44	1,096	1,541	1.4
2011	107	794	4,885	0.61	1,087	3,226	3.0
2012	9	836	5,733	0.56	570	1,815	3.2
2013	24	794	4,883	0.58	1,524	4,341	2.8
2014	89	769	4,437	0.51	796	1,786	2.2
Avg	42	765	4414	0.51			2.3

Table 2.9. Summary of estimates 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.

	2010	2011	2012	2013	2014
Brohm Escapement					
Resistivity Counter	65	54	NA[1]	NA[1]	NA[1]
Redd Counts	70	70	40	43	27
Derived Brohm Escapement					
Cheakamus Wild Escapement	672	730	570	1524	796
Brohm Immigration Rate	5.9%	6.5%	6.2%[2]	6.2%[2]	6.2%[2]
Escapement to Brohm River	40	48	35	95	49

[1]Problems were encountered with the resistivity counter in 2012 and counter was not installed in 2013 or 2014.

[2]Telemetry was not conducted in 2012-2014, so estimates of the proportion of fish from the Cheakamus that immigrated to Brohm in these years was calculated as the average from 2010 and 2011 estimates.

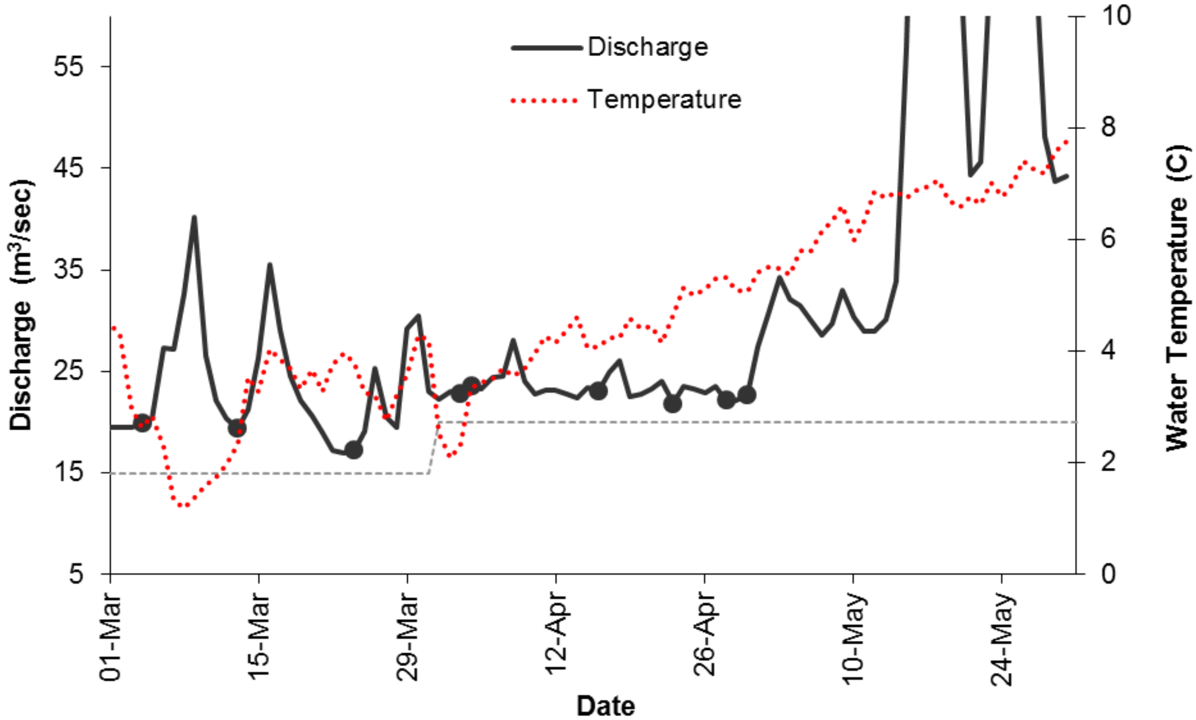


Figure 2.1. Discharge (black solid line) and water temperature (red dashed line) at the Brackendale gauge on the Cheakamus River in winter and spring of 2014. The gray dashed line shows minimum discharge requirements at the Brackendale gauge before and after March 31st. The points denote the dates that adult swim surveys were conducted.

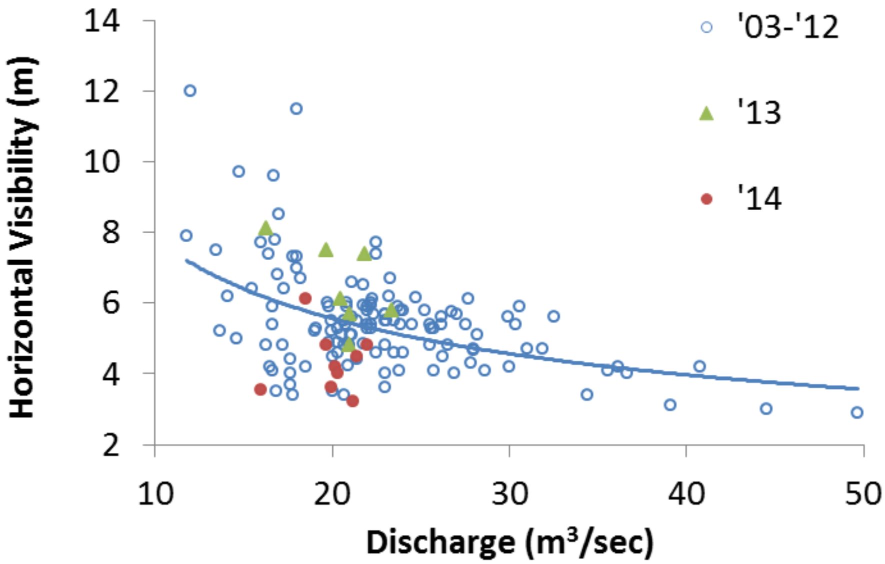


Figure 2.2. Relationship between discharge at the Brackendale gauge and horizontal visibility measured during adult steelhead snorkel swims during winter and spring. The solid line shows the relationship based on data from 2003-2012 only.

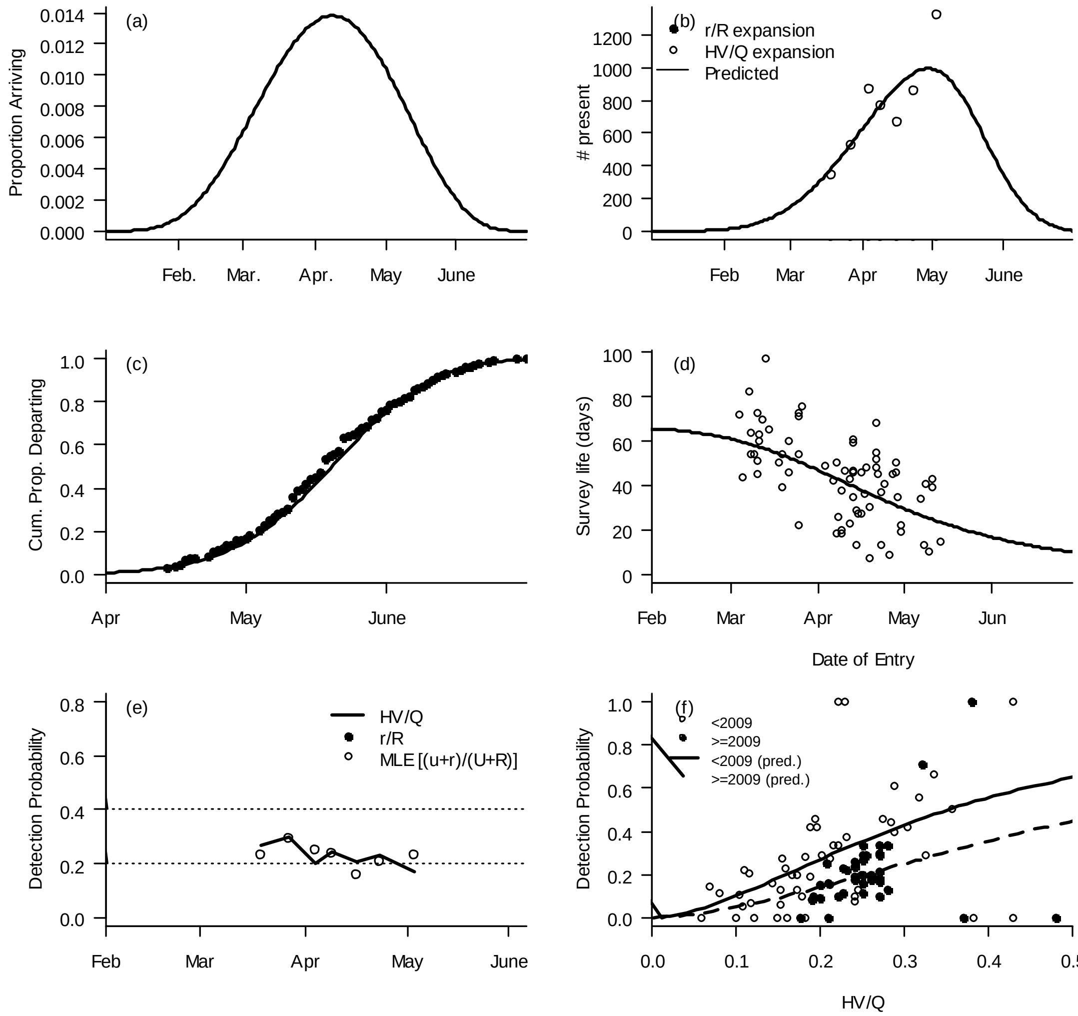


Figure 2.3. Fit of the Steelhead escapement model to the 2013 data. a) shows the predicted proportion of the run arriving by day. b) shows the predicted number present (line) through the run, and the expected numbers present on individual surveys based on expanding counts by the ratio of tags observed 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).

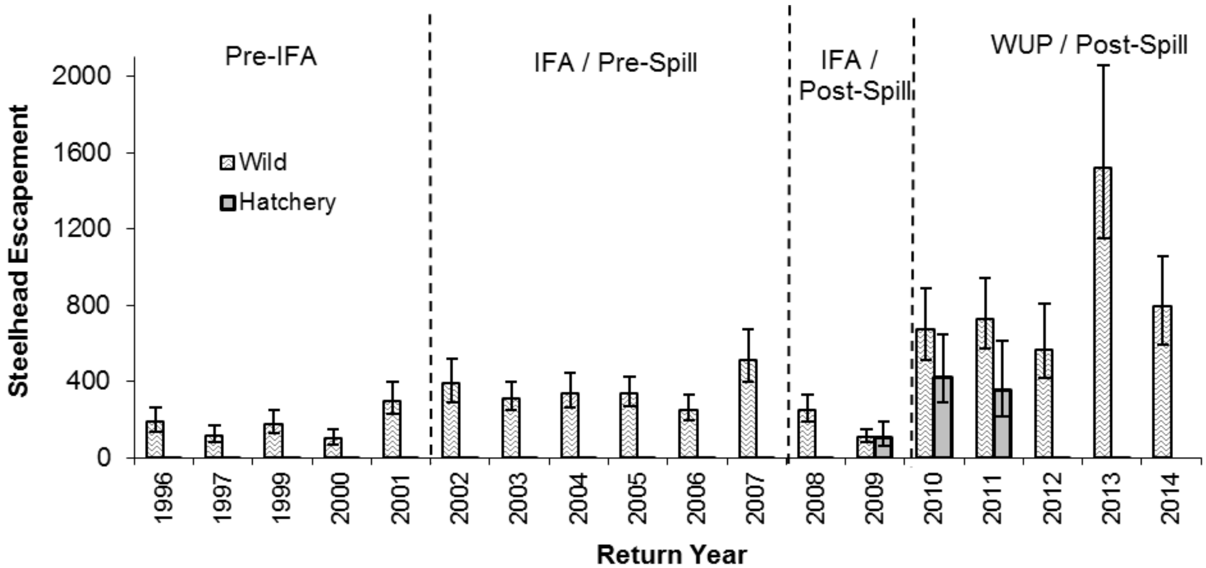


Figure 2.4. The Steelhead escapement trend in the Cheakamus River, 1996-2014 showing abundance of returns that reared as juveniles in the river before and after the Instream Flow Agreement (IFA) and Water Use Plans (WUP) were implemented and the year that the sodium hydroxide spill occurred (Pre- and 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.

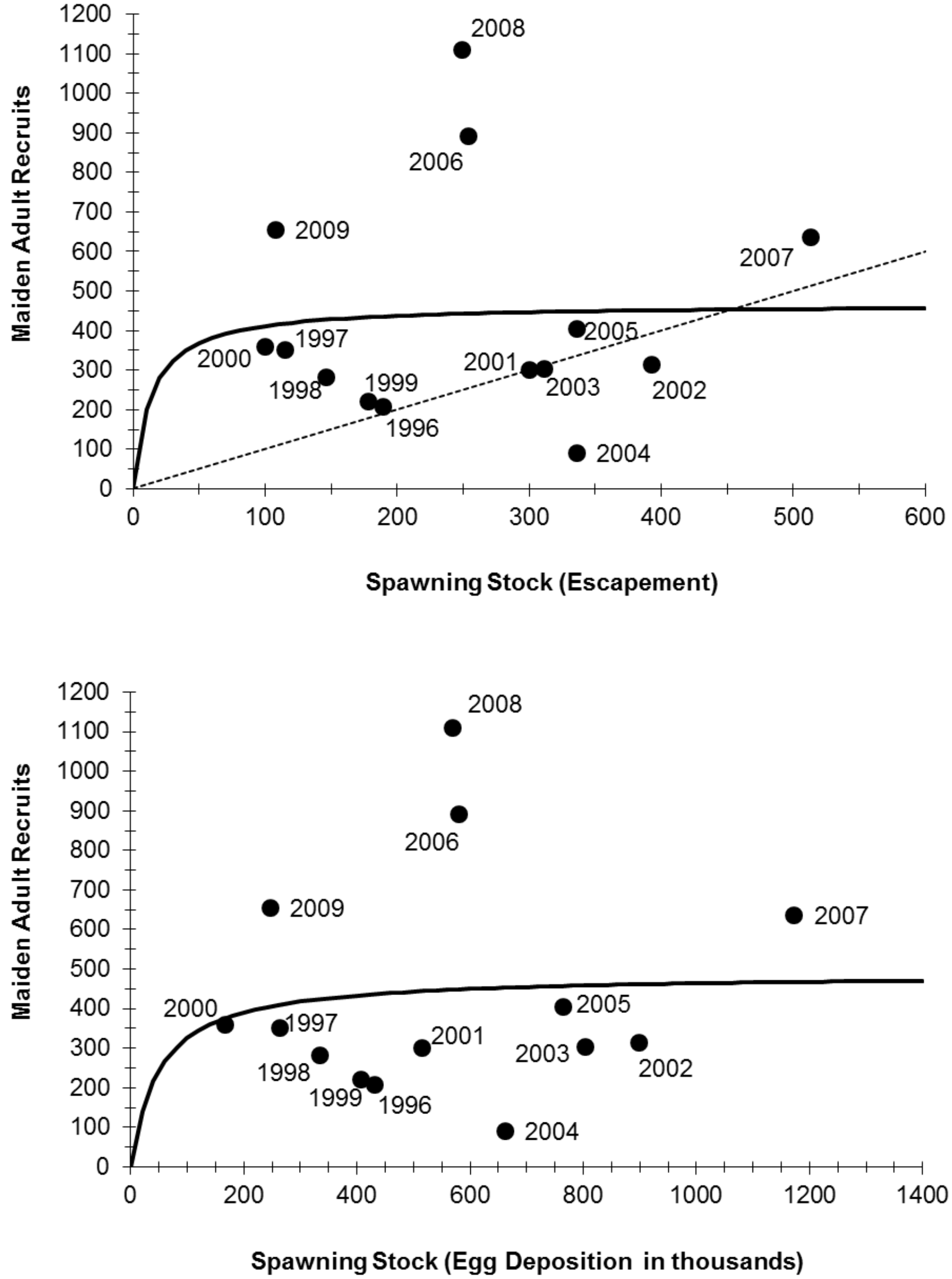


Figure 2.5. The relationship between the number of Steelhead spawners (top) and Steelhead egg deposition (bottom) in the Cheakamus River and the resulting maiden adult returns (total returns less repeat spawners). The year beside each point represents the brood year. The solid lines represent a best-fit Beverton-Holt models and the dashed line (top) represents the 1:1 relationship. Note that the recruitment estimate for the 2009 brood year is incomplete as it does not yet include 6 year old fish that will return in 2015.

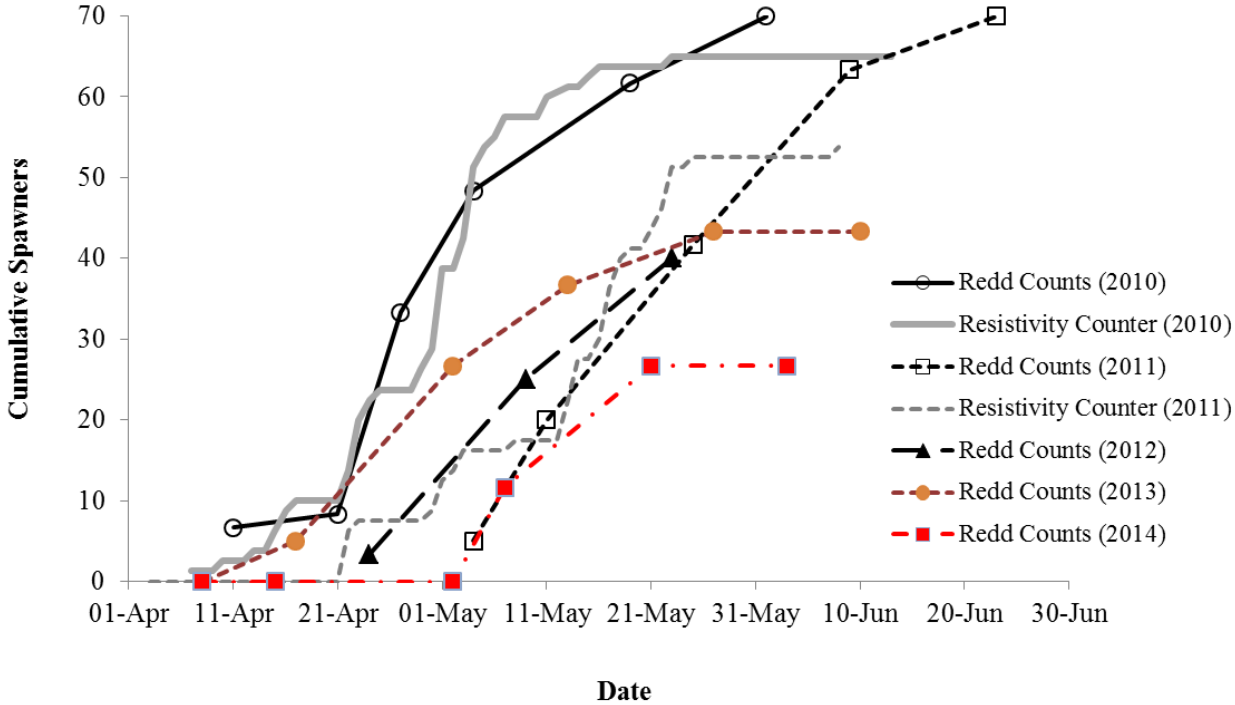
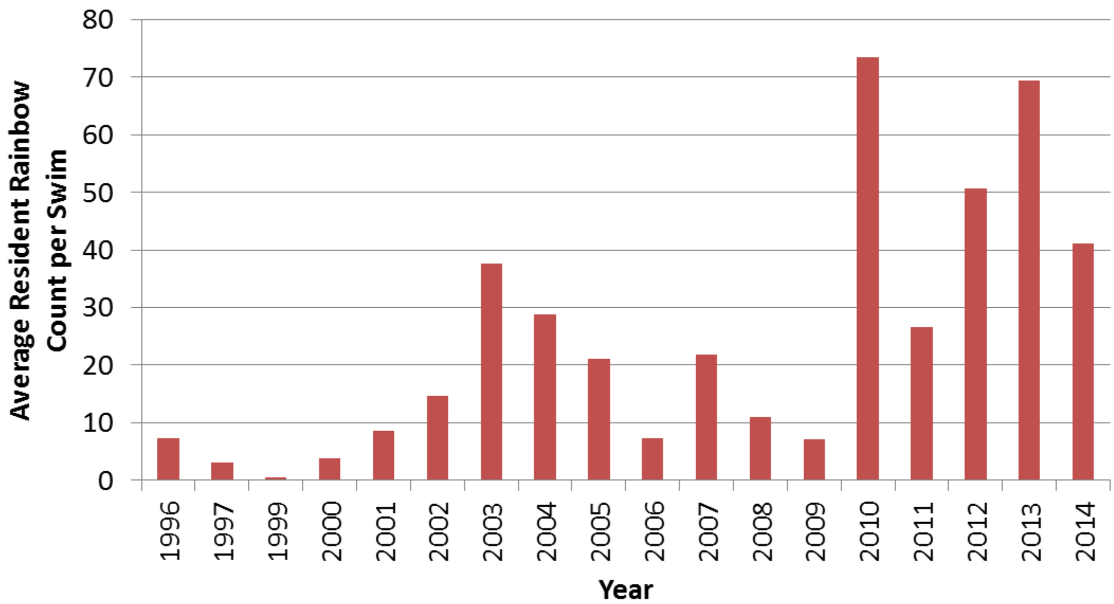


Figure 2.6. Comparison of Steelhead run-timing in Brohm River based on redd counts (expanded to spawners) and net cumulative arrivals based on a resistivity counter near the mouth. Resistivity counter data from 2012 and 2013 were not available.

Figure 2.7. The average number of resident rainbow trout counted across all swim surveys by year.



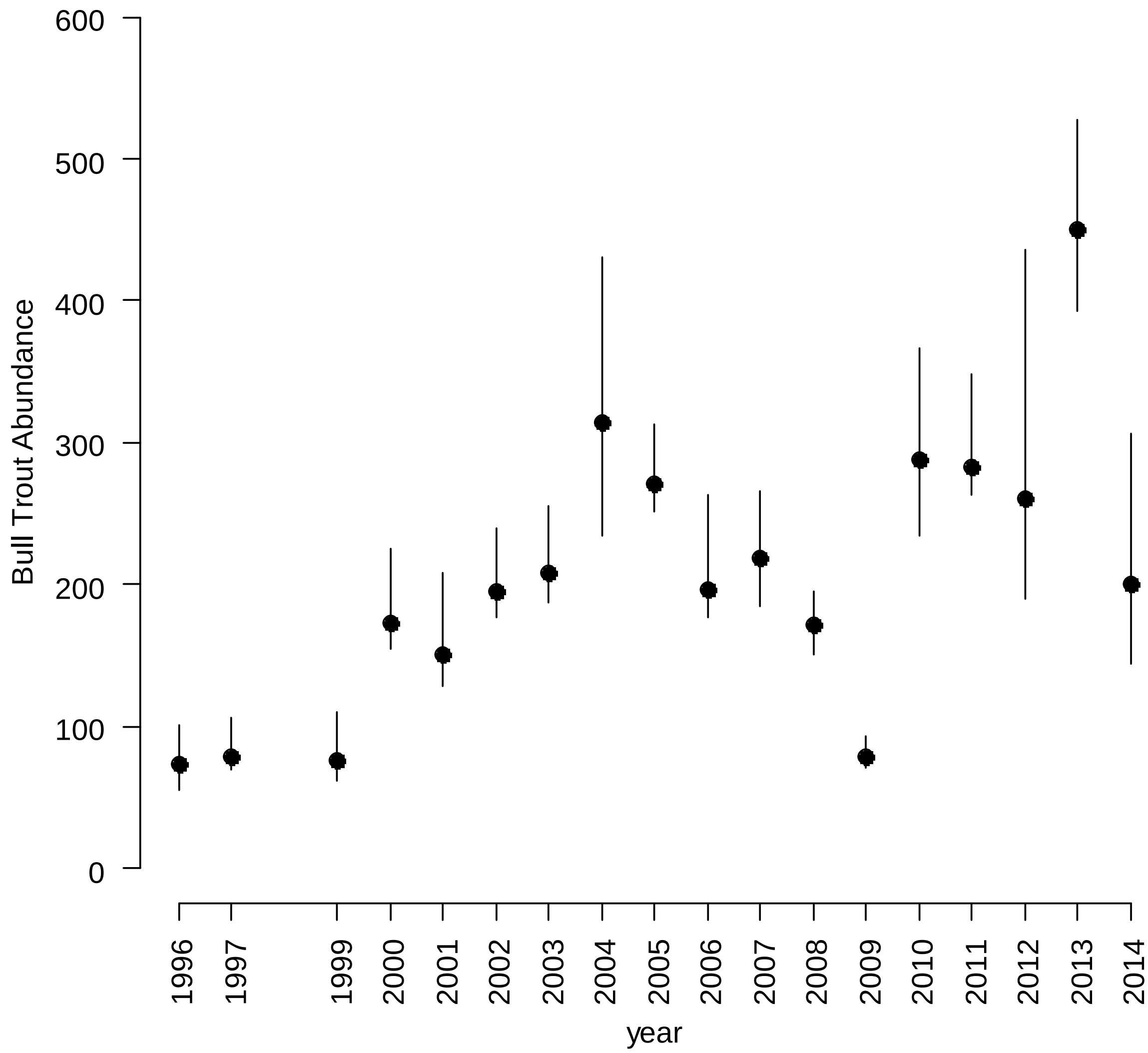


Figure 2.8. Estimates of bull trout abundance in the Cheakamus River survey area, 1996-2014. Points and vertical lines denote the mean and 95% credible intervals of the annual posterior distributions of abundance.

7.0 Tables and Figures for Chapter 3

Table 3.1. Summary of juvenile Steelhead sampling effort in Fall 2013 and Spring 2014 in Brohm and Cheakamus Rivers. 'EF' and 'SN' denote electrofishing and snorkeling sampling gear types, respectively. Index sites were sampled using one pass, while mark recapture sites were sampled using two passes.

a) Index Sites

		# Index Sites			Sampled	Useable	Proportion
		EF	SN	Total	Length (m)	Length (m)	Sampled
Fall	Brohm	15		15	462	2,675	0.17
2013	Cheakamus	118		118	3535	46,197	0.08
Spring	Brohm	15	15	30	1165	2,675	0.44
2014	Cheakamus	102	122	224	8407	46,197	0.18

b) Mark-Recapture

		# Mark Recapture Sites		
		EF	SN	Total
Fall	Brohm	4		4
2013	Cheakamus	8		8
Spring	Brohm			
2014	Cheakamus			

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.

Priors and Transformation	
(3.11)	$\mu_{\theta,g} \sim dunif(0,1)$ $\sigma_{\theta,g} \sim dunif(0.05,10)$
(3.12)	$\tau_{\theta,g} = \sigma_{\theta,g}^{-2}$ $\alpha_g = \mu_{\theta,g}\tau_{\theta,g}$ $\beta_g = (1-\mu_{\theta,g})\tau_{\theta,g}$
(3.13)	$\mu_\lambda \sim dnorm(0,0.01)$ $\sigma_\lambda \sim dhcauchy(0,0.5)$
(3.14)	$\tau_\lambda = \sigma_\lambda^{-2}$

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.

a) Brohm - Fall

Fork																		
Length		2008			2009			2010			2011			2012			2013	
(mm)	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+
<45							2											
45-49							6											
50-54							8						1					
55-59							3						2					
60-64							1						5			5		
65-69							2	1						1		2		
70-74					1		1	3			2			1		3	1	
75-79	2				2		1	3			1						4	
80-84		1			3			4			3						4	
85-89		2			6			2			3			1			4	
90-94		4			4			5			3			3			6	
95-99		3			4			3			5						4	
100-104		1			4			3			4						5	
105-109					4			3	1					1			7	
110-114						2		1			1			1			3	
115-119									1		1			1	1		2	4
120-124						1			1						1		1	1
125-129			1			2			2			4			1		1	2
130-134			1			3			6			1			3			6
135-139																		5
140-144									1			2		1	2			6
145-149			1												2			2
150-154						1									3			5
155-159						1						1			3			2
160-164															2			2
165-169																		1
170-174									1									
175-179																		
180-184																		
185-190			1															
>190																		
Total	2	11	4	0	28	10	24	28	13	0	23	8	8	10	18	10	42	36

Table 3.4. Con't.

b) Brohm - Spring

Fork Length (mm)	2009			2010			2011			2012			2013			2014		
	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+
<45																		
45-49							5											
50-54				2			4			5			5					
55-59	1			1			4			2			2					
60-64				9			4			5			6			6		
65-69				4			2			4			4			5		
70-74	1			3				1		4			3			5		
75-79		1		1						2			2			5		
80-84					2		1	1			4			5		1	2	
85-89		3			1		1	6		1	2		1	2		1	6	
90-94		2			2			6		1	3			4			6	
95-99		4			2			4		1	5			5			5	
100-104					3			3	1	2	8		1	5			9	
105-109		1			4			6			3			6			1	
110-114		1			1				1		4			5			3	1
115-119					1			5	1		3			4			2	1
120-124		2						2	8		4			3				2
125-129					3	1			1			4			5		1	1
130-134									4			2			2			
135-139		1							7			1		1	2			1
140-144									6			6			5			
145-149			2						3			1			1			
150-154			1						1									1
155-159		1	1						2			1			1			
160-164			1						2			1			1			
165-169			1									1			2			
170-174																		
175-179																		
180-184																		
185-190																		
>190																		
Total	2	16	6	20	19	1	21	34	37	27	36	17	24	40	19	23	35	7

Table 3.4. Con't.

c) Cheakamus - Fall

Fork Length (mm)	2008			2009			2010			2011			2012			2013		
	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+
<45																		
45-49				1						1						1		
50-54				1			4			1			4			3		
55-59				6			8			6			3			3		
60-64				6			10			6			2			11		
65-69	1			11			3			3						10		
70-74	1	1		6	1		3						1	2		4	2	
75-79				3	2		6	1			1			3		4	9	
80-84		1		4	2		1	2			1			4		3	13	
85-89					1						5			7			9	
90-94		3			5						5			5			8	
95-99		5			2						5			6			3	
100-104		3			3			3			8			4			3	
105-109		7			4			2			1			1			5	1
110-114					6	1		4			5			4			9	
115-119		2			4	1		2			2	1		1	2		3	2
120-124		2			6	1		3	2		1	1			4		3	2
125-129		4			5	1		2	1		5	3		1	2		1	2
130-134		2	2		3				3						1		1	3
135-139		1	2		1	1			1			6			1			3
140-144		1	3			2			4		1	4			1			3
145-149			2			2						3						2
150-154									1			3						4
155-159									2									3
160-164			3						1			1						3
165-169																		
170-174			2									1						1
175-179			2						1									
180-184																		
185-190																		
>190									1									
Total	2	32	16	38	45	9	35	19	17	17	40	23	10	38	11	39	69	29

Table 3.4. Con't.

d) Cheakamus - Spring

Fork Length (mm)	2008			2009			2010			2011			2012			2013			2014		
	0+	1+	2+	0+	1+	2+	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			2			3		
60-64				6			3	1		7			6			9			5		
65-69				2			6	1		6			1			8			6		
70-74				6			6	2		6			6			6			7	2	
75-79				3			6	4		7	1		7			11	2		5	1	
80-84		1		6	1		1	5		6	1		3			10			4	2	
85-89	1			3			2	11		5	1		9	1		5	1		5	4	
90-94		7		7	2			10		6	1		4	1		6	3		2	4	
95-99		3		1	2		1	11		5	3		1	2	1		3		3	4	
100-104		1			1			7		1	4		3	3			6			3	
105-109		1			3			12		2	6		2	2			7			6	
110-114					2			5			6		1	4		1	8			3	
115-119					6			5			4	1		1			3			5	
120-124					1			4	1		5	3		8			8			1	
125-129					7	1		1	1		2	1					2			3	
130-134		3			4			1			2	2		1	3		5			2	1
135-139		3	1		7	2			1		3	2		1				1			1
140-144		4			1	2		1	2			2		2	1			3			1
145-149		3	4		1	1			4			1		2	2		1	7			1
150-154		1	2			1			2			4	1		2						
155-159			4			3			4						2						
160-164		1	1			1						1			1			1			
165-169		1	1			1			1			5			1						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	58	49	12	40	40	5

Table 3.5. Mean fork length by age class in Brohm and Cheakamus Rivers, by year and season. Missing values denote cases where no scales were collected for an age class.

Brohm				Cheakamus			
Fall				Fall			
Year	**0+**	**1+**	**2+**	**Year**	**0+**	**1+**	**2+**
2008	78	93	138	2008	68	107	149
2009		90	127	2009	56	105	136
2010	52	91	129	2010	59	106	142
2011		91	137	2011	51	105	136
2012	55	94	136	2012	55	92	127
2013	56	92	129	2013	56	84	129
Avg	60	92	133	Avg	57	100	137
Spring				**Spring**			
Year	**0+**	**1+**	**2+**	**Year**	**0+**	**1+**	**2+**
2008				2008	88	116	154
2009	67	105	158	2009	63	115	157
2010	68	101	128	2010	70	97	143
2011	57	97	133	2011	70	106	151
2012	69	112	151	2012	69	114	150
2013	66	101	143	2013	71	109	150
2014	60	95	129	2014	62	91	132
Avg	65	102	140	Avg	70	107	148

Table 3.6. Total number of juvenile Steelhead captured by electrofishing (EF) or observed by snorkelling (SN) at index sites in fall 2013 and spring 2014 sample sessions.

Season Year	Gear	River	Age 0+	1+	2+	0+ - 2+
Fall	EF	Brohm	563	264	49	876
2013	EF	Cheakamus	4,654	119	33	4,806
Spring	EF	Brohm	127	73	19	219
2014	SN		64	450	148	662
	EF	Cheakamus	1,004	286	7	1,297
	SN		1,451	3,498	466	5,415

Table 3.7. 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 2014.

			KM Sampled		Catch Per KM					
					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	356	158			
		2012	0.38		2,406	453	276			
		2013	0.46		1,219	571	106			
	spring	2009	0.46	0.40				73	590	125
		2010	0.00	0.50	292	193	23	277	836	311
		2011	0.30	0.50	317	178	86	50	182	288
		2012	0.33	0.81	189	90	16	46	639	138
		2013	0.37	0.72	286	99	27	61	406	154
		2014	0.44	0.75	307	176	46	85	599	197
Cheak	fall	2008	1.13		1,550	85	32			
		2009	2.55		642	38	9			
		2010	3.00		483	20	8			
		2011	2.99		2,322	39	7			
		2012	2.76		858	153	13			
		2013	3.54		1,317	34	9			
	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	643	12	4	633	98	36
		2013	2.91	5.96	422	39	8	226	140	31
		2014	2.47	5.94	407	116	3	244	589	78

Table 3.8. 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 ('Recaps') to the total that were marked ('Marked'). CV θ is the coefficient of variation in detection probability estimates across sites.

Brohm Age-0 Electrofishing					
Year	**Season**	**Marks**	**Recaps**	**θ**	**CV θ**
2008	Fall	131	16	0.12	0.23
2008	Fall	101	12	0.12	0.27
2009	Fall	98	24	0.24	0.18
2009	Fall	111	27	0.24	0.17
2010	Spring	54	11	0.20	0.27
2010	Spring	72	14	0.19	0.24
2010	Fall	160	36	0.23	0.15
2010	Fall	93	21	0.23	0.19
2011	Spring	52	5	0.10	0.43
2011	Spring	44	6	0.14	0.38
2011	Spring	45	8	0.18	0.32
2011	Spring	51	7	0.14	0.35
2011	Spring	37	9	0.24	0.29
2011	Spring	53	7	0.13	0.35
2012	Fall	127	28	0.22	0.17
2012	Fall	132	44	0.33	0.12
2013	Spring	78	26	0.33	0.16
2013	Fall	113	20	0.18	0.20
2013	Fall	63	33	0.52	0.12
2013	Fall	78	14	0.18	0.24
2013	Fall	139	20	0.14	0.21
Brohm Age-1+ Electrofishing					
Year	**Season**	**Marks**	**Recaps**	**θ**	**CV θ**
2008	Fall	74	18	0.24	0.21
2008	Fall	69	27	0.39	0.15
2009	Fall	46	10	0.22	0.28
2009	Fall	20	11	0.55	0.20
2010	Spring	26	6	0.23	0.36
2010	Spring	41	5	0.12	0.42
2010	Fall	43	14	0.33	0.22
2010	Fall	58	24	0.41	0.16
2011	Spring	41	10	0.24	0.27
2011	Spring	50	6	0.12	0.38
2011	Spring	32	8	0.25	0.31
2011	Spring	37	4	0.11	0.47
2011	Spring	40	10	0.25	0.27
2011	Spring	43	10	0.23	0.28
2012	Fall	64	25	0.39	0.16
2012	Fall	46	19	0.41	0.18
2013	Spring	18	6	0.33	0.33
2013	Fall	106	31	0.29	0.15
2013	Fall	44	26	0.59	0.13
2013	Fall	74	23	0.31	0.17
2013	Fall	52	17	0.33	0.20

Table 3.8. 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		2013	Fall	1	0	0	
2010	Fall	136	34	0.25	0.15		2013	Fall	1	0	0	
2010	Fall	25	0	0.00			2013	Fall	1	0	0	
2010	Fall	129	22	0.17	0.19		2013	Fall	3	2	0.66667	0.41
2011	Fall	186	59	0.32	0.11		2013	Fall	1	0	0	
2011	Fall	120	54	0.45	0.10		2013	Fall	1	0	0	
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							
2013	Fall	274	138	0.50	0.06							
2013	Fall	125	24	0.19	0.18							
2013	Fall	159	51	0.32	0.12							
2013	Fall	156	28	0.18	0.17							
2013	Fall	128	32	0.25	0.15							
2013	Fall	82	33	0.40	0.13							
2013	Fall	296	58	0.20	0.12							
2013	Fall	263	111	0.42	0.07							

Table 3.8. 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 3.9. Summary statistics of detection probability from mark-recapture experiments 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 stratum.

Strata	N	Mean	CV
Brohm Age-0 EF	21	0.21	0.46
Brohm Age-1+ EF	21	0.30	0.42
Cheakamus Age-0 EF	57	0.31	0.38
Cheakamus Age-1+ EF	45	0.16	1.55
Both Rivers, Age-0 SN	20	0.39	0.64
Both Rivers, Age-1+ SN	20	0.61	0.28

Table 3.10. Sample sizes used in hierarchical Bayesian model to estimate juvenile Steelhead abundance in Brohm and Cheakamus Rivers in fall 2013 and spring 2014. 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. Age '1-2 RST' denotes estimates for age 1 and 2 yr. Steelhead above the rotary screw trap only.

				Index Sites			Mark Recapture		
River	**Year**	**Season**	**Age**	**EF**	**SN**	**Total**	**EF**	**SN**	**Total**
Brohm	2013	Fall	0	15		15	21		21
			1-2	15		15	21		21
Cheakamus			0	118		118	57		57
			1-2	118		118	45		45
Brohm	2014	Spring	0	15		15	21	20	41
			1-2	15	15	30	21	20	41
Cheakamus			0	102	81	183	57	20	77
			1-2	102	117	219	45	20	65
			1-2 RST	70	93	163	45	20	65

Table 3.11. Comparison of HBM estimates of steelhead abundance based on alternate schemes for stratifying the lognormal fish density distribution by reach. Cheakamus River estimates were based on no stratification (one stratum), two strata (reaches 1, 2-5) and three strata (reaches 1, 2-4, and 5). Brohm River estimates were based on no stratification or two strata (reaches 1, 2). The table shows the mean and coefficient of variation (CV) of abundance estimates and the deviance information criteria (DIC), which indicates the out-of-sample predictive power of the model. Models with lower DIC values within a river-year-season-age (row) estimation group are considered better. Cells highlighted in green indicate there were no substantive differences in DIC among alternate stratification models (|ΔDIC|<4), while yellow cells identify the best model (lowest DIC). Cells in gray highlight difficulties in estimation (high CV, unrealistic means).

	One Stratum				Two Strata				Three Strata (Cheakamus Only)		
River-Year-Season-Age	**Mean**	**CV**	**DIC**		**Mean**	**CV**	**DIC**		**Mean**	**CV**	**DIC**
Cheakamus 2011 Fall Age 0	398.4	0.17	1,119		426.1	0.21	1,117		473.88	0.48	1,122
Cheakamus 2012 Fall Age 0	156.1	0.21	956		157.9	0.23	964		154.07	0.27	954
Cheakamus 2013 Fall Age 0	254.5	0.19	1,168		191.9	0.13	1,142		188.52	0.13	1,141
Cheakamus 2010 Spring Age 0	22.6	0.19	1,018		23.3	0.19	1,031		23.78	0.23	1,052
Cheakamus 2011 Spring Age 0	32.2	0.1	1,338		32.8	0.11	1,341		33.1	0.11	1,370
Cheakamus 2012 Spring Age 0	88.9	0.14	1,430		85.1	0.14	1,447		86.66	0.17	1,422
Cheakamus 2013 Spring Age 0	49.3	0.12	1,494		48.3	0.11	1,523		46.57	0.1	1,514
Cheakamus 2014 Spring Age 0	53.6	0.16	1,399		51.3	0.15	1,382		52.66	0.18	1,417
Cheakamus 2010 Spring Age 1	18.5	0.12	1,124		18.8	0.12	1,127		18.92	0.12	1,133
Cheakamus 2011 Spring Age 1	3.6	0.09	860		3.5	0.09	866		3.46	0.09	868
Cheakamus 2012 Spring Age 1	19.8	0.1	1,229		20.6	0.12	1,220		21.08	0.12	1,201
Cheakamus 2013 Spring Age 1	11.7	0.11	1,122		11.5	0.1	1,123		11.5	0.1	1,126
Cheakamus 2014 Spring Age 1	46.0	0.11	1,429		44.6	0.11	1,445		44.61	0.1	1,466
Cheakamus 2010 Spring Age 2	3.4	0.11	718		3.4	0.11	710		3.48	0.13	729
Cheakamus 2011 Spring Age 2	2.4	0.1	744		2.3	0.1	740		2.28	0.12	766
Cheakamus 2012 Spring Age 2	3.8	0.11	762		3.8	0.11	743		4.41	0.18	733
Cheakamus 2013 Spring Age 2	2.5	0.09	756		2.5	0.1	757		2.45	0.1	764
Cheakamus 2014 Spring Age 2	3.9	0.1	779		3.8	0.1	756		4.08	0.13	769
Brohm 2012 Fall Age 0	31.2	0.15	236		35.9	0.18	234				
Brohm 2013 Fall Age 0	15.9	0.17	254		16.0	0.55	245				
Brohm 2012 Fall Age 1	4.1	0.16	213		7.7	9.31	213				
Brohm 2013 Fall Age 1	5.1	0.13	227		5.1	0.15	226				
Brohm 2012 Fall Age 2	2.4	0.17	206		2.3	0.73	204				
Brohm 2013 Fall Age 2	1.0	0.19	192		1.0	0.22	192				

Table 3.12. 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+	245.6	236.5	0.22	168.9	377.7
	2009	Spring	0+	50.7	48.6	0.24	33.8	81.0
			1+	5.8	5.7	0.17	4.2	8.1
			2+	2.1	2.1	0.15	1.6	2.8
Brohm	2008	Fall	0+	24.4	19.2	9.34	12.0	42.0
			1+	Not estimable due to low density and sample size				
			2+	Not estimable due to low density and sample size				
	2009	Spring	0+	Not reliable, no electrofishing conducted				
			1+	2.77	2.7	0.18	2.02	3.87
			2+	0.59	0.58	0.23	0.4	0.91
Cheakamus	2009	Fall	0+	101.6	97.7	0.22	70.4	156.6
	2010	Spring	0+	22.6	22.0	0.19	16.3	32.4
			1+	18.5	18.3	0.12	15.0	23.3
			2+	3.4	3.3	0.11	2.8	4.2
Brohm	2009	Fall	0+	21.0	20.3	0.20	15.0	31.0
			1+	4.6	4.5	0.15	3.5	6.1
			2+	2.3	2.2	0.20	1.6	3.3
	2010	Spring	0+	4.3	4.1	0.28	2.8	6.7
			1+	2.7	2.7	0.11	2.2	3.3
			2+	1.0	1.0	0.17	0.8	1.4
Cheakamus	2010	Fall	0+	71.3	70.0	0.14	55.6	94.6
	2011	Spring	0+	32.2	31.9	0.10	27.0	39.0
			1+	3.6	3.5	0.09	3.0	4.3
			2+	2.4	2.4	0.10	2.0	2.9
Brohm	2010	Fall	0+	18.9	18.7	0.11	15.4	23.6
			1+	3.4	3.4	0.13	2.7	4.4
			2+	3.1	3.0	0.13	2.4	3.9
	2011	Spring	0+	3.9	3.8	0.18	2.8	5.5
			1+	1.1	1.1	0.14	0.9	1.5
			2+	1.1	1.1	0.13	0.9	1.5

Table 3.12. Con't.

River	Year	Season	Age	Mean	Median	CV	LCL	UCL
Cheakamus	2011	Fall	0+	398.4	389.4	0.17	291.2	556.9
	2012	Spring	0+	88.9	87.3	0.14	69.3	117.4
			1+	19.8	19.6	0.10	16.3	24.6
			2+	3.8	3.8	0.11	3.1	4.6
Brohm	2011	Fall	0+	29.0	21.9	6.22	13.7	52.9
			1+	3.4	3.2	0.28	2.2	5.2
			2+	1.6	1.4	3.80	0.9	2.8
	2012	Spring	0+	4.6	4.3	0.28	3.1	7.4
			1+	2.3	2.2	0.14	1.8	2.9
			2+	0.5	0.5	0.15	0.4	0.7
Cheakamus	2012	Fall	0+	156.1	150.3	0.21	109.1	235.4
	2013	Spring	0+	49.3	48.9	0.12	39.2	61.9
			1+	11.7	11.6	0.11	9.5	14.4
			2+	2.5	2.4	0.09	2.0	2.9
Brohm	2012	Fall	0+	31.2	30.7	0.15	23.7	41.3
			1+	4.1	4.0	0.16	3.1	5.6
			2+	2.4	2.4	0.17	1.7	3.3
	2013	Spring	0+	3.6	3.6	0.16	2.7	4.9
			1+	1.5	1.5	0.08	1.3	1.8
			2+	0.6	0.6	0.10	0.5	0.7
Cheakamus	2013	Fall	0+	254.5	246.7	0.19	180.9	373.2
	2014	Spring	0+	53.6	52.5	0.16	40.0	73.1
			1+	46.0	45.6	0.11	37.5	57.0
			2+	3.9	3.9	0.10	3.2	4.7
Brohm	2013	Fall	0+	15.9	15.5	0.17	11.9	22.3
			1+	5.1	5.1	0.13	4.0	6.6
			2+	1.0	0.9	0.19	0.7	1.4
	2014	Spring	0+	3.9	3.8	0.19	2.8	5.5
			1+	2.3	2.3	0.10	1.9	2.8
			2+	0.8	0.7	0.20	0.6	1.1

Table 3.13. Juvenile survival statistics for Cheakamus (a) and Brohm (b) River Steelhead Cohorts (year of spawning). Abundance for each age class and sampling period is the median of the posterior distribution of the total abundance estimates from the HBM. Survival between periods is the ratio of abundances across adjacent rows. Survival rates are not calculated in cases where abundance estimates needed for the calculation are unreliable.

a) Cheakamus

Brood Year	Age (Yr. from Emergence)	Sampling Period	Abundance ('000s)	Survival between Periods	Survival Fall Age-0 Spring Age-1
2008	Eggs	Spring-08	570		
	0+	Fall-08	236.5	41%	
	0+	Spring-09	48.6	21%	
	1+	Spring-10	18.3	38%	8%
2009	Eggs	Spring-09	488		
	0+	Fall-09	97.7	20%	
	0+	Spring-10	22.0	22%	
	1+	Spring-11	3.5	16%	4%
2010	Eggs	Spring-10	1,541		
	0+	Fall-10	70.0	5%	
	0+	Spring-11	31.9	46%	
	1+	Spring-12	19.6	61%	28%
2011	Eggs	Spring-11	3,226		
	0+	Fall-11	389.4	12%	
	0+	Spring-12	87.3	22%	
	1+	Spring-13	11.56	13%	3%
2012	Eggs	Spring-12	1,815		
	0+	Fall-12	150.3	8%	
	0+	Spring-13	48.9	33%	
	1+	Spring-14	45.6	93%	30%
2013	Eggs	Spring-13	4,341		
	0+	Fall-13	246.7	6%	
	0+	Spring-14	52.5	21%	
	1+	Spring-15	NA	NA	NA

Table 3.13. Con't.

b) Brohm

River	Brood Year	Age (Yr. from Emergence)	Sampling Period	Abundance ('000s)	Survival between Periods	Survival Spring Age-0 Spring Age-1	Survival Fall Age-0 Spring Age-1
Brohm	2008	0+	Fall-08	19.2			
		0+	Spring-09	NA			
		1+	Fall-09	4.5	NA		
		1+	Spring-10	2.7	59%	NA	14%
	2009	0+	Fall-09	20.3			
		0+	Spring-10	4.1	20%		
		1+	Fall-10	3.4	82%		
		1+	Spring-11	1.1	32%	26%	5%
	2010	0+	Fall-10	18.67			
		0+	Spring-11	3.83	21%		
		1+	Fall-11	3.23	84%		
		1+	Spring-12	2.22	69%	58%	12%
	2011	0+	Fall-11	21.87			
		0+	Spring-12	4.32	20%		
		1+	Fall-12	4.04	94%		
		1+	Spring-13	1.51	37%	35%	7%
	2012	0+	Fall-12	30.69			
		0+	Spring-13	3.59	12%		
		1+	Fall-13	5.1	142%		
		1+	Spring-14	2.3	45%	63%	7%
	2013	0+	Fall-13	15.5			
		0+	Spring-14	3.8	25%		
		1+	Fall-14	NA	NA		
		1+	Spring-15	NA	NA		NA

Table 3.14. Comparison of Steelhead smolt production estimates for the Cheakamus River from 2009-2014 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**	**2013**	**2014**
Juvenile Survey Parr Abundance						
Age 1 Parr (--> 2 Yr Smolt)	5,070	14,310	2,410	10,830	8,520	32,850
Age 2 Parr (--> 3 Yr Smolt)	1,560	2,640	1,610	2,770	1,670	2,760
RST Estimates of Smolts						
Total Smolts	11,088	4,974	5,518	2,208	4,455	10,107
% 2 Yr Smolts	75%	49%	56%	33%	55%	33%
% 3 Yr Smolts	23%	44%	43%	61%	45%	45%
% 4 Yr Smolts	2%	3%	2%	6%	0%	22%
2 Yr Smolts	8,272	2,452	3,084	738	2,471	3,361
3 Yr Smolts	2,561	2,179	2,348	1,346	1,984	4,553
4 Yr Smolts	252	143	86	124	0	2,194
RST 3 Yr Smolt / Juvenile Survey 2+ Parr Ratio	1.64	0.83	1.46	0.49	1.19	1.65
% Difference (100*(2+ parr - 3 yr smolt)/3 yr smolt)	-39%	21%	-31%	106%	-16%	-39%

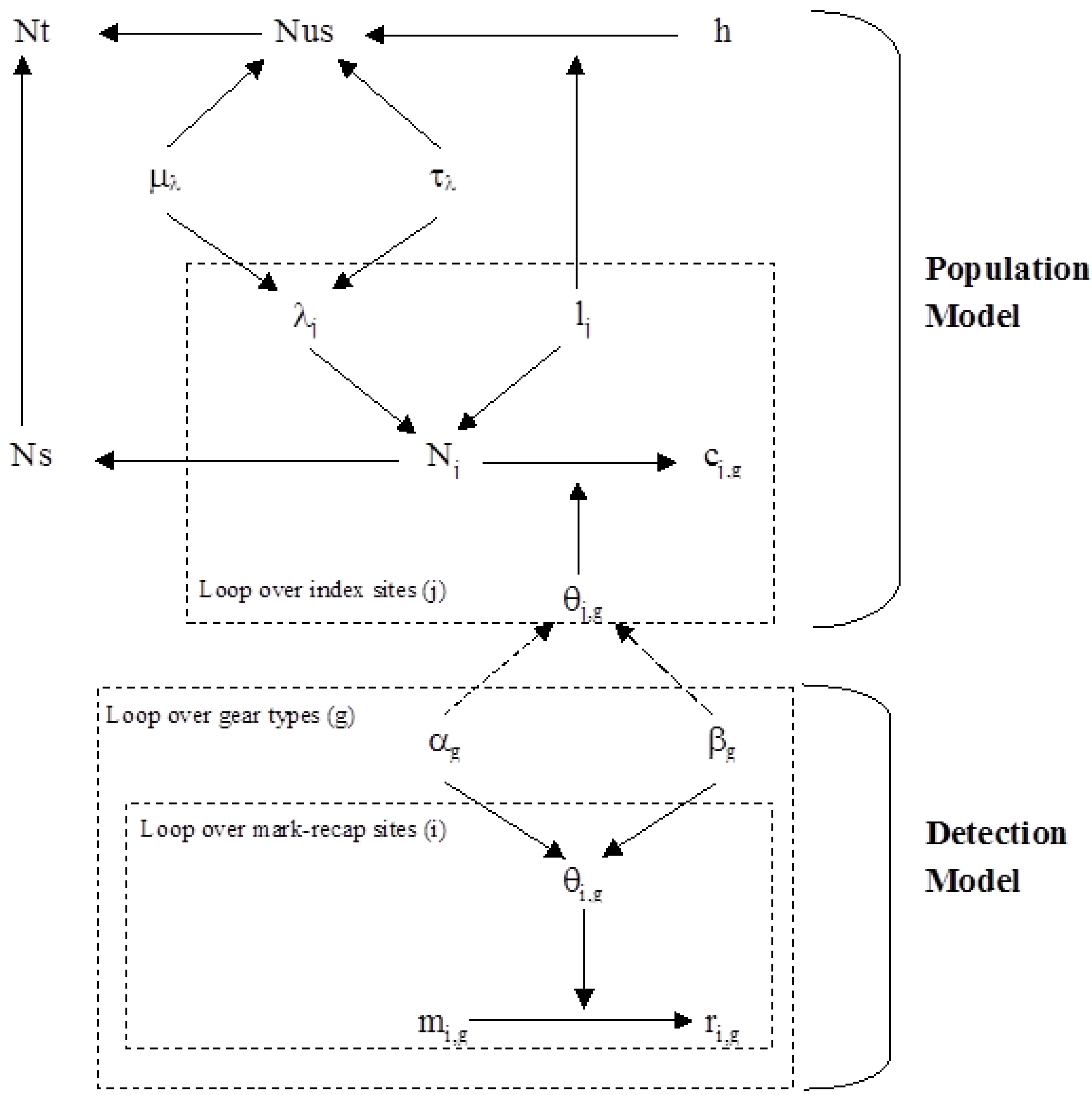


Figure 3.1. Graphical representation of the two-phase hierarchical Bayesian model to estimate juvenile Steelhead abundance in the Cheakamus River. See Table 3.2 for definition of model variables. Arrows indicate conditional dependencies between the variables. The dashed arrows indicate that the hyper-parameters 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.

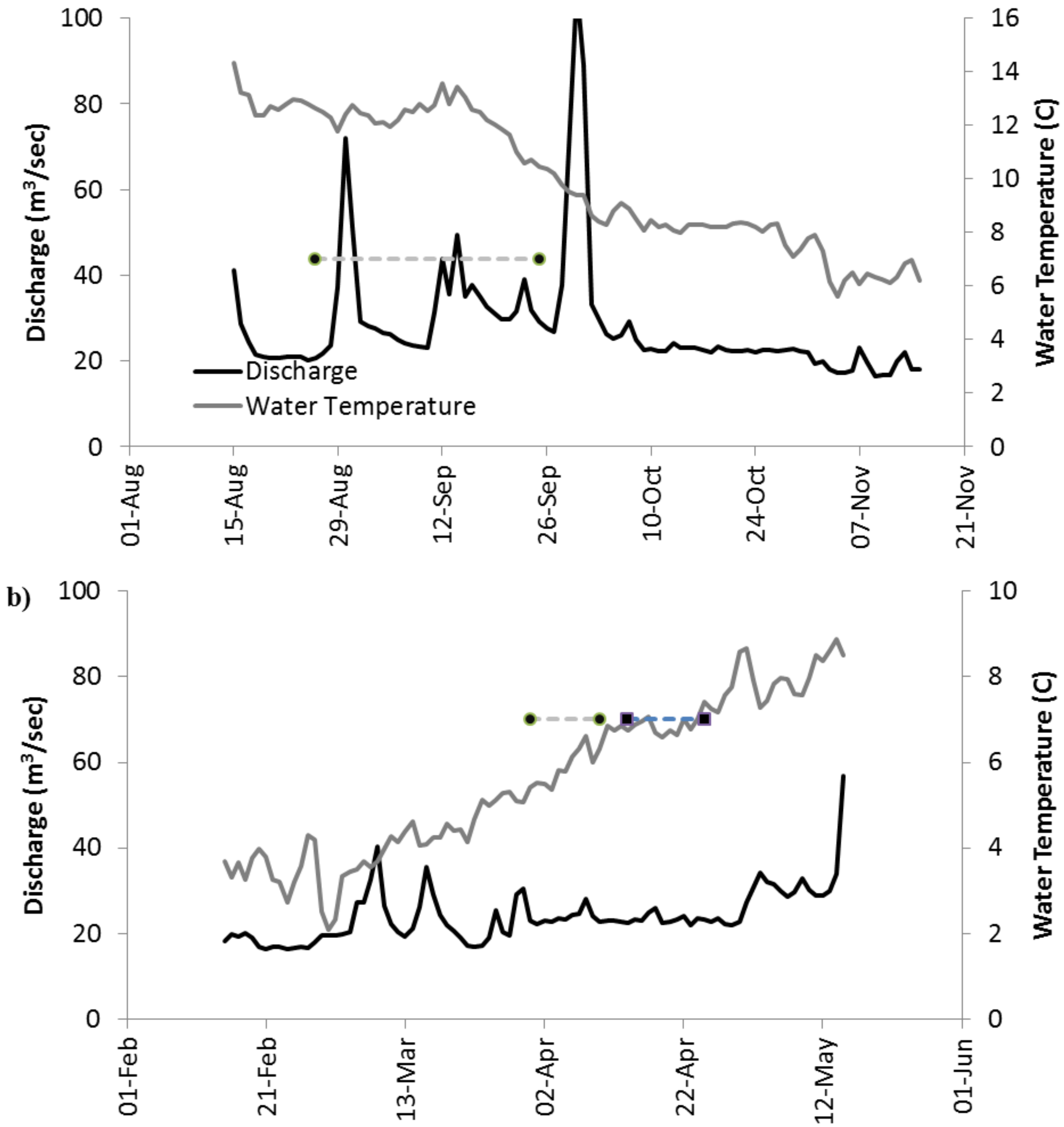


Figure 3.2. Discharge and water temperature at the Brackendale gauge (near Rotary Screw Trap) in the Cheakamus River during the fall 2013 (a) and spring 2014 (b) sampling periods. The horizontal lines show the fish sampling periods. In b), horizontal lines with circles and squares denote snorkeling and electrofishing sampling periods, respectively.

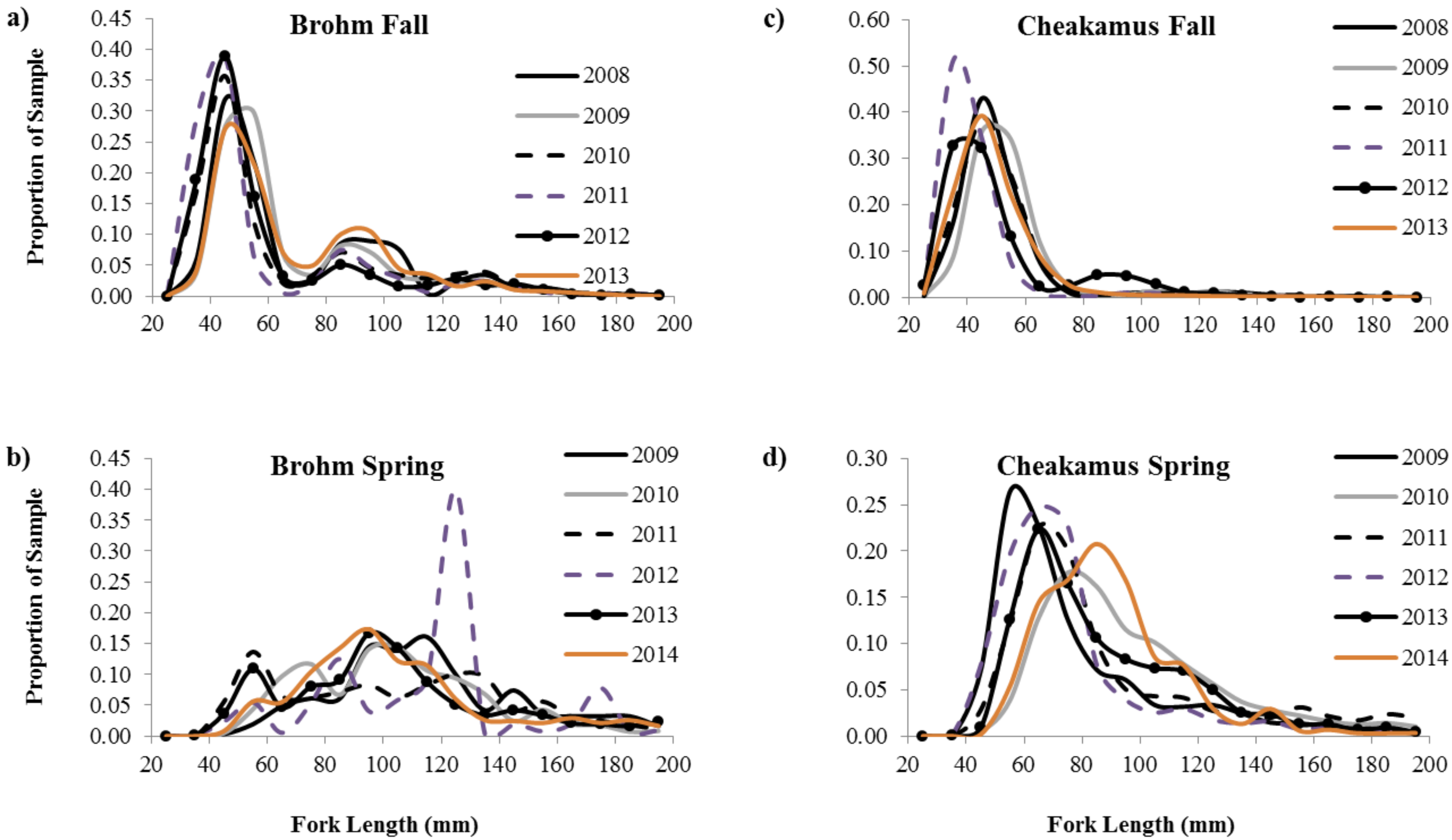


Figure 3.3. Interannual comparisons of length frequency distributions for juvenile Steelhead between years within rivers and seasons. Distributions from fall samples are based on electrofishing only while distributions for spring samples are based on electrofishing and snorkelling for all Cheakamus River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

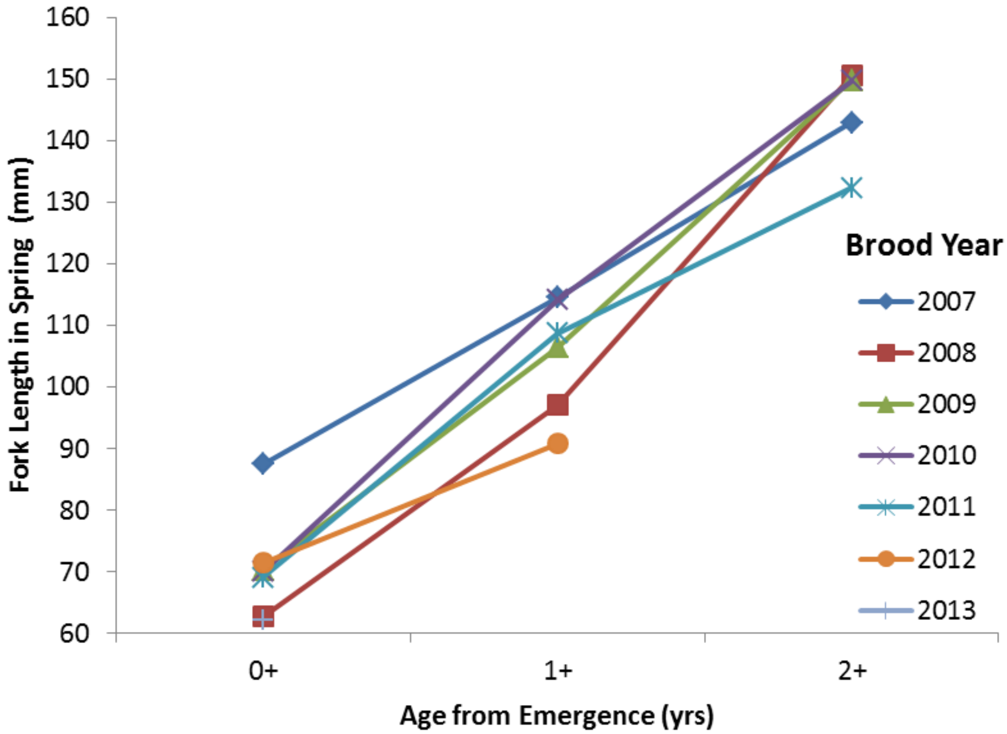


Figure 3.4. Mean size-at-age by brood year for Cheakamus River juvenile Steelhead.

a) Cheakamus River, all years combined

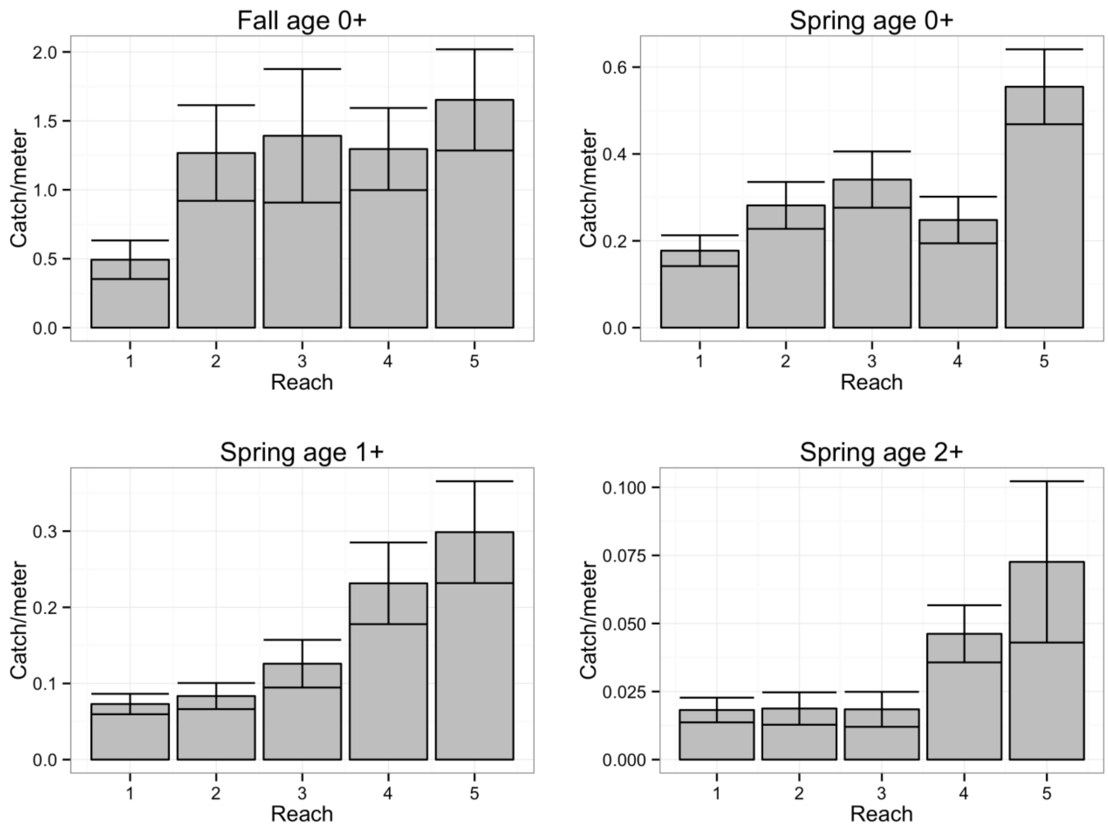


Figure 3.5. Variation in juvenile steelhead density among reaches in the Cheakamus and Brohm Rivers. The height of the bar represents the mean catch per meter across sites in each reach, and the error bars represent the 95% confidence interval.

b) Cheakamus River, Fall Age-0+

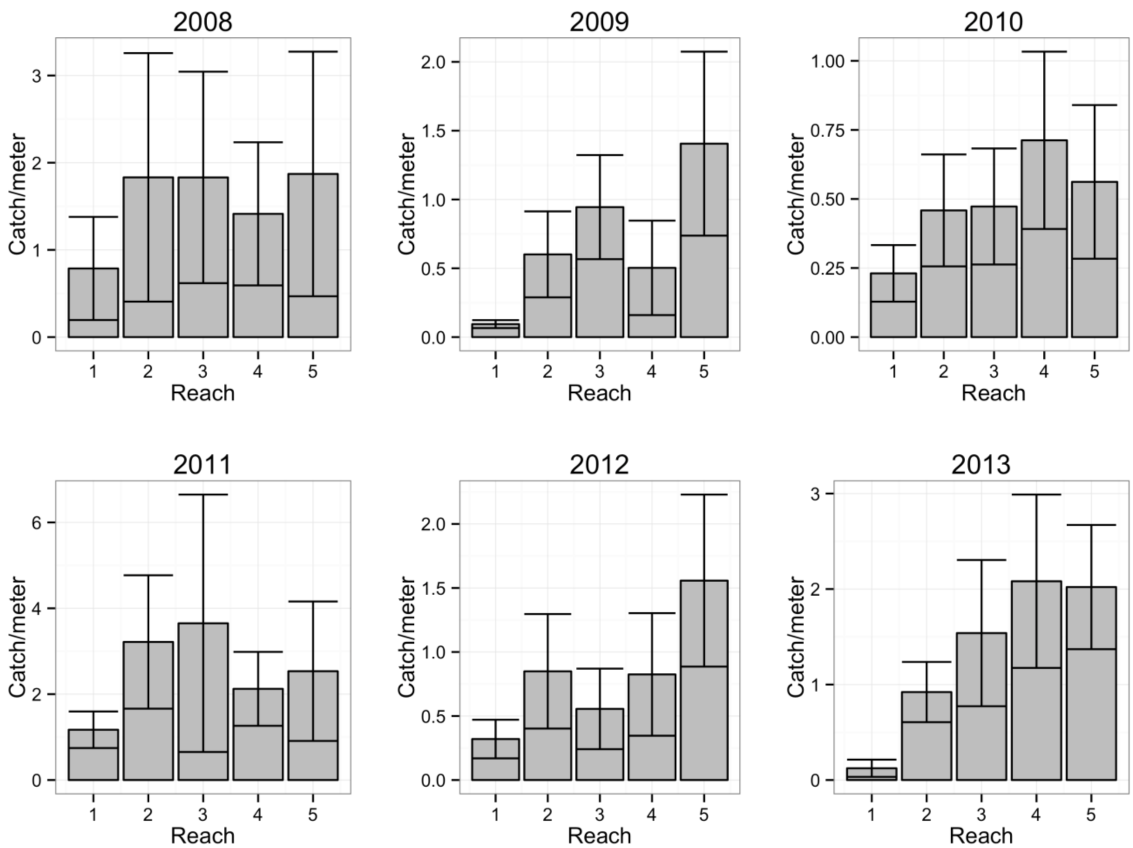


Figure 3.5. Con't.

c) Cheakamus River, Spring Age-0+

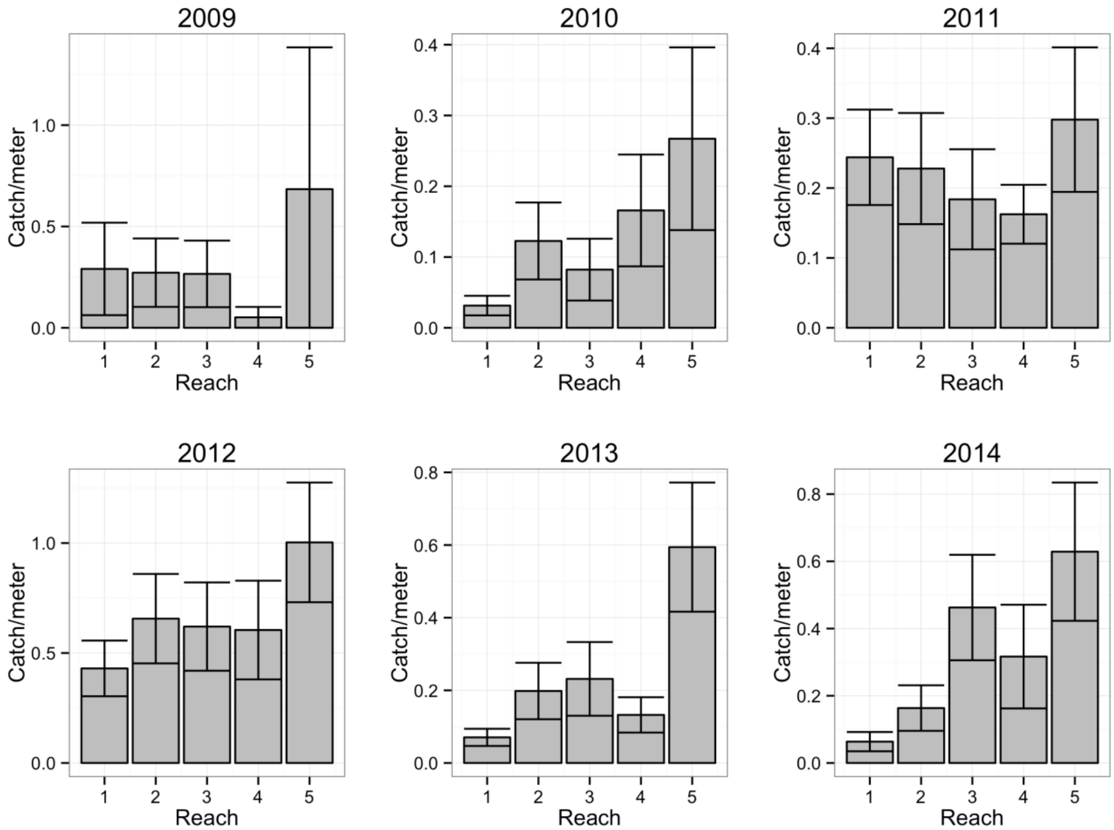


Figure 3.5. Con't.

d) Cheakamus River, Spring Age-1+

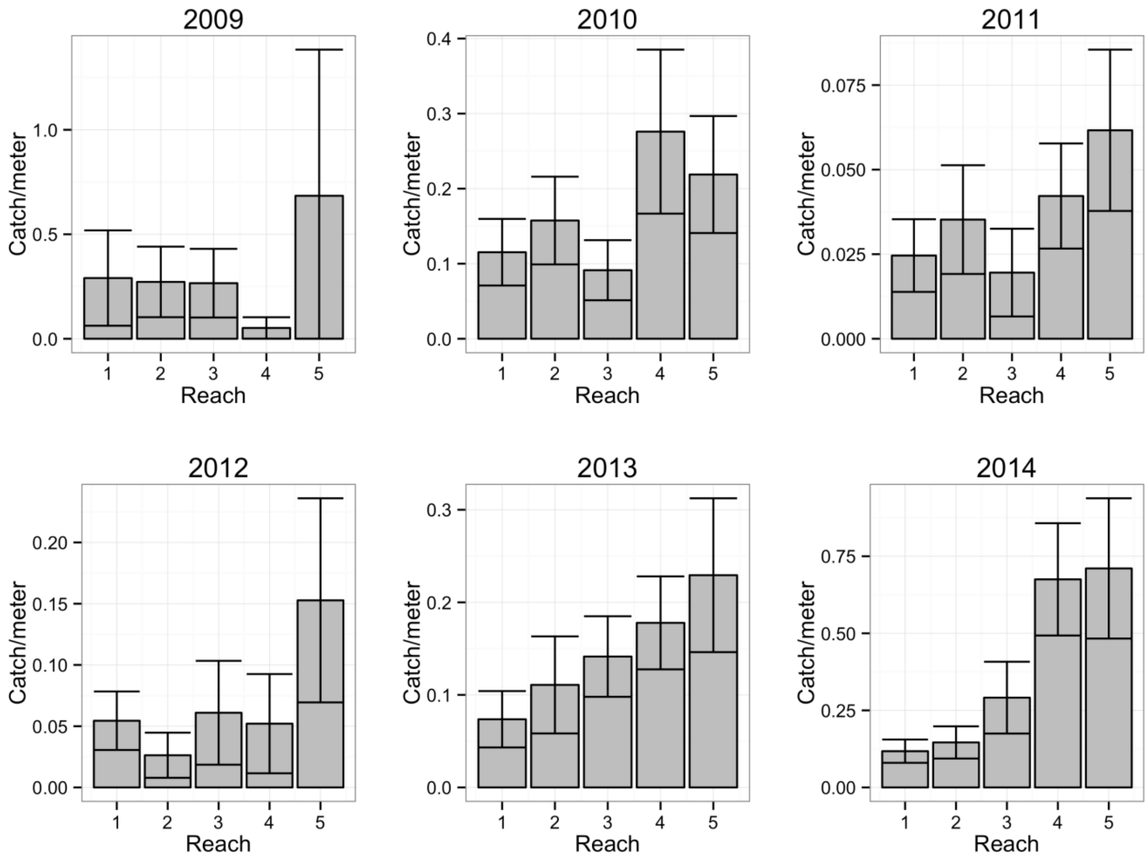


Figure 3.5. Con't.

e) Cheakamus River, Spring Age-2+

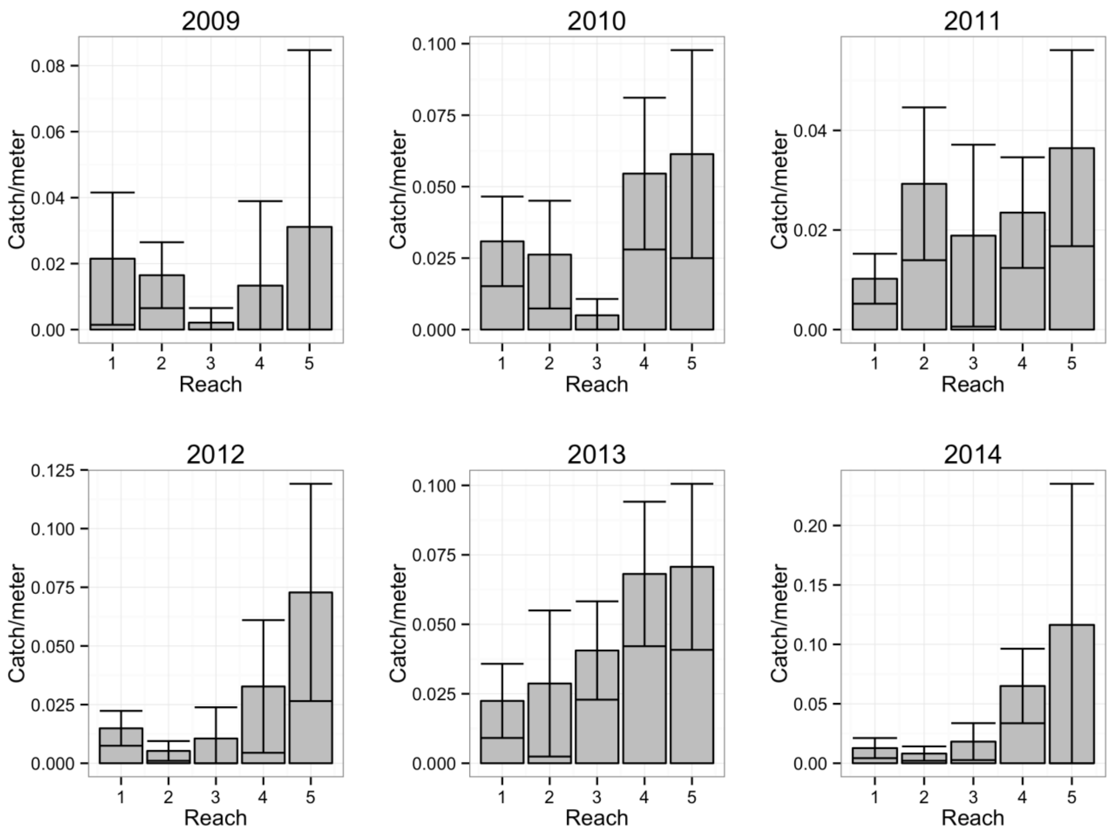


Figure 3.5. Con't.

f) Brohm River, all years combined

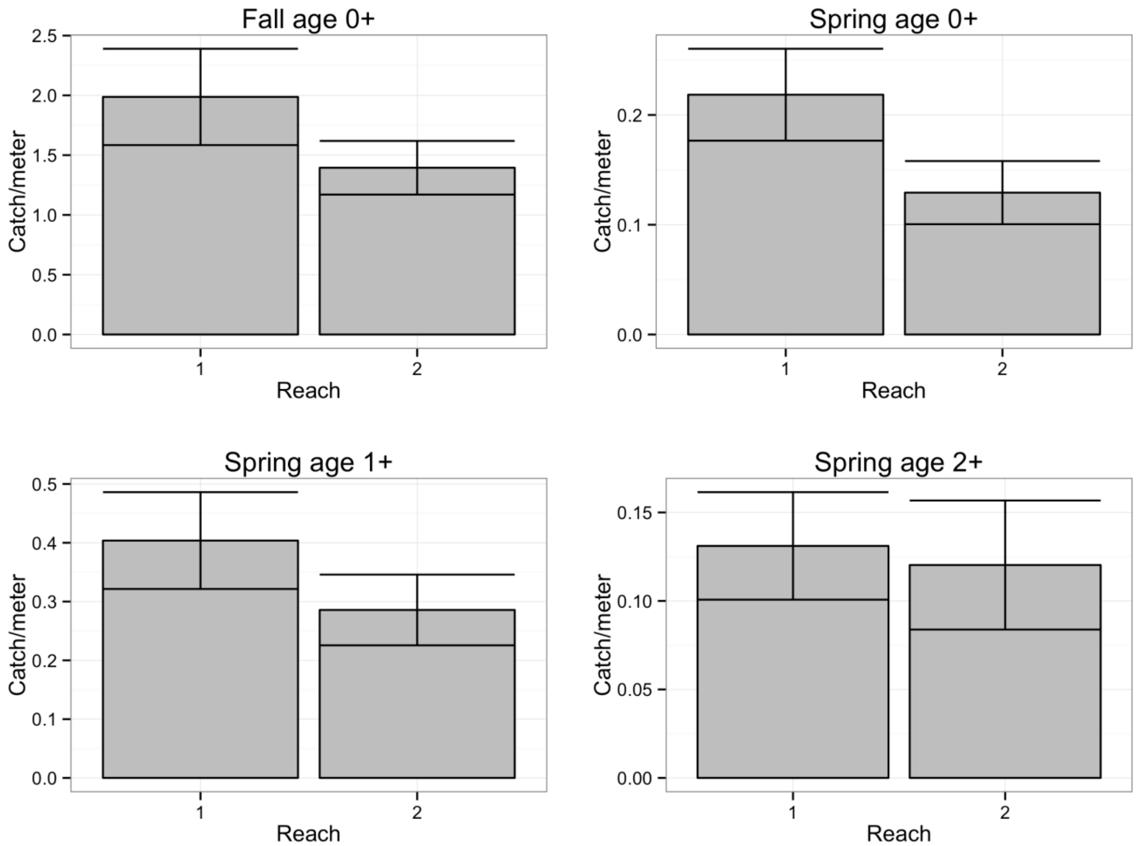


Figure 3.5. Con't.

g) Brohm River, Fall Age-0+

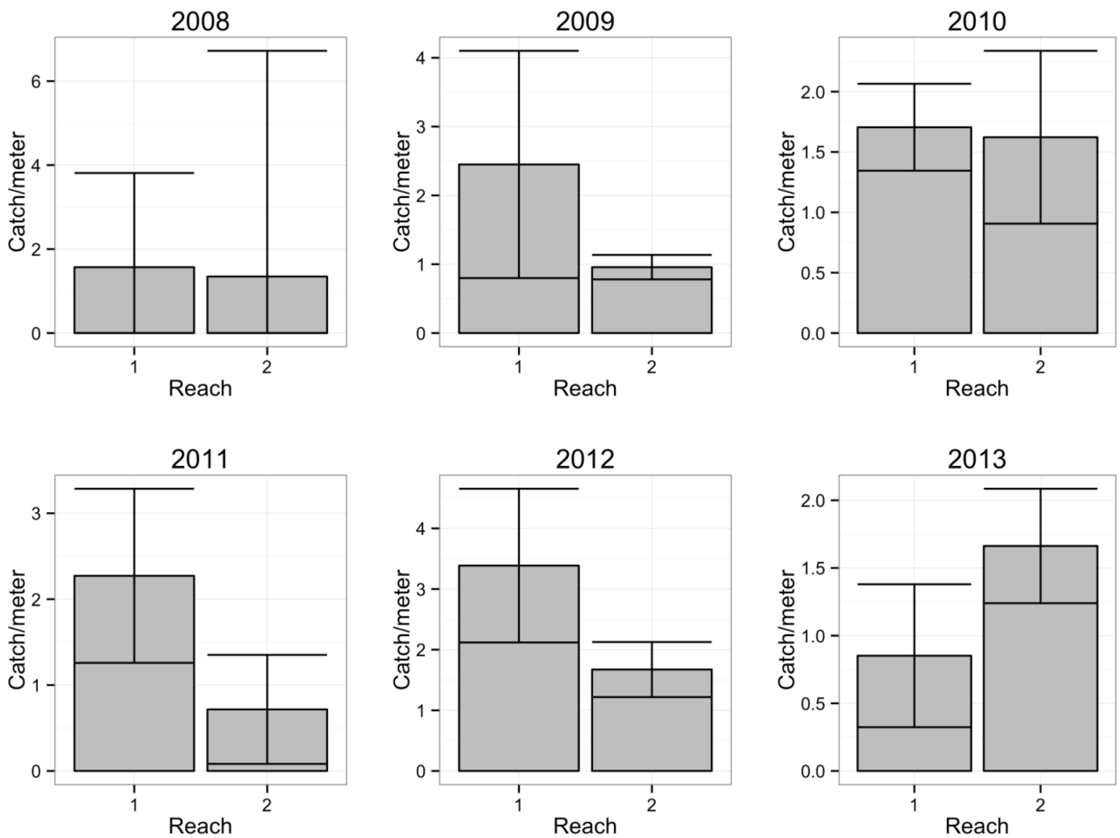


Figure 3.5. Con't.

h) **Brohm River, Spring Age-0+**

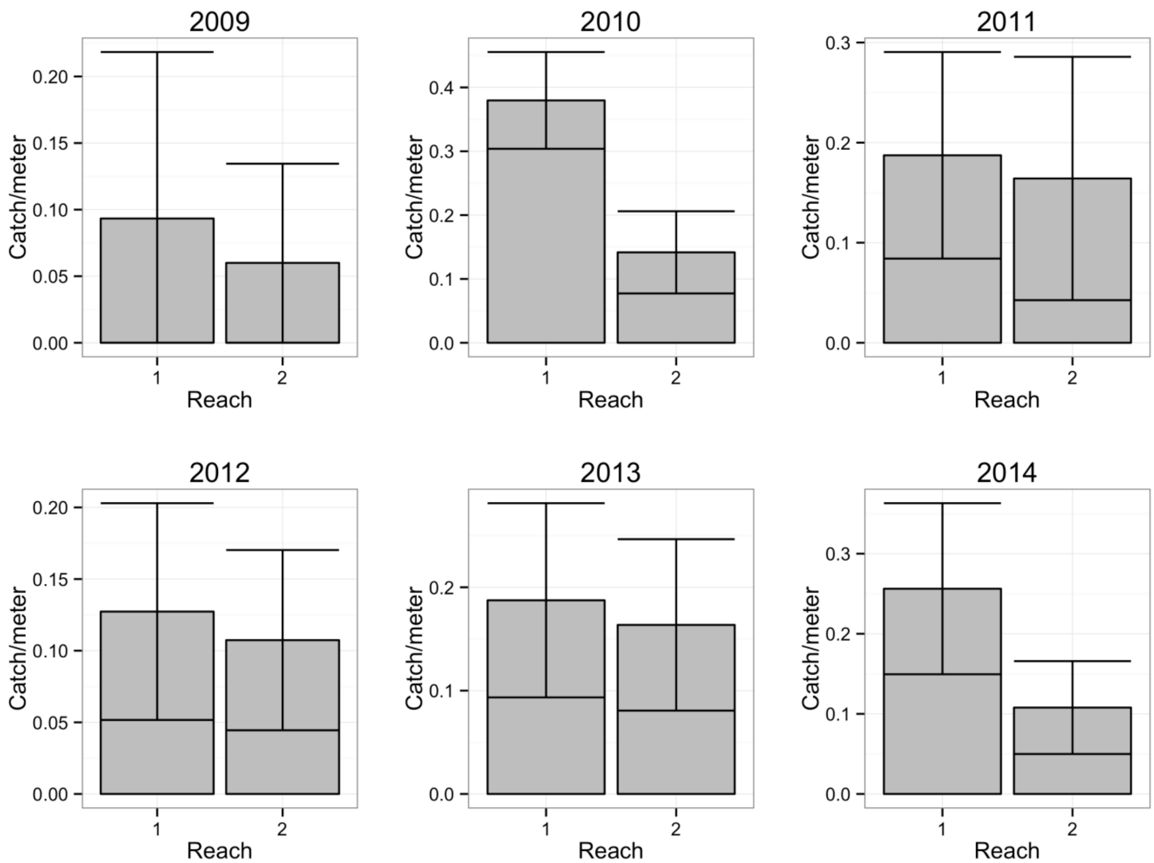


Figure 3.5. Con’t.

i) **Brohm River, Spring Age-1+**

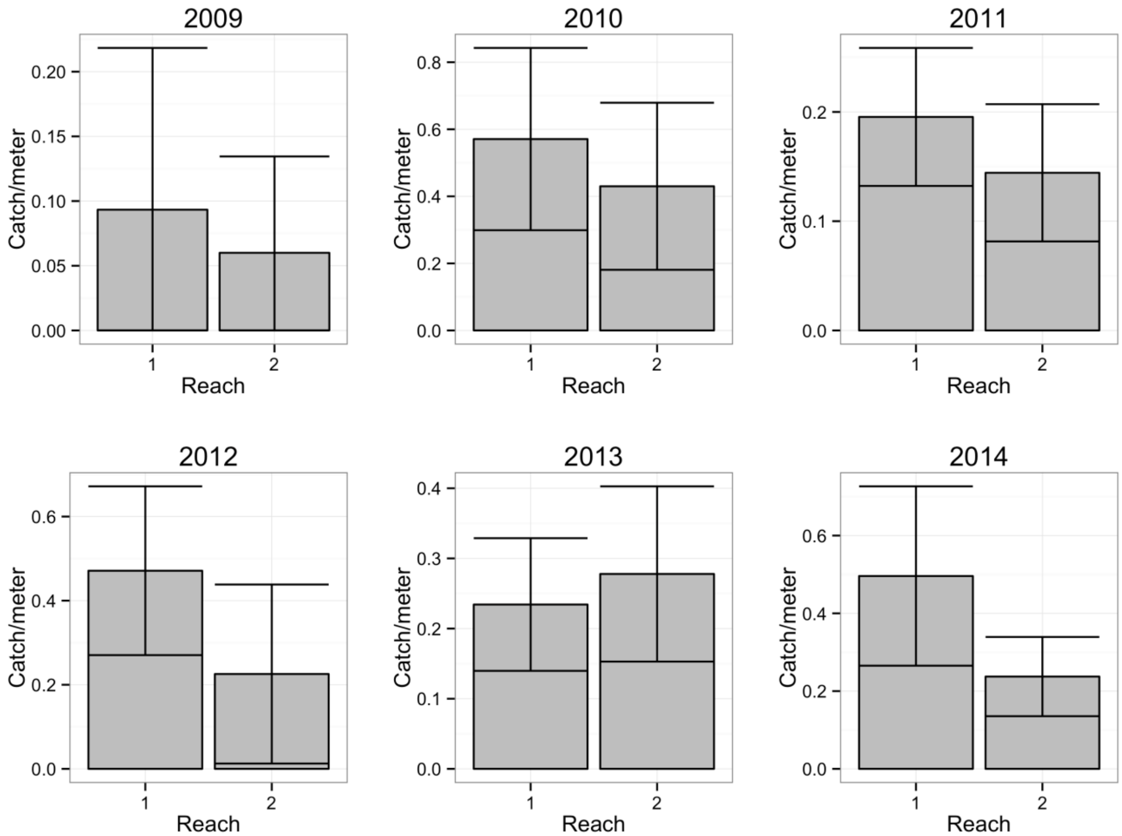


Figure 3.5. Con't.

j) Brohm River, Spring Age-2+

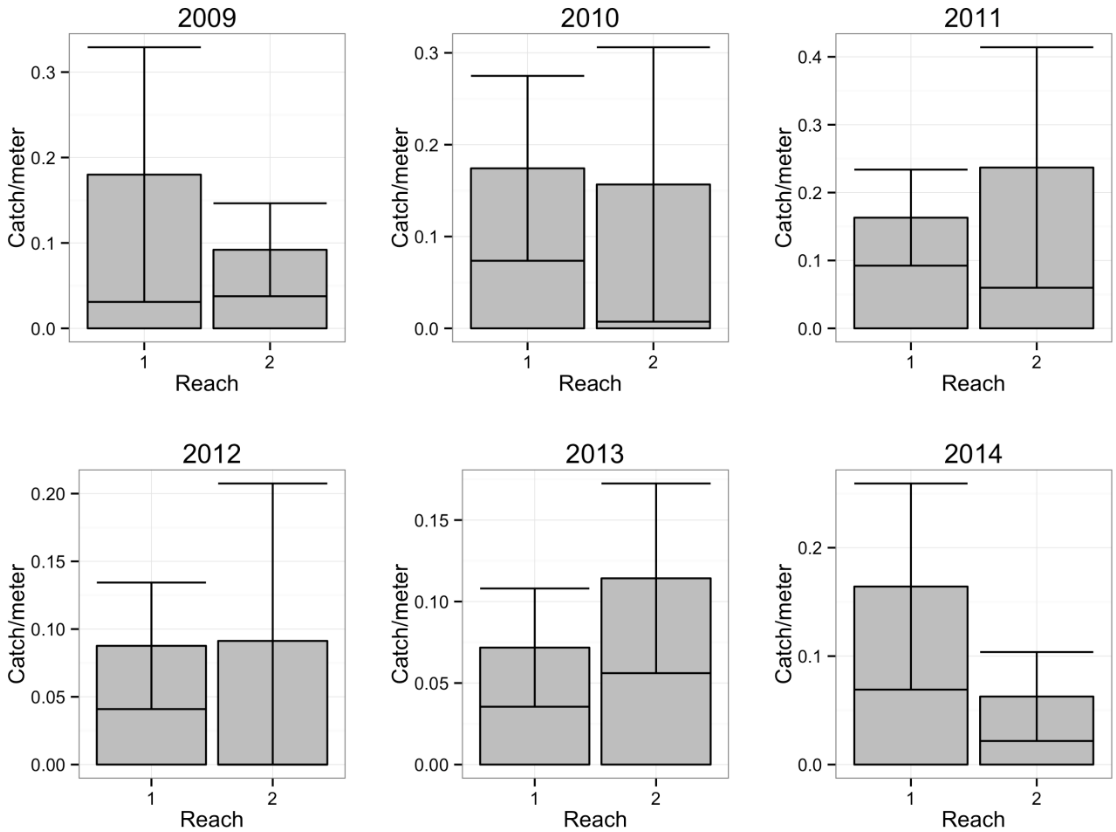


Figure 3.5. Con't.

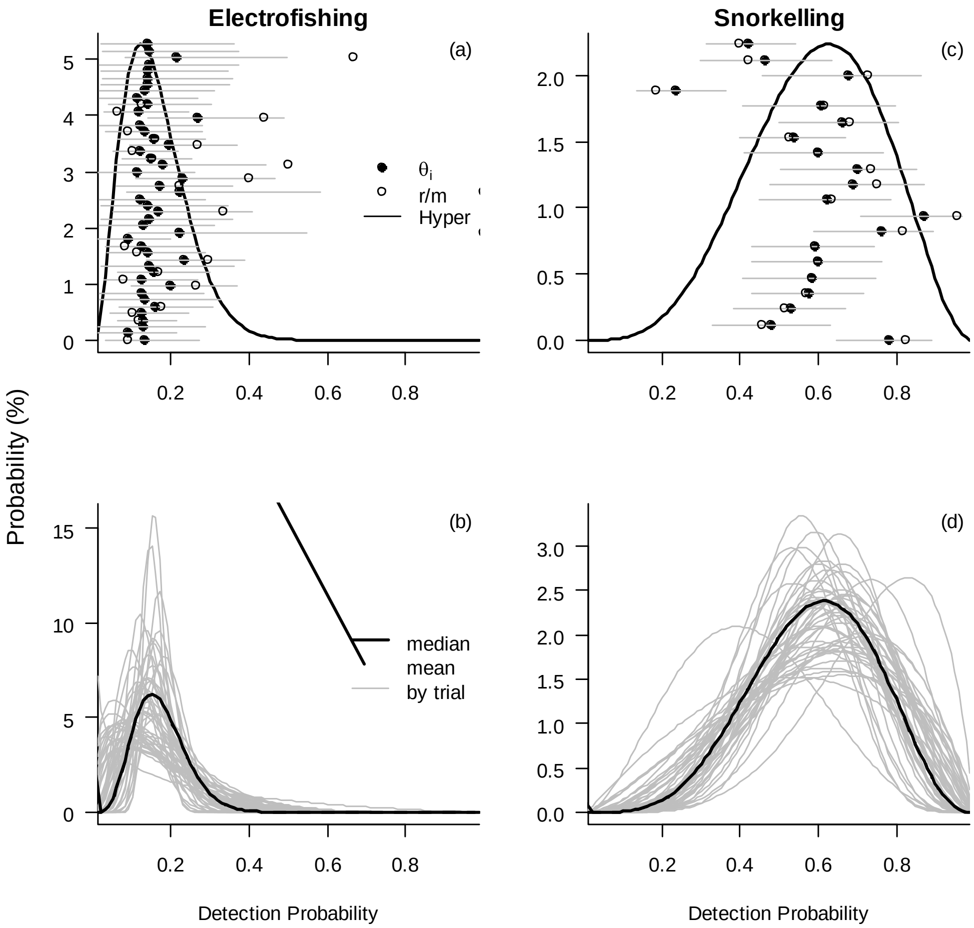


Figure 3.6. Graphical representation of output from the hierarchical Bayesian model that estimates juvenile Steelhead abundance showing results for age 1+ fish in the Cheakamus River in spring 2014. a) and c) show the median hyper-distribution for detection probability, the median estimates of site-specific 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 a) and c) is from earliest (lowest points on y-axis) to latest. 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.

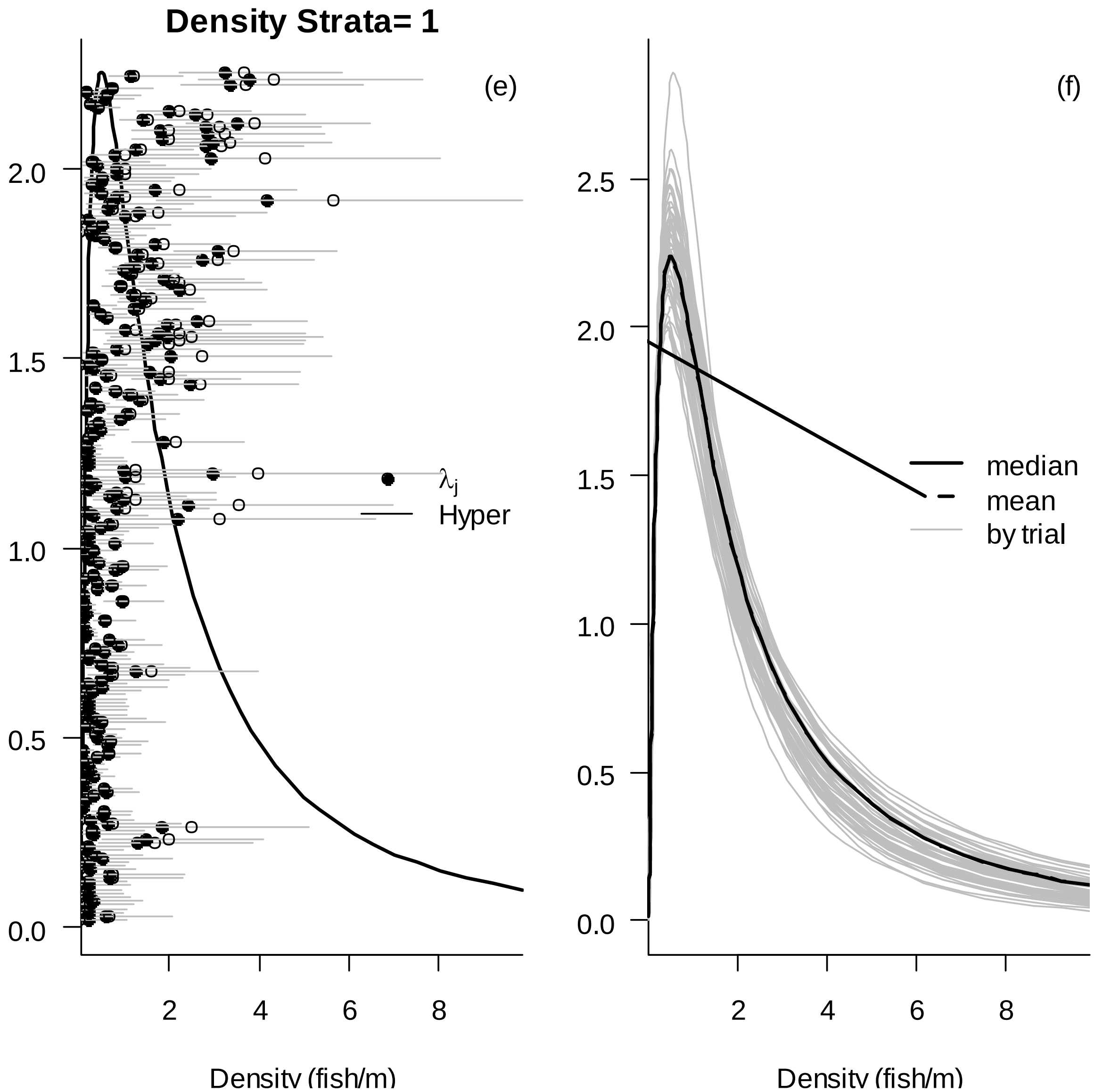


Figure 3.6. Con't.

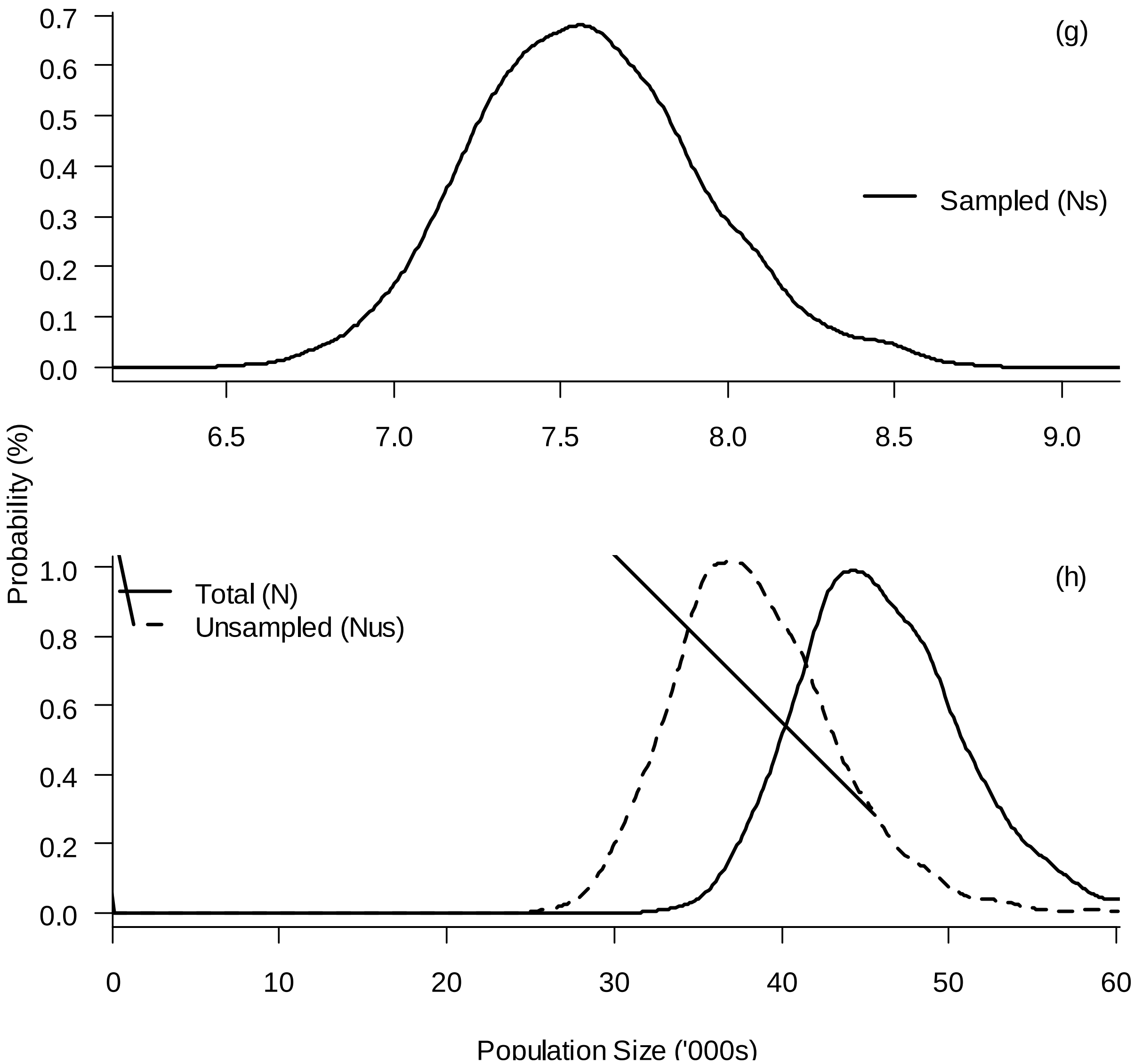


Figure 3.6. Con’t.

a) Cheakamus River

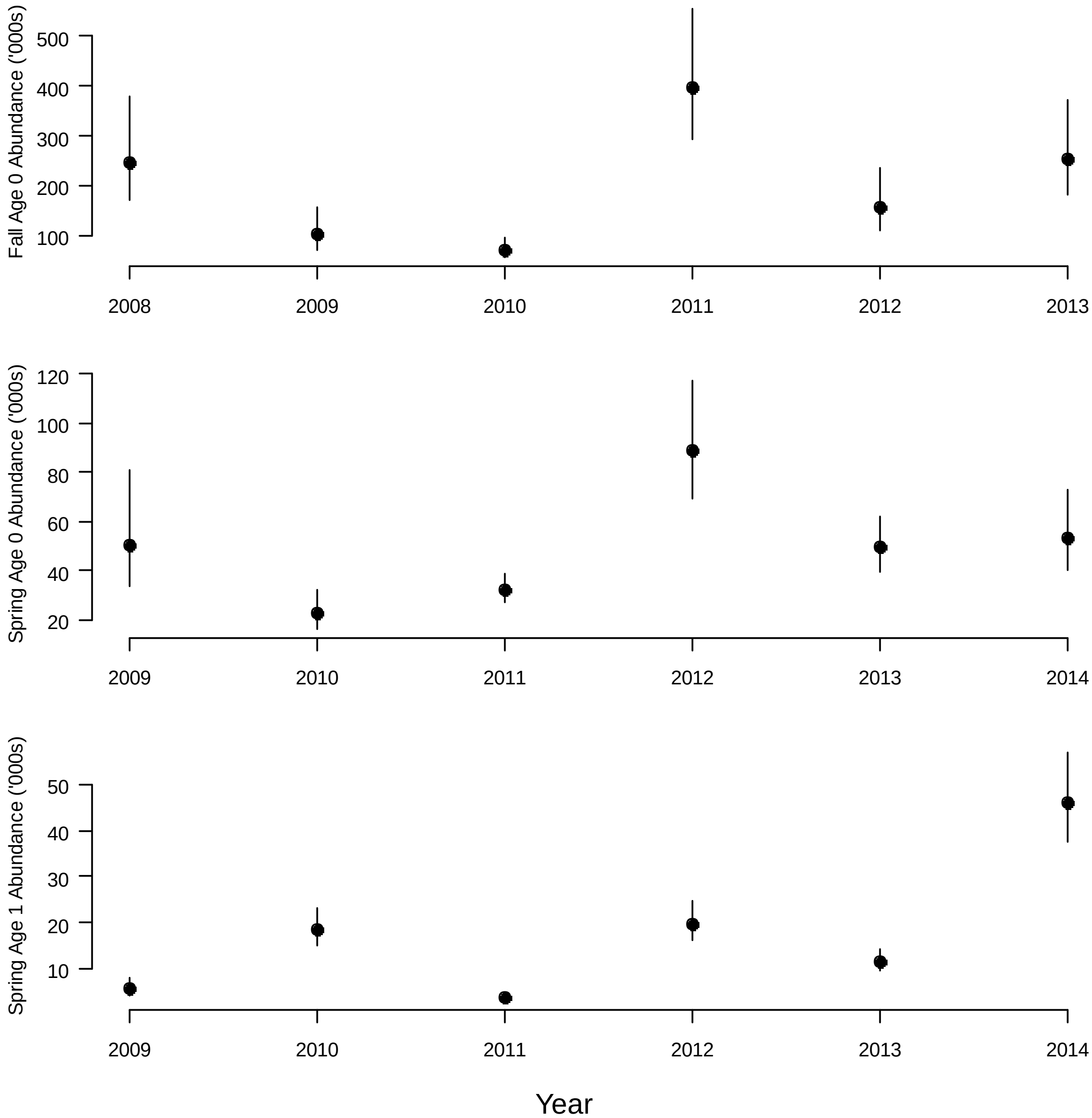


Figure 3.7. Juvenile steelhead abundance estimates in Cheakamus (a) and Brohm (b) Rivers. The height of bars and error bars represent median values and the 95% credible intervals from the HBM (see Table 3.12).

b) Brohm River

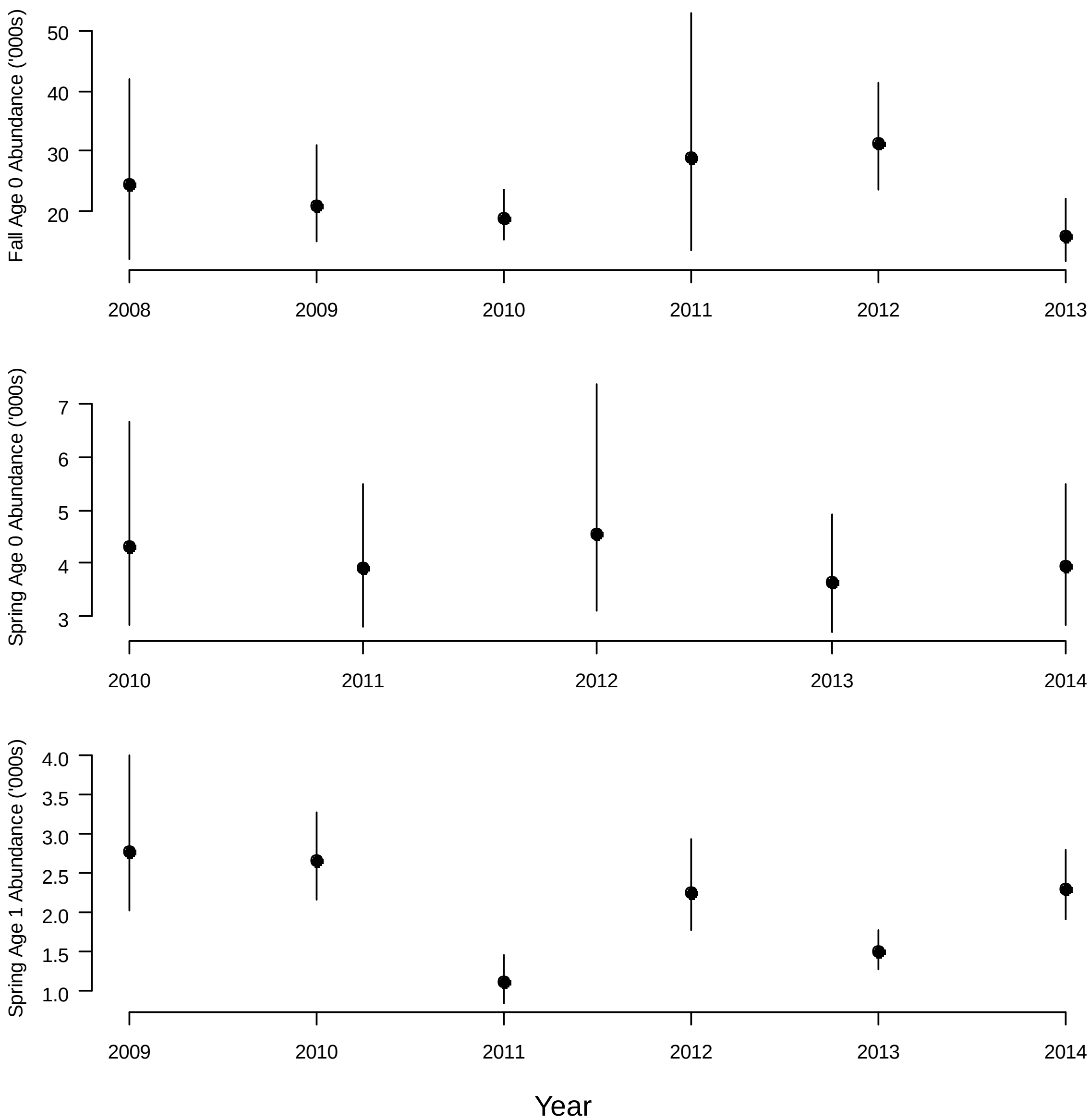


Figure 3.7. Con't.

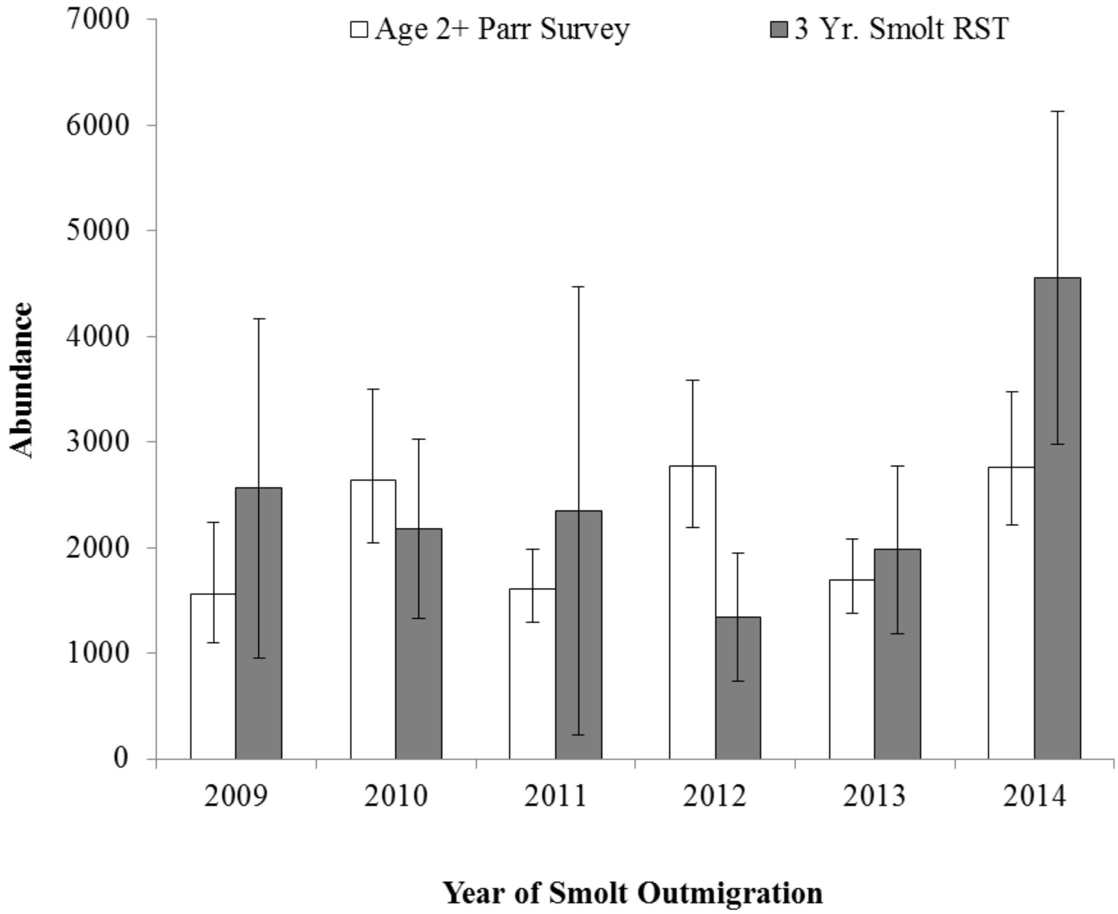


Figure 3.8. Comparison of abundance estimates of age 2 Steelhead parr in the Cheakamus River above the Rotary Screw Trap (RST) in 2009-2014 based on juvenile surveys (based on HBM results developed in this report) with abundance of 3 year smolts at the RST in the same year (based on the Bayesian spline non-diagonal model). Error bars denote 95% confidence limits.

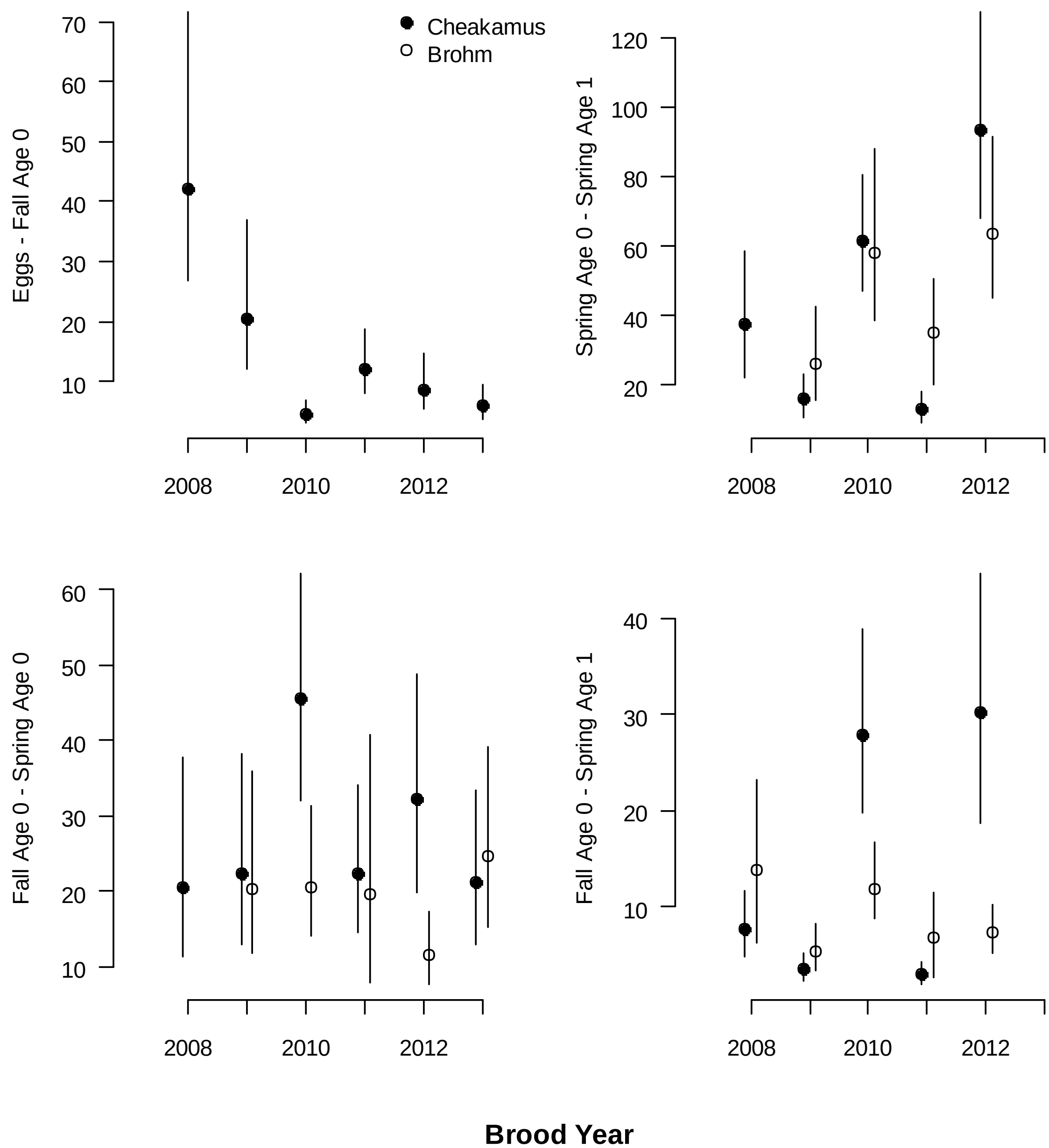


Figure 3.9. Survival by Steelhead life stage in Cheakamus and Brohm Rivers by brood year. Points and vertical lines denote means and 95% credible intervals, respectively.

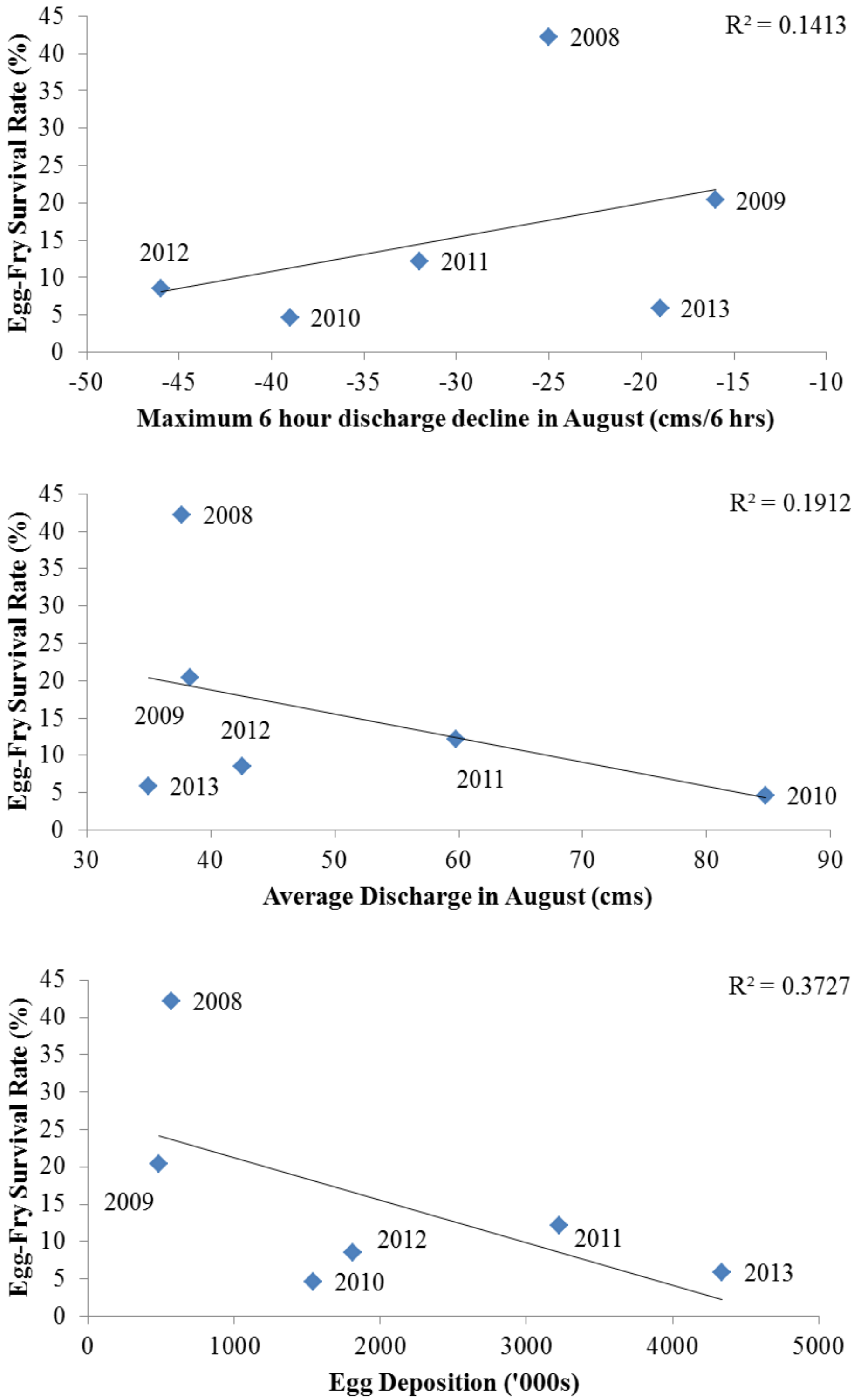


Figure 3.10. Relationship between Steelhead egg-fry survival rate in the Cheakamus River and the rate of discharge decline (top) and average discharge (middle) in August, and egg deposition the previous spring (bottom).