Cheakamus Project Water Use Plan

Project: Cheakamus River Steelhead Juvenile and Adult Abundance Monitoring – Data Report

Implementation Year 11

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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 support this population. A proportion of the Cheakamus River is diverted to the Squamish River for power generation. In 2006, BC Hydro received an Order from the BC Comptroller of Water Rights modifying rules controlling the timing and extent of the diversion, which affects the flow regime in the Cheakamus River downstream of Daisy Dam, 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 juvenile life 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 eleven of the project. It includes results on the 2018 escapement and on the juvenile abundance in spring and fall 2018. Results from year eleven are compared with estimates from previous years. The relationships between abundance and survival rates and discharge statistics are examined in the forthcoming steelhead summary report.

Adult Returns

Measurement of escapement of Steelhead to the Cheakamus River has been conducted annually since 1996 and is determined by combining data from repeat snorkel swim counts and radio telemetry. In 2018, only 7 swim surveys were conducted due to funding constraints. The estimated escapement in 2018 was 386 fish (CV=0.13) which was the lowest estimate for fish that reared in the Cheakamus River under WUP flows. The historical escapement trend for the Cheakamus River was segregated into four periods. Adult returns were low (average 170) in years when the juveniles that produced these returns reared in freshwater prior to the imposition of the Interim Flow Agreement (IFA, escapement from 1996-2001), and the average was more than twice as high after this period but prior to the sodium hydroxide spill (385, escapement from 2002-2007). Wild-origin escapement declined over two consecutive years for returns produced from juveniles that were present in the river during the spill (231, 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 that is 1.5-fold higher (592) than the average escapement over the IFA/pre-spill period (385). Interpretations for the causes for these changes are provided in the forthcoming steelhead summary report.

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 juvenile abundance and survival rates through time and to relate these patterns to spawning escapement and changes in flow or other factors, such as increasing escapement of pink salmon. 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 7% of the total useable shoreline length in the Cheakamus River in the spring and fall of 2018, respectively. Juvenile sampling in Brohm River was not conducted in 2018 owing to funding limitations. Median abundance of age-0+ Steelhead in the Cheakamus River in spring and fall 2018 was 79,400 (CV=0.16) and 178,400 (CV=0.14), respectively. Median abundance of age-1+ and -2+ Steelhead in the Cheakamus River in spring 2018 were 9,600 (CV=0.11) and 2,400 (CV=0.10), respectively.

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 29% for the 2008 spawning Cohort, to a low of 5% for the 2010 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. Lower apparent survival rates in Brohm River are likely indicative of downstream movement into the Cheakamus River. There is 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.

Steelhead juvenile surveys provide good precision in estimates of juvenile abundance and survival rates. These estimates will help evaluate effects of major changes in flow and other abiotic and biotic variables on freshwater Steelhead production. The average annual survival of parr (spring age-0+ to spring age-1+) in the Cheakamus River was 54% in even brood years (2008, 2010, 2012, 2014, 2016), compared to 19% in odd brood years (2009, 2011, 2013, 2015). Pink salmon return to the Cheakamus River in odd years, and escapements were elevated in 2009, 2011, and 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. Conclusions regarding effects of flow of escapement, juvenile abundance, and juvenile survival rates are presented in the forthcoming steelhead summary report.

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: Interim Flow Agreement and Interim Flow Order 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 Interim Flow Order (IFO) to BC Hydro in 1997. This order was subsequently modified to become an Interim 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. Discharge in the Cheakamus River is characterized by snowmelt floods during the spring freshet, moderate and declining flows through summer and early fall, and a long low flow period during late fall and winter punctuated by occasional large floods driven by rainfall events (Fig. 1.2). 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. 1.3). 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. 1.4). Flows into the Cheakamus River downstream of the dam have been greater in years when maintenance has occurred at the Powerhouse and when diversions were reduced (e.g., 2010 and 2011). Other operations during this period have occasionally led to sudden reductions in flow (e.g. drops in early and mid-August 2010 to help Chinook broodstock collection).

There was considerable debate during the Cheakamus River WUP process on the effects of flow regime on juvenile salmon and Steelhead production (Marmorek and Parnell 2002). Proponents of the IFA regime argued that both seasonal and daily elements of the hydrograph could be important to juvenile salmonid production and that higher flows would provide benefits in off-channel rearing areas that were not accounted for in the WUP fish habitat modeling efforts. Proponents of the WUP flow regime had more confidence in the fish habitat modeling results, which suggested that dam operations do not affect the quantity or quality of mainstem and side channel rearing areas except at very low flows (Fig. 1.5). 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 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 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 out-migrating 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. 1.6).

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. 1.6a). 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. 1.6b). 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. 1.6c). As data points accumulate (Fig. 1.7), 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. 1.6c).

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. 1.8). 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 results from the 11th year of the Cheakamus River WUP Steelhead monitoring project, covering the spring and fall sampling sessions in 2018 (Fig. 1.7). This report is divided into three chapters. Chapter two summarizes the adult escapement program conducted in winter and spring of 2018, and chapter three summarizes the results from the juvenile abundance program conducted in the spring and fall of 2018. Owing to the nature of how we compute juvenile and adult abundance estimates, this report includes data collected prior to the 2018. These data are reviewed with respect to how they influence the long-term time series as well as how they influence estimates in 2018. Unlike previous annual reports we do not include a discussion of results with respect to long-term trends or answers to WUP questions. This discussion and supporting analysis are presented in the steelhead summary report.

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 2018 as well as estimates of resident rainbow trout abundance. A synthesis of relevant physical data, other supporting information required to generate the 2018 escapement estimate, and counts of resident Rainbow Trout and char are also provided. We also provide the full time series of Steelhead escapement, resident rainbow trout abundance, and bull trout abundance estimates from 1996 to the present.

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. Owing to funding limitations, steelhead escapement estimates to Brohm River were not conducted in 2018. However, for continuity, we summarize previous estimates.

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

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 2018 only seven surveys were conducted (between March 12th and April 25th) due to funding limitations. Discharge in the Cheakamus at Brackendale was low and stable throughout most of March and April which facilitated swim surveys (Fig. 2.1). As in other years, a large and prolonged freshet beginning in late April (shortly after the last survey) precluded our ability to conduct surveys after this date 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 returning adults. Sex was determined based on external characteristics. Freshwater and ocean ages were estimated by scale reading. Approximately five scales from each fish were collected from the preferred area above the lateral line and immediately below the dorsal fin. Samples were placed in coin envelopes marked with appropriate data for cross-reference. After a period of air-drying, scales 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.

We re-analyzed scales from earlier years using multiple age-readers to determine if age estimates have been consistent among years. The proportion of freshwater age 3 yr and ocean age 3 yr steelhead has been increasing in recent years and we were concerned that this could be an artefact of bias in age estimates, rather than a true change in age structure. Results from this study indicate that age estimates were consistent across years. Results from this study are presented in appendix A.1.

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 ten (2000, 2001, 2003-2005, 2009-2011, 2016-2017) of 22 years that the swim surveys have been conducted (1996-2018, 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). A hierarchical Bayesian analysis indicated that separate constants for p-HV/Q relationship should be estimated for each telemetry year, but the data support a single estimate of the slope across all years (appendix A2). In the escapement estimation model we use annual parameters of the p-HV/Q relationship in years radio telemetry was conducted, and the mean of the hyper-distribution for the constant (describing the mean and variation across telemetry years) for outlying years. 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.

Escapements, run-timing and other parameters for all years are estimated jointly since they share information on departure timing, survey life, and detection probability from years when telemetry was conducted to derive estimates of the number of wild-origin fish from 1996-2018 and hatchery-origin fish from 2009-2011, a total of 92 parameters are estimated. This includes 22 estimates of wild escapement, 22 x 2 wild arrival-timing parameters, 3 escapements for years when hatchery fish returned, and 3 x 2 hatchery arrival-timing parameters, a mean constant and slope for the logistic p-HV/Q relationship as well as 10 annual deviates for the constant for each telemetry year and the standard deviation of these deviates (13 parameters), 3 parameters describing the relationship between survey life and date of entry, and one parameter predicting the extent of overdispersion in the data used in the fitting.

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 asymptotic standard errors estimated from the Hessian matrix.

2.2.4 Steehead Redd Counts in Brohm River

We used a visual count of Steelhead redds, or egg nests, to estimate escapement in Brohm River between 2010 and 2017. 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).

Between 2010 and 2018, about five surveys were conducted each spring at roughly two-week interval over the entire 2.4 km of Brohm River that is accessible to Steelhead. 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).

2.2.5 Resident Rainbow Trout Abundance

We used swim counts combined with radio telemetry data collected in 2016 and 2017 to estimate annual abundance of resident rainbow trout in the Cheakamus River in the spring between 1996 and 2018. Radio-tagged resident trout were given different colored external tags in 2016 and 2017, and only tags placed in the same year that the fish were counted in were used in the analysis. In 2017, tags placed in 2016 could have fallen off or would be more difficult to see due to the accumulation of algae. As for steelhead, the radio tags allowed us to determine how many tagged resident trout were in the swim area during each survey. The abundance estimation model assumes no resident rainbow trout leave the swim area during the survey period. This was confirmed through the radio tracks which showed that none of the 51 effectively tagged resident trout left the survey area prior to the last swim dates in 2016 and 2017. As a result, the estimation model was very simple.

We estimated abundance for each year swims were conducted. Detection probability for resident trout was very high and not sensitive to river conditions. As a result we estimated detection probability from all swims when tags were present, and expanded the number of residents counted on each swim to determine the number present. These values were then used to estimate the abundance, which was effectively a weighted-average of swims-specific abundance estimates. The weight was essentially determined by how many fish were seen and the detection probability on that swim. As for the steelhead model, detection probability on each swim is assumed to be drawn from a hyper-distribution whose mean and variance is estimated using data from all swims when tags were present. The expansion of counts for each swim depends on that swims detection probability if tags were present, or a random draw from the detection probability hyper-distribution if none were present. And swim-specific detection estimates when tags were present could be heavily affected by the mean if few tags were present. The model was implemented in WinBUGS. Commented source code for the model is presented in appendix A3.

2.3 Results and Discussion

2.3.1 Swim Counts and Creel Survey

Discharge in the Cheakamus River during the swim survey period was generally low and stable providing relatively high detection probabilities (Fig. 2.1). Due to high flows or turbidity, there were no opportunity to conduct surveys after April 25th, which limited our ability to estimate the abundance of spawners entering late in the migration period. Observer efficiency is correlated with the ratio of horizontal visibility to discharge, with higher efficiency when the river is clear and discharge is low. Discharge and horizontal visibility in 2018 were similar to other years (Fig. 2.2). Counts of steelhead, resident rainbow trout and char for the 2018 surveys are shown in Table 2.3.

2.3.2 Age structure

Volunteers sampled a total of 29 adult resident rainbow trout or steelhead for length, sex, and age in 2018 (Table 2.4). Based on the scale patterns, 12 and 17 of these fish were designated as resident rainbow trout and steelhead, respectively. Males were slightly more prevalent than females in 2018 though differences could be driven solely by sampling error. The average size of resident rainbow trout and steelhead was 30 cm larger for males, and residents were considerably smaller than steelhead. Resident trout were rarely larger than 60 cm while steelhead were rarely smaller than this size (Fig. 2.3). The overlap in the size distributions of resident rainbow trout and steelhead leads to some uncertainty in their classification during swim surveys, as other distinguishing characteristics can be difficult to determine for fish that are only very briefly seen due to their flight response.

Freshwater and ocean ages could be determined for 16 and 14 Steelhead sampled in 2018, respectively (Table 2.5a and b). The percentage of steelhead returning in 2018 that left the river as age 2 and 3 yr. smolts was 44% and 56%, respectively. These proportions are similar to those seen in 2005 and from 2011-2015. Returns were dominated by age 3 smolts in 2016 and 2017. Ocean age 3 yr. fish are considerably larger than age 2 yr. fish, but size differences can vary considerably (Fig. 2.4). There has been an increase in the proportion of ocean age 3 yr. fish beginning in 2011, but ocean age 2 and 3 yr. proportions in 2018 were similar to proportions prior to 2011 (Fig. 2.5). Total age could be determined for 14 of the steelhead sampled in 2018 and consisted of 21%, 50%, and 29% age 4, 5, and 6 yr. fish (Table 2.5c). Only six resident rainbow trout could be reliably aged in 2018 (Table 2.6). Mean size of rainbow trout increased from an average of 294 mm at age 3 yrs. to 635 mm at age 8.

2.3.3 Escapement Estimates

Steelhead escapement estimates for years reported in 2016 and earlier summaries have been revised owing to a significant change in the escapement model. Recall that annual escapement estimates depend on telemetry data collected over ten years (Table 2.7), which includes information on detection probability (Fig. 2.6), survey life (Fig. 2.7) and departure timing (Fig. 2.8). Previously reported escapement estimates were based on applying one of two different p-HV/Q detection relationships. Telemetry data from 2000-2005 indicated higher detection probability for a given HV/Q ratio compared to data collected in 2009-2011 (Fig. 2.6). Based on this information previous escapement estimates collected in years prior to 2009 (with or without telemetry data) were expanded using a relationship calculated from the 2000-2005 data, while counts from years from 2009 to 2016 were expanded using telemetry data from 2009-2011. We re-analyzed that data with the inclusion of the most recent telemetry information using a hierarchical Bayesian model. This model allowed the constant of the p-HV/Q function to vary by telemetry year but not the slope as there was little evidence annual variation for the slope in the data (see Appendix A2). Telemetry data in 2016 and 2017 did not indicate reduced detection probability for a given HV/Q level as seen in 2009-2011. It was therefore logical to use parameters of the average relationship (as determined by the hyper-distribution of p-HV/Q parameters) to expand counts in all years when telemetry years were not conducted, rather than data from specific groups of telemetry years as previously done. As the average relationship indicates higher detection for a given HV/Q level compared to the 2009-2011 data grouping, this resulted in reducing escapement estimates from 2012-2016 that have been previously reported. See Appendix A2 for additional details.

Steelhead escapement for 2018 was based on only seven surveys and did not include swims after April 25th (Table 2.3). Reduced effort in 2018 due to funding limitations lead to a 30% reduction in effort (on average 10.3 swims were conducted per year from 1996-2017). The expected value for wild escapement to the Cheakamus River in 2018 was 386 and uncertainty was slightly higher due to reduced sampling effort (CV=0.13, Table 2.8). Peak arrival occurred in early- to mid-April (Fig. 2.9a) similar to other years, and expanded counts continued to rise through the survey period (Fig. 2.9b). Due to this latter pattern, the 2018 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 beta distributions used to model arrival and departure time resulted in a numbers-present vs. time relationship that was unable to capture elevated estimates of abundance on the last two swims. The parametric formulation of the model is not flexible enough to capture sudden increases in the number of arrivals. This likely results in an underestimate of escapement in 2018.

The model provided good fits to telemetry-based patterns in departure timing (Fig. 2.9c) and survey life (Fig. 2.9d). Average detection probability across surveys, as estimated from the ratio of horizontal visibility to discharge (HV/Q) was approximately 0.3 which is similar or slightly higher than in most other years (Fig. 2.9e). Year-specific p-HV/Q relationships and the mean relationship across years, which was used to expand counts in 2018, are shown in Figure 2.9f.

The historical escapement trend for the Cheakamus River can be segregated into four periods (Fig. 2.10, Table 2.8). Adult returns were low (average 170) in years when the juveniles that produced these returns reared in freshwater prior to the imposition of the Interim Flow Agreement (IFA, escapement from 1996-2001), and the average was more than twice as high after this but prior to the sodium hydroxide spill (385, escapement from 2002-2007). This difference was statistically significant ($p=0.002$). Wild-origin escapement declined over two consecutive years for returns produced from juveniles that were present in the river during the spill (231, escapement in 2008, 2009). This decline was not statistically significant ($p=0.063$). The average escapement since

2010, which was produced from juveniles which have reared in the river under WUP flows, is 1.5-fold higher (592) than during IFA pre-spill period and the difference is statistically significant (p=0.009).

2.3.4 Steelhead Redd Counts in Brohm River

A summary of red counts and escapement estimates between 2010 and 2017 are presented in Table 2.9 and Figure 2.11. The estimated number of spawners in Brohm River based on the product of the total escapement to the Cheakamus River and telemetry-based Brohm migration rates are also shown, and are close to estimates based on redd counts.

2.3.5 Resident Rainbow Trout Abundance and Movement

We radio tagged 33 and 19 resident rainbow trout in 2016 and 2017, respectively (Table 2.10). 51 of the 52 fish were effectively tagged. One fish died shortly after tagging and was recovered during a swim survey. 10 of the 51 fish (20%) were detected in the Squamish system between the confluence of the Cheakamus and Squamish Rivers and the start of the spit downstream of the Mamquam confluence. However all movement to the Squamish occurred outside of our swim survey period, and no fish from the survey area moved in the lower Cheakamus River (downstream of the Cheekye confluence below our survey area) during the swim survey period between late February and early May.

Detection probability for resident rainbow trout was high with an average of 0.4 across 23 swims surveys with tags present in 2016 and 2017 (Fig. 2.12). Surprisingly detection probability was not dependent on river conditions (horizontal visibility or discharge), likely because the range of these conditions was not great enough to see an effect for this more detectable morph. Detection probability of resident rainbow trout was almost 2-fold higher than for steelhead and much more consistent across river conditions.

Over the 21-year index period, resident rainbow trout abundance ranged from almost zero (1999) to a peak of 329 fish (2016) with a mean of 83. Based on angled fish, the minimum age of fish that we count during swim surveys is likely four yrs. old. Using this value, the mean escapement during the pre-IFA period (1996-2001) was 14 fish, compared to 68 fish that reared in the Cheakamus under the IFA regime prior to the spill

(2002-2005). This 5-fold increase was statistically significant (p=0.003). Average abundance of resident fish that reared under WUP flows (2010-2018) was 147. This 2.2-fold increase relative to the IFA pre-spill average was statistically significant (p=0.031). The rainbow trout abundance model generally fit the data pretty well. Recall that we assume that abundance cannot change over the survey period within each year because the radio telemetry data did not indicate that fish left the survey area during the survey period. To check this, we plotted the predicted abundance on each survey relative to the conditional abundance (Fig. 2.13), which was simply the count expanded by the detection probability drawn from the hyper-distribution for that survey (see appendix A3). Generally, the conditional abundance estimates fell with the 95% credible intervals for model predictions on each survey. There were however a few concerning exceptions. For example, in 2003 conditional abundance estimates are initially low and less than the 95% credible intervals, and then rise steeply and eventually exceed the 95% intervals. This suggests that there is either decrease detection probability over the survey period (resulting in larger expansions of count data) or that the population is not closed and resident trout are entering the survey area. Similar patterns are also seen in 2010 and 2011. Either of these scenarios suggests that the model may be underestimating abundance in some years. Additional radio telemetry data would help resolve this uncertainty.

2.3.6 Bull Trout Abundance

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 abundance has averaged 224 fish between 1996 and 2018 with minimum and maximum values of 75 and 447 fish, respectively (Fig. 2.15).

3.0 Juvenile Steelhead Abundance

3.1 Introduction

This section summarizes the methods and results from Steelhead juvenile abundance surveys conducted in Cheakamus River in the spring and fall of 2018. Owing to funding limitations juvenile surveys of Brohm River were not conducted in 2018. This section of the report also provides 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. 1.6b). The evaluation of habitat effects includes assessing potential benefits and impacts of the 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. 1.6c). 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 (seven years) are now available (Fig. 1.7). 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). In this chapter, we report on the results from surveys conducted in year 11. 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 potentially be updated to reflect additional mark-recapture data collected in the most recent year. Estimates from earlier surveys have not changed since the fall 2013-spring 2014 report as no additional mark-recapture work has been completed since spring 2014.

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 fish 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 80 and 112 index sites were sampled in the Cheakamus River in the spring of 2018 using electrofishing (EF) and snorkeling (SN), respectively (Table 3.1). A total of 107 index sites were electrofished in fall 2018 in the Cheakamus Rivers. Owing to funding limitations juvenile sampling in Brohm River was not conducted in 2018. 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 146 and 163 juvenile Rainbow Trout from the Cheakamus River in spring and fall of 2018, 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.

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 2009-2017 determined from the HBM with the estimated number of smolts passing the Rotary Screw Trap (RST) at ages 2 and 3 years, respectively. The analysis could not be extended into 2018 owing to reduced effort from the Rotary Screw

Trap. That program does not extend into April and May and can therefore no longer provides estimates of coho or steelhead smolt abundance. 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 7% of the useable shoreline length of the Cheakamus River during the spring and fall 2018 surveys, respectively (Table 3.1). Flows were generally very near base flow levels of 20 m^3/sec during the juvenile surveys (Fig. 3.2). Results from scale ageing (Table 3.4) were used to assign maximum lengths for age 0+, and 1+ year old Steelhead. Maximum lengths for age 0+ and 1+ year old Steelhead in spring 2018 were 94 and 124 mm, respectively. 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 spring sample. Age-length cutoffs in Brohm River from past years are also presented in Table 3.4.

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 58, 93, and 134 mm in Brohm River, and 55, 97, and 135 mm in Cheakamus River, respectively. On average in the Cheakamus River, age 0+ fish only grow about 13 mm from fall (average 55 mm) to the following spring (68 mm). There was also very little growth for age 0+ fish in Brohm River over this same period (about 9 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 mm). As for age 0+ fish, there is very limited growth between fall and spring survey periods for age 1+ fish in both rivers (~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 is 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 4,314 juvenile Steelhead were captured or counted at index sites on the Cheakamus River in the spring of 2018 (Table 3.6). A total of 3,495 juvenile steelhead were captured in the fall of 2018. 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 in abundance.
5. Exceptionally high abundance of age-1+ parr in the Cheakamus River on the spring 2014 survey seen in both electrofishing and snorkel surveys.
6. High abundance of age-0+ fry in fall of 2017 in the Cheakamus River.

No snorkeling mark-recapture experiments have been conducted since the fall of 2016 owing to the already large sample size (Table 3.8). 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).

3.3.3 Estimates of Juvenile Steelhead Abundance from the Hierarchical Bayesian Model

Sampling effort was sufficient in spring and fall of 2018 to provide 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 2018) is shown in Figure 3.5. 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. 3.5a and b). Detection probability for snorkeling is approximately 3-fold higher (Fig. 3.5c 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. 3.5e), resulting in a fish density distribution with a long right-hand tail (Fig. 3.5f). Due to the large number of index sites, the total estimate of abundance across the sampled sites was relatively precise (Fig. 3.5g) 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. 3.5h).

Total abundance estimates in 2018 were relatively precise with an average CV across rivers, seasons, and age classes of 0.15 (Table 3.11). 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 9,700 with a CV of 0.11. 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 3.11, Fig. 3.6). 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 were above average.

A strong cohort from 2011 in the Cheakamus River was seen by high age-0+ abundance in the fall of 2011 and high age-0+ abundance in spring of 2012 (Fig. 3.6a). Spring age-1+ and age-2+ abundance estimates showed a consistent alternating pattern with low abundance in odd years and high abundance in even years, though this pattern has broken down in the last few years. As shown below, this pattern is driven by higher survival rates associated with greater food supply due to pink salmon returns in odd years (which have been low since 2015). 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 2008-2016 Steelhead cohorts (fish from the spawn in 2008-2013) by combining estimates across strata (Table 3.12). As an example, the 2008 Cohort from the Cheakamus River declined from an estimated egg deposition of 814 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 29%, 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 15-46% 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, 2014), 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 22-63%. 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 0.4-3.6% in the Cheakamus, compared to 0.2%-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 2009-2017 were compared to estimates of 3 year smolt abundance at the RST. On average, juvenile survey-based estimates 14% lower than RST-based estimates. (Table 3.13). 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. 3.7).

Survival estimates between juvenile life stages and uncertainty in estimates are provided in Fig. 3.8. Egg-fry survival rate in the Cheakamus River was exceptionally low for the 2010 brood year and also low for later brood years 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 2012 brood years. Overwinter survival rate of age-0 steelhead in the Cheakamus was the lowest on record between fall 2014 and spring 2015. This could be the result of higher mortality associated with frequent and high floods in late 2014 and early 2015 (Fig. 1.2). Annual survival of parr (spring age-0+ to spring age-1+) in the Cheakamus River was higher in even brood years (2008, 2010, 2012, 2014, 2016) with an average of 54%, approximately 4-fold higher than the average survival for odd brood years (19%). Pink salmon return to the Cheakamus River in odd years, and escapements were high in 2009, 2011, and 2013, leading to very high parr survival rates for brood years 2010, 2012, and 2014. As juvenile steelhead feed on salmon eggs and carcasses, it is likely that improved condition of parr prior to winter in these high pink escapement years owing to the large increase in food supply, led to greater overwinter survival.

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 2009-2017 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 (average of 23%). 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.

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5.0 Tables and Figures

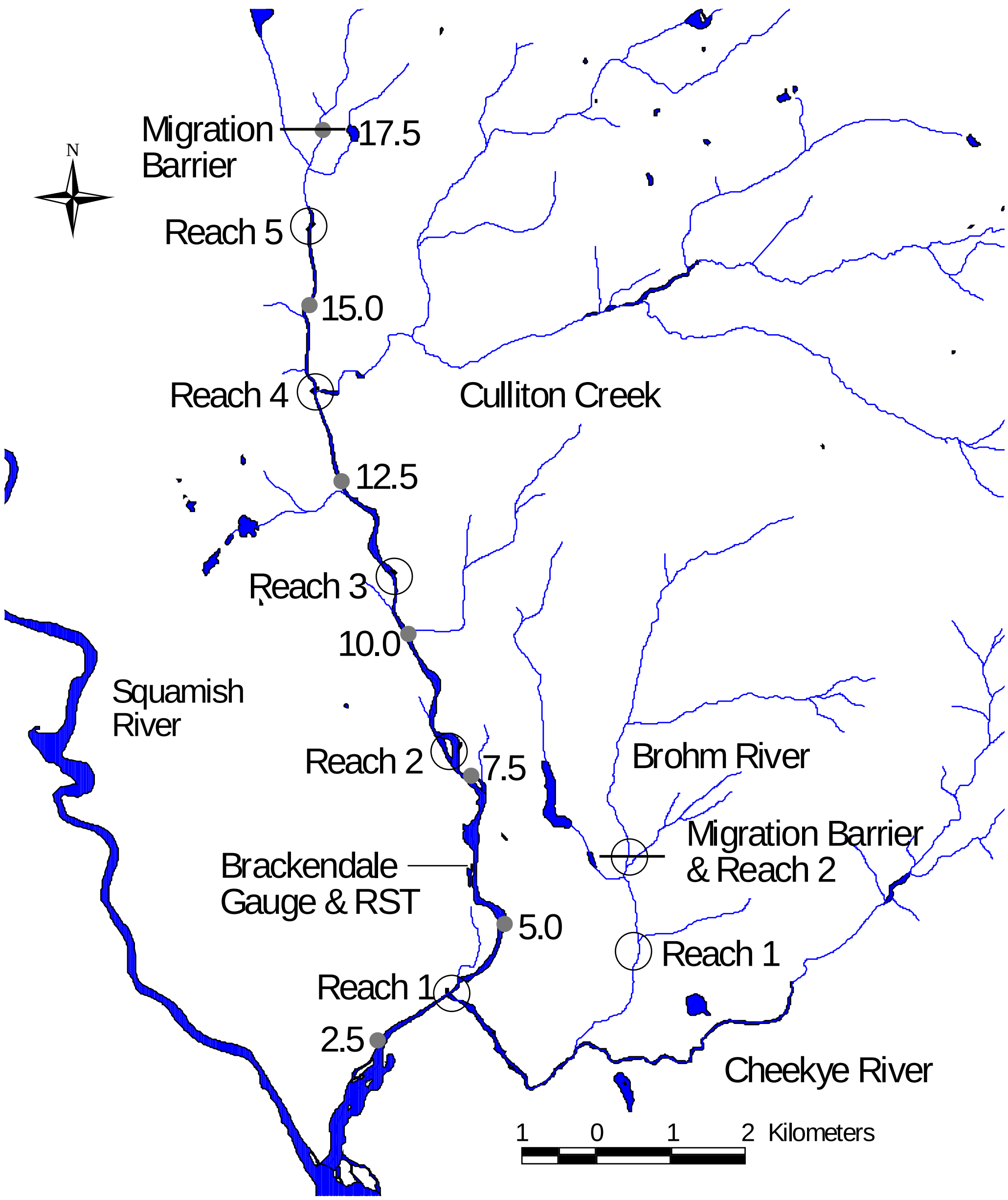


Figure 1.1. Map of the Cheakamus River study area showing the locations of the upstream limit of reach breaks used for habitat and juvenile surveys (open circles), distance (km) from the Squamish River confluence (gray points), migration barriers for anadromous fish in the Cheakamus and Brohm Rivers,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

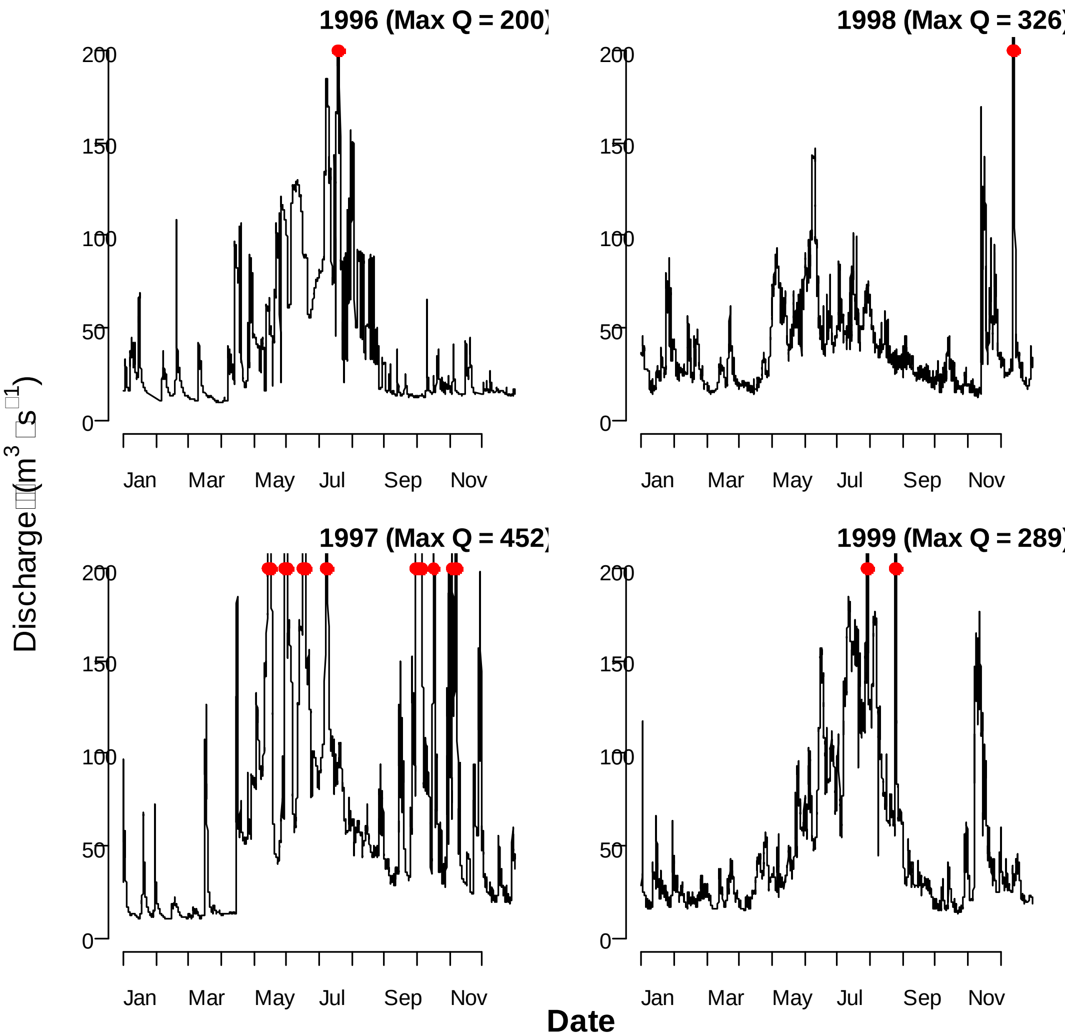
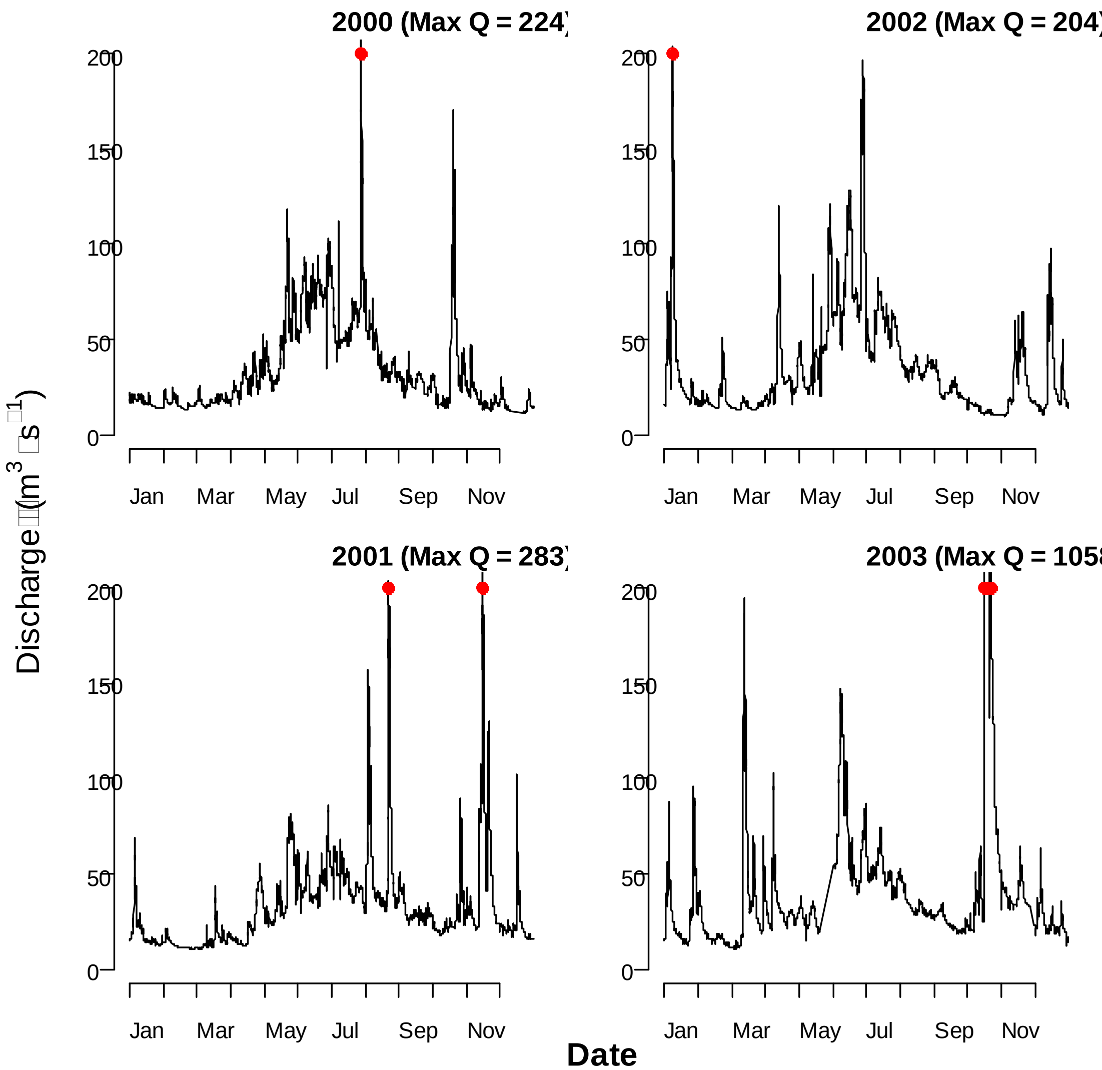


Figure 1.2. Hourly discharge at the WSC Brackendale gauge 1996-2018. Red points denote hours when discharge exceeded the y-axis maxima of 200 $m^3 \cdot sec^{-1}$.



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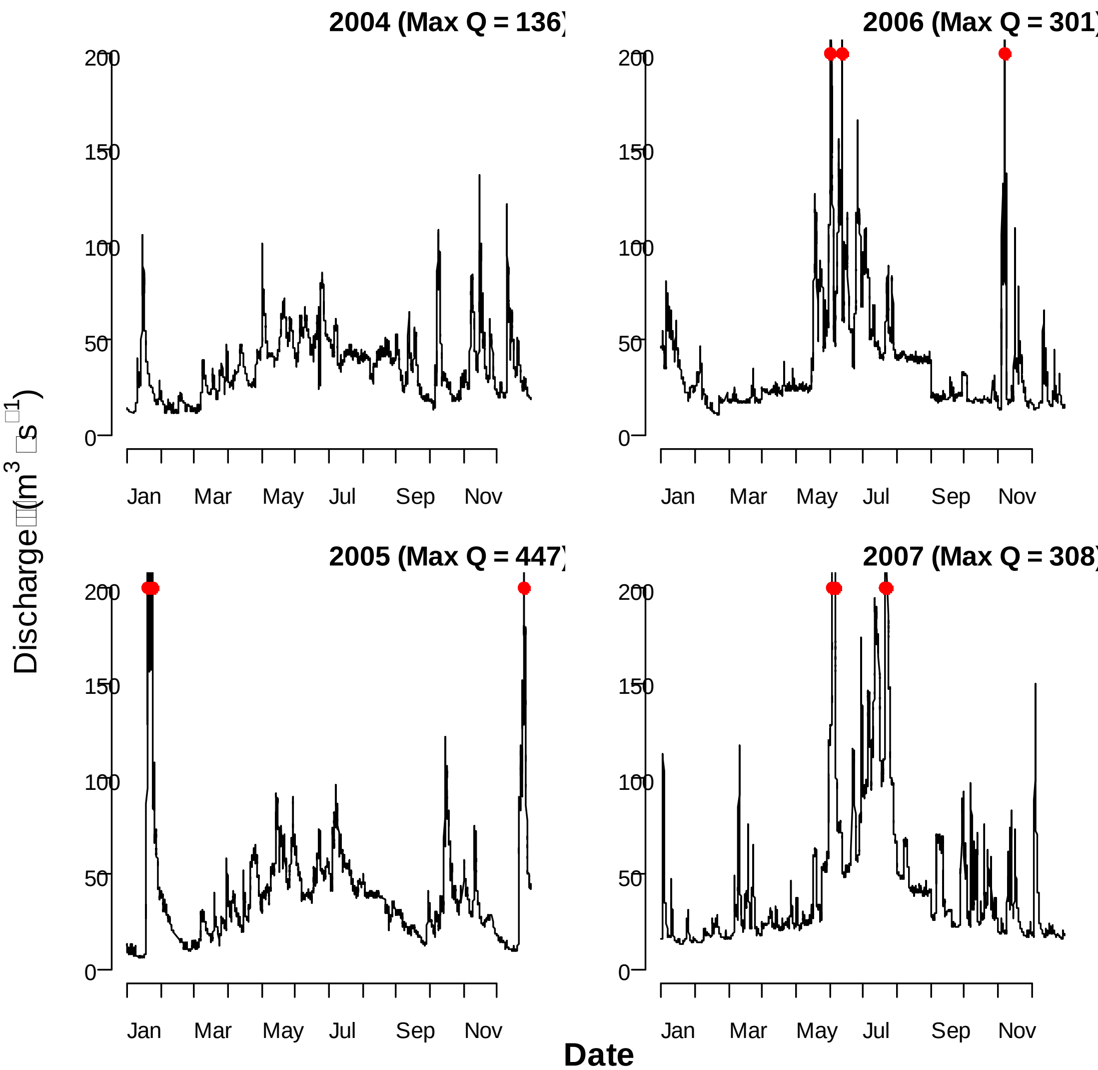

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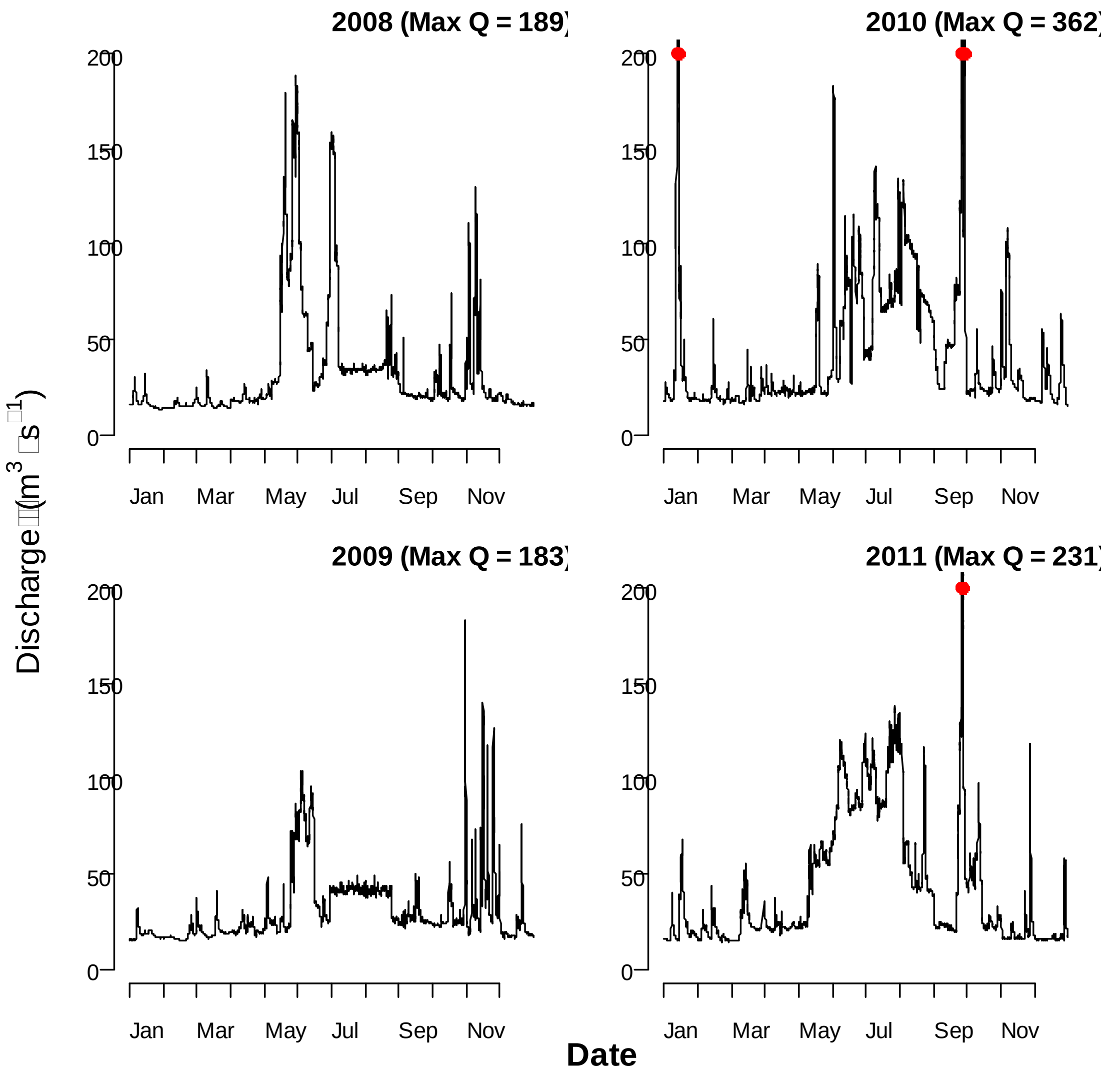

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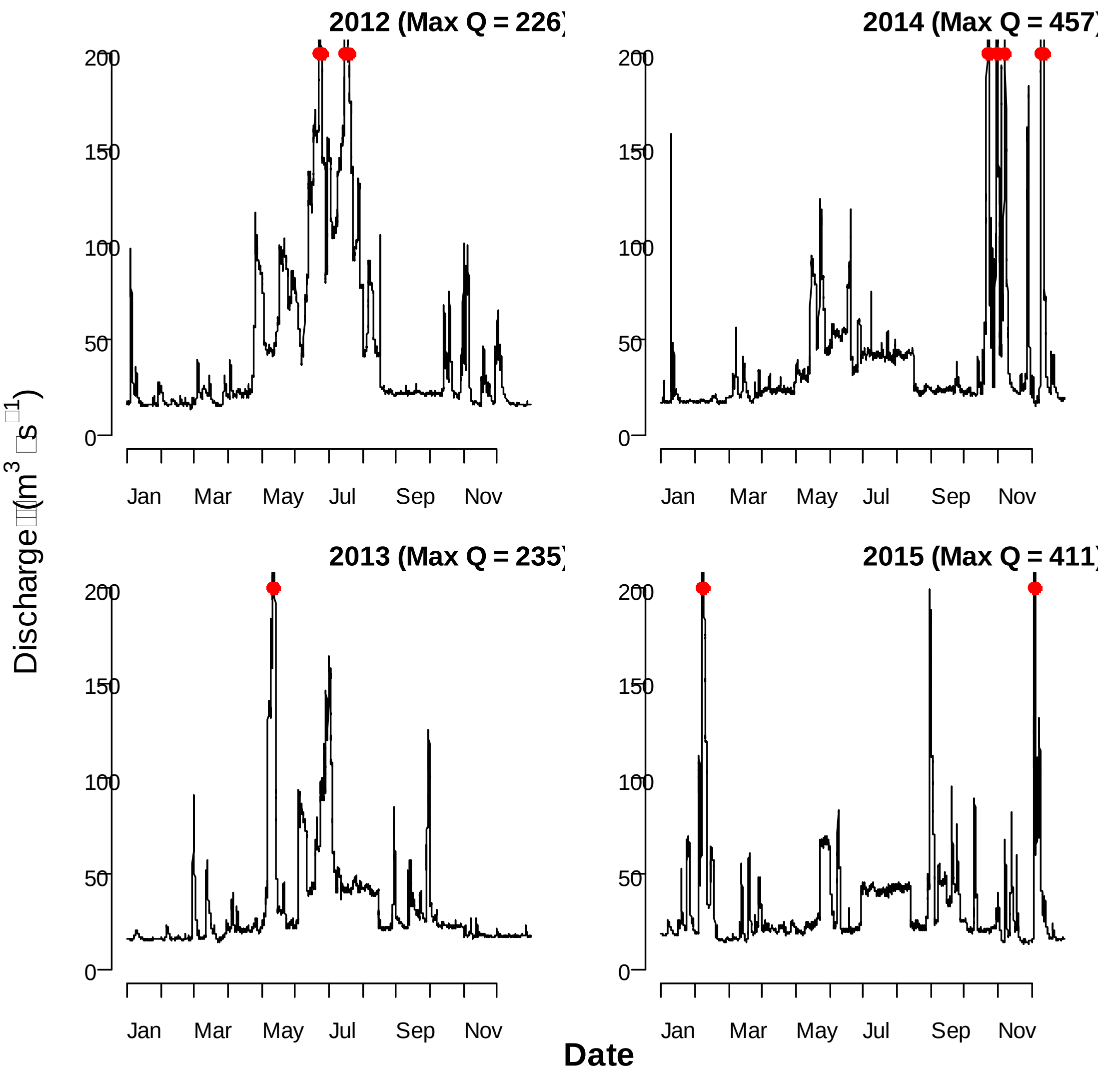

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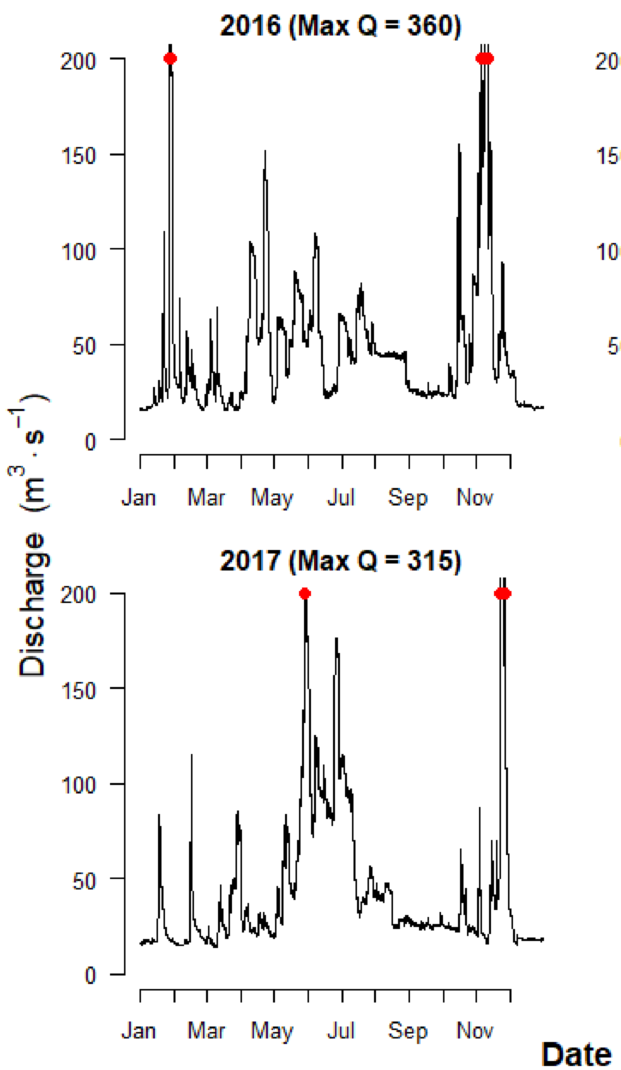

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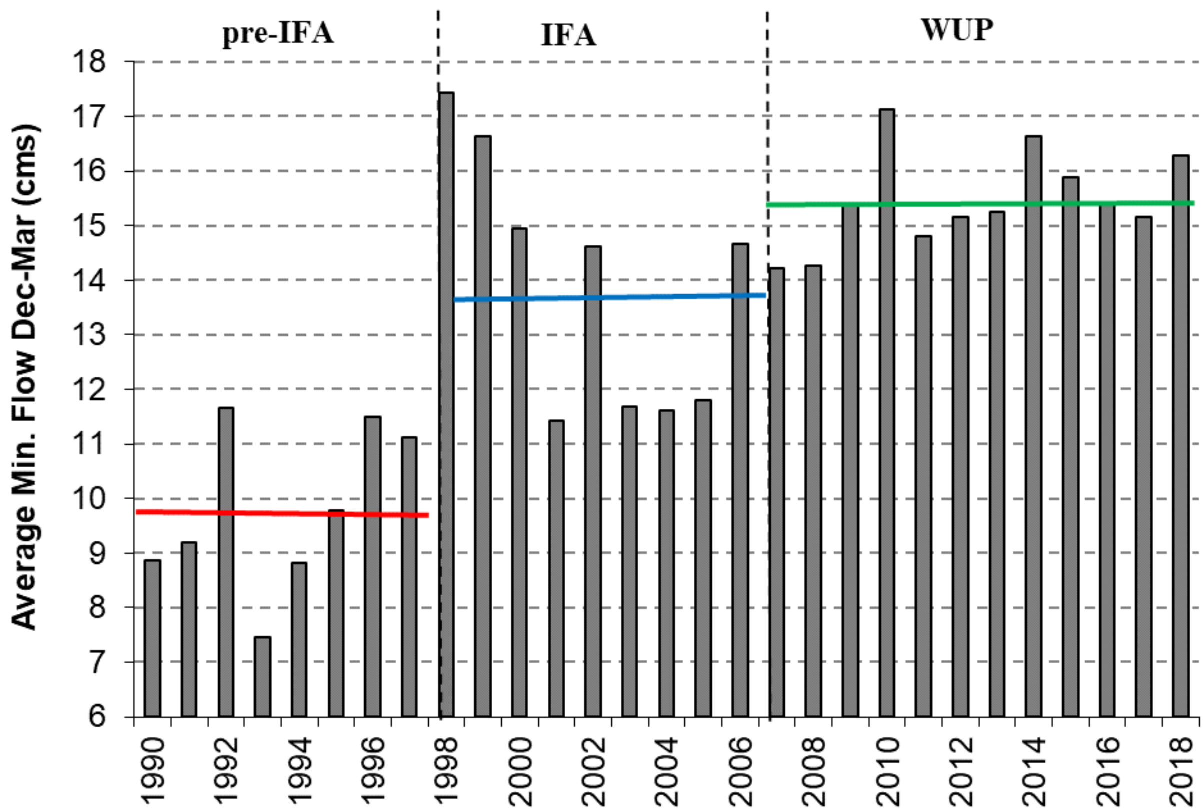

Figure 1.3. The average minimum flows during winter at the Brackendale gauge on the Cheakamus River, 1990-2018. The average minimum flow between December and March was computed as the average of the minimum flow in December from the previous year (based on average daily flows), and the minimum flows 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 Interim Flow Order (IFO), Interim 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.

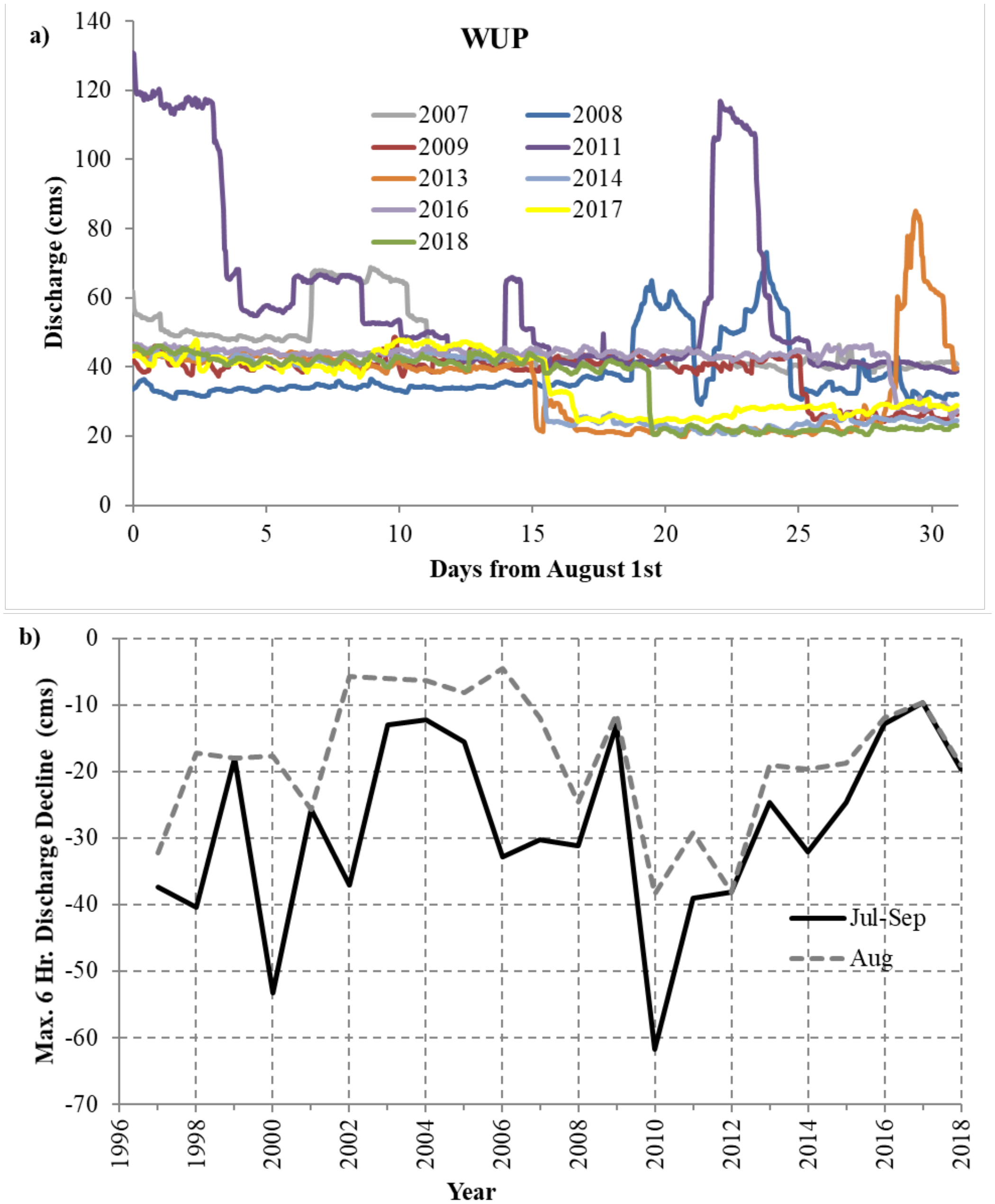

Figure 1.4. Hourly discharge at the Brackendale gauge on the Cheakamus River over August (a) from 2008-2018, and the maximum 6 hour discharge decline over August and from July 1st to September 30th by year since 1997 (b).

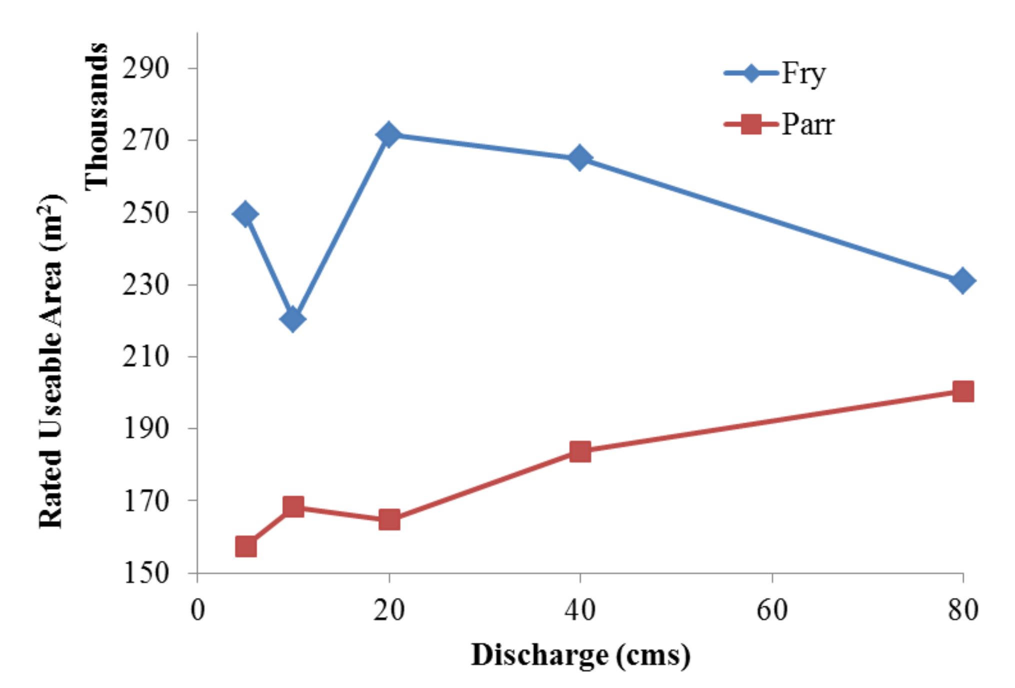

Figure 1.5. Changes in predictions of rated useable Steelhead habitat in the Cheakamus River (summed across reaches) as a function of discharge. This habitat model was used in the initial WUP assessment (BC Hydro 2007).

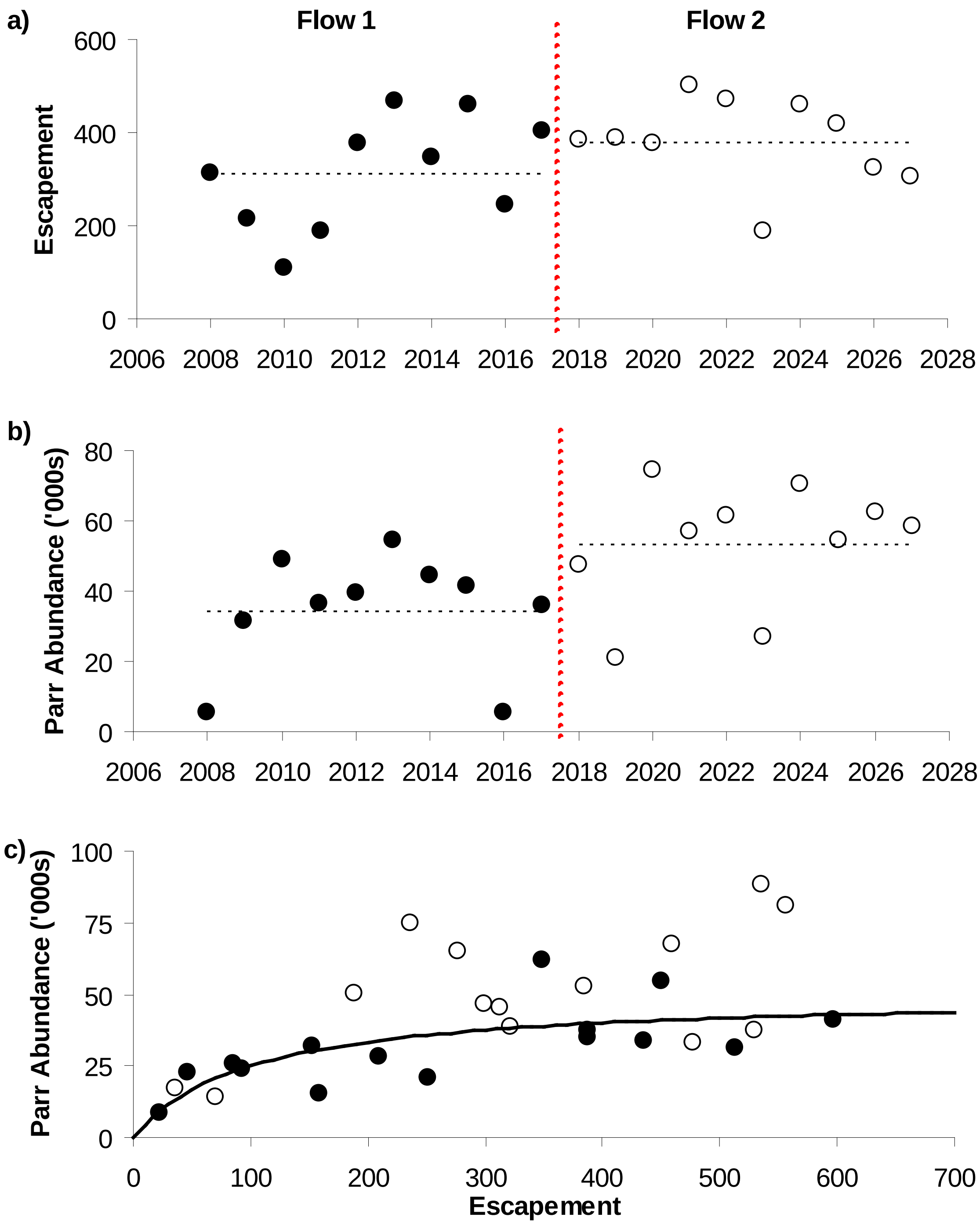

Figure 1.6. Theoretical responses of escapement (a) and parr abundance (b) under two flow regimes, with 10 years of data collected under each regime, and the stock-recruit relationship between these life stages over the two periods (c). Solid and open circles represent data collected under flow regimes 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).

Year	Year	Season	Escapement	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			2 yr smolt	3 yr smolt	
2015 (8)		Fall					
	2015	Spring			2 yr smolt	3 yr smolt	
2016 (9)		Fall					
	2016	Spring			2 yr smolt	3 yr smolt	
2017 (10)		Fall					
	2017	Spring			2 yr smolt	3 yr smolt	WUP Phase II Monitroing Ends
		Fall					
2018 (11)	2018	Spring					WUP Monitoring Extension
		Fall					

Figure 1.7. 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. This report covers reporting year 2018 (WUP year 11). 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 or the next year as an ag-3 smolt.

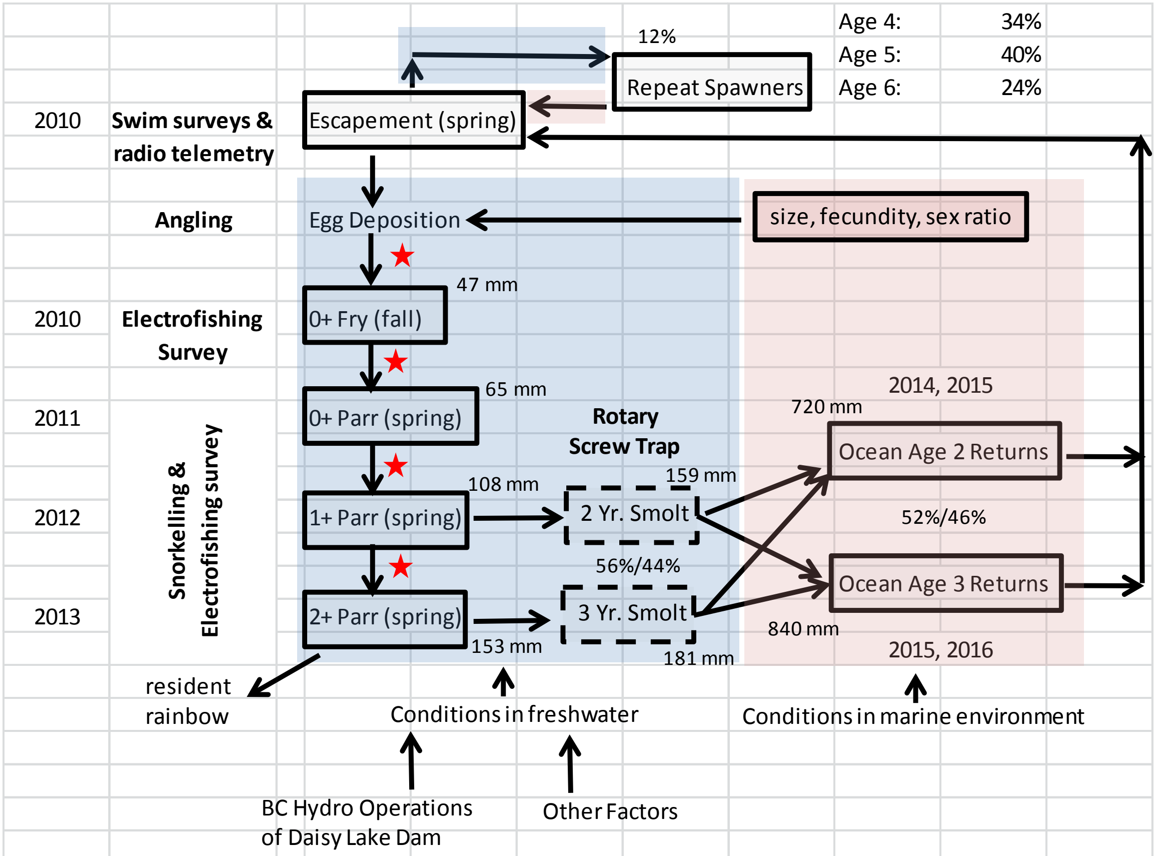

Figure 1.8 Summary of Steelhead life history in the Cheakamus River in relation to WUP monitoring activities. The years on the left of the diagram track the timing of a cohort spawned in 2010 to a 3 yr. smolt exiting the Cheakamus River in 2013 or remaining in the river as a resident trout. The typical size of each life stage and proportion of fish by age class are also shown. Blue and pink shaded boxes identify life stages effected by freshwater and marine conditions, respectively.

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	$\text{logit}(p_i) = \rho_h + \rho\_dev_{iyr} + \rho_s \cdot \frac{HV_i}{Q_i}$
2.13	Likelihood for marked fish 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	Penalty on normal deviates for the constant of qp-HV/Q relationship	$dev\_pen \sim norm(\rho\_dev_{iyr}, \sigma_\rho)$
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	$s_{sl} = \sqrt{\dfrac{\sum (slobs_i - SL_i)^2}{n-1}}$
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)	$L_T(data \mid \theta) = \dfrac{L_r + L_{pr}}{2} + \dfrac{L_u + L_{pu}}{2} + L_p + L_s + L_{dW} + L_{dH} + L_f - Hpen - dev\_pen$

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	Constant of qp-HV/Q detection probability relationship by telemetry
ρ_s	Slope of the qP-HV/Q relationship by telemetry yr
$\rho_{\_dev}$	Annual deviates (in telemetry years) for constant of qp-HV/Q
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 2018.

Survey #	Survey Date	Discharge (Q in m3/sec)	Horizontal Visibility (HV in m)	HV/Q	Count Steelhead	Count Resident Rainbow	Count Bull Trout
1	12-Mar	16.5	7.5	0.45	36	69	147
2	30-Mar	17.9	5.4	0.30	51	42	67
3	10-Apr	26.3	4.5	0.17	34	20	20
4	16-Apr	25.3	4.7	0.19	32	36	32
5	18-Apr	21.9	4.8	0.22	53	43	81
6	24-Apr	22.5	4	0.18	64	49	70
7	25-Apr	23.4	4.2	0.18	81	54	70

Table 2.4. Number of resident rainbow trout and steelhead sampled for size, sex, and age in 2018, and average, minimum, and maximum fork lengths.

Origin	Female	Male	Unknown	Total
# Sampled				
Resident	4	6	2	12
Steelhead	7	10		17
Total	11	16	2	29
Fork Length (mm)				
Average				
Resident	478	508	461	
Steelhead	732	786		
Minimum				
Resident	432	356	432	
Steelhead	670	660		
Maximum				
Resident	590	737	490	
Steelhead	880	864		

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	0.42	0.57	0.01	76
2015	W	0.00	0.38	0.59	0.03	78
2016	W	0.00	0.16	0.81	0.03	32
2017	W	0.00	0.13	0.87	0.00	31
2018	W	0.00	0.44	0.56	0.00	16
Avg	H	0.98	0.02	0.00	0.00	56
	W	0.00	0.47	0.52	0.01	448

Table 2.5. Con't.

Year	Origin	Ocean Age 1	2	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	0.39	0.57	0.00	23
2014	W	0.00	0.67	0.32	0.10	72
2015	W	0.00	0.26	0.74	0.26	65
2016	W	0.13	0.35	0.52	0.34	23
2017	W	0.00	0.17	0.80	0.12	30
2018	W	0.00	0.57	0.43	0.13	14
Avg	H	0.11	0.50	0.39	0.10	55
	W	0.02	0.51	0.46	0.15	459

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	0.28	0.53	0.18	72
2015	W	0.00	0.00	0.11	0.42	0.45	65
2016	W	0.00	0.00	0.13	0.48	0.39	23
2017	W	0.00	0.04	0.04	0.19	0.74	27
2018	W	0.00	0.00	0.21	0.50	0.29	14
Avg	H	0.11	0.49	0.39	0.00	0.00	50
	W	0.00	0.01	0.33	0.41	0.24	383

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**	**8**	
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		12	6	10	2	1	31
2015	W		4	3	7	2		16
2016	W		7	7	3	3		20
2017	W			7	8			15
2018	W	1	2	2		1		6
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		417	491	489	550	635	471
2015	W		511	413	478	530		485
2016	W		431	496	493	518		477
2017	W			418	436			428
2018	W	394	445	473		737		495
Avg. Wild		394	437	452	474	541	635	463

Table 2.7. Summary of Cheakamus River Steelhead radio telemetry data. Table shows the number of fish tagged in each year and the number where survey life and departure time was determined. Also shown is the sum of the number of tags available for resighting across swims used to determine detection probability.

Year	**# Tagged**	**Detection Probability (tag-swims)**	**Survey Life**	**Departure Timing**
2000	17	22	0	0
2001	31	113	8	26
2003	33	188	14	22
2004	36	126	7	30
2005	37	261	4	26
2009	20	95	4	17
2010	51	313	20	33
2011	46	209	14	30
2016	17	78	1	10
2017	28	246	5	22
Total	316	1,651	77	216

Table 2.8. Steelhead escapement estimates to the Cheakamus River, 1996-2018. Mean and CV denote the mean and coefficient of the posterior distribution of escapement estimates. Average values by Cheakamus River rearing period are shown at the bottom of the table.

	Wild		Hatchery		Wild+Hatchery	
Year	**Mean**	**CV**	**Mean**	**CV**	**Mean**	**CV**
1996	173	0.17				
1997	112	0.16				
1999	163	0.17				
2000	79	0.19				
2001	324	0.13				
2002	442	0.12				
2003	318	0.09				
2004	346	0.13				
2005	337	0.10				
2006	322	0.11				
2007	542	0.09				
2008	346	0.11				
2009	116	0.19	102	0.34	218	0.19
2010	630	0.09	421	0.16	1,051	0.09
2011	607	0.10	283	0.26	890	0.11
2012	398	0.14				
2013	948	0.09				
2014	547	0.11				
2015	582	0.09				
2016	515	0.10				
2017	713	0.08				
2018	386	0.13				
Pre-IFA ('96-'01)	170	0.17				
IFA Pre-Spill ('02-'07)	385	0.11				
IFA Post-Spill ('08-'09)	231	0.15				
WUP ('10-'18)	592	0.10				

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	2015	2016	2017
Brohm Escapement								
Resistivity Counter	65	54	NA	NA	NA	NA	NA	NA
Redd Counts	70	70	40	43	27	65	28	38
Derived Brohm Escapement								
Cheakamus Wild Escapement	633	608	396	949	548	583	514	716
Brohm Immigration Rate	5.9%	6.5%	6.2%	6.2%	6.2%	6.2%	6.2%	6.2%
Escapement to Brohm River	37	40	25	59	34	36	32	44

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

[2]Telemetry was not conducted in 2012-2015 and the number entering Brohm was not determined in 2016 and 2017, so the estimate 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.

Table 2.10. Summary of resident rainbow trout radio telemetry data. A total of 52 trout were tagged in the Cheakamus River, but two were lost shortly after tagging due to mortality or tag failure, so only 50 were effectively tagged.

	Year	# of Fish
	2016	33
	2017	19
	Total	52
# Effectively tagged fish		51
# Detected in Squamish (alive)		10
% that moved to Squamish		20%
Dates of detections in Squamish	**Date**	
	Jan-17	1
	May-16	2
	Nov-16	1
	Apr-17	1
	May-17	3
	Aug-17	1

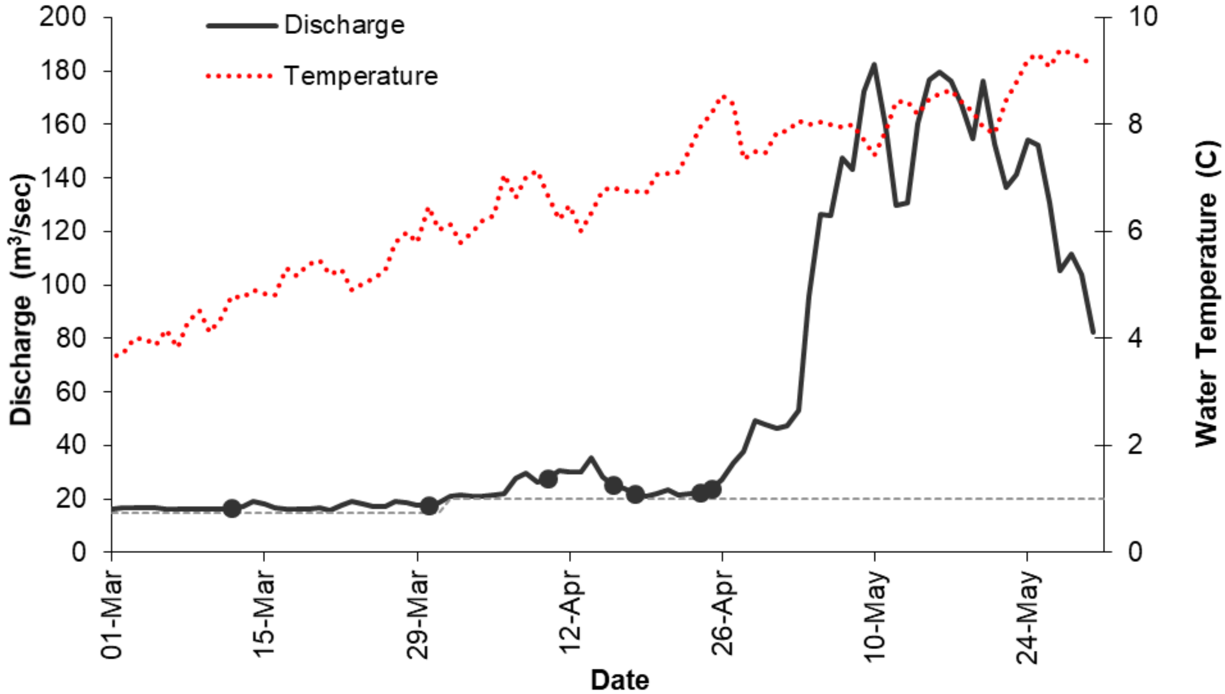

Figure 2.1. Discharge (black solid line) and water temperature (red dashed line) at the Brackendale gauge on the Cheakamus River in winter and spring of 2018. The gray dashed line shows minimum discharge requirements at the Brackendale gauge before and after March 31st. The points denote the dates that adult swim surveys were conducted.

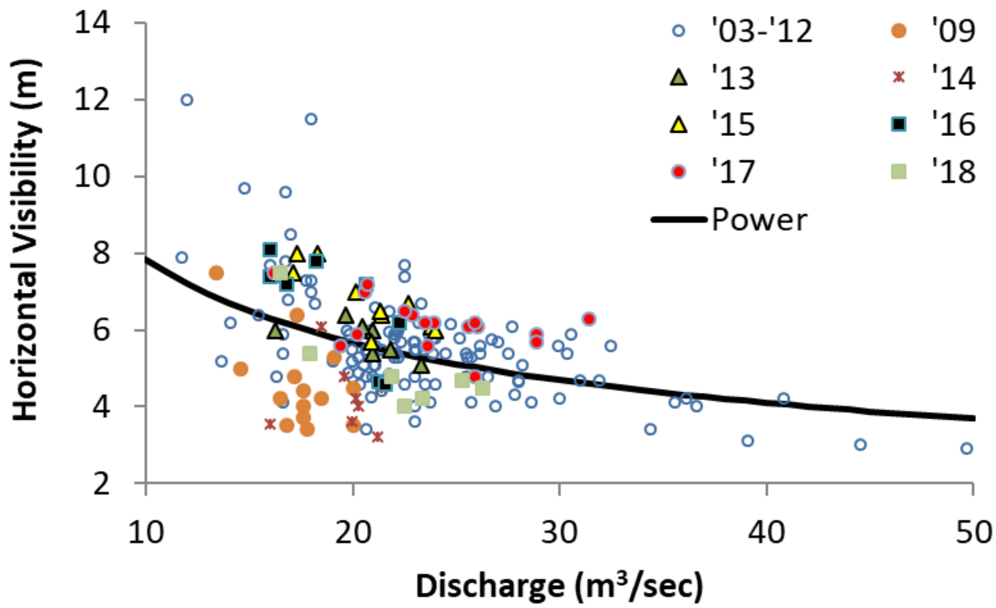

Figure 2.2. Relationship between discharge at the Brackendale gauge and horizontal visibility measured during adult steelhead snorkel swims during winter and spring. The solid line shows a power relationship fit to all years of data.

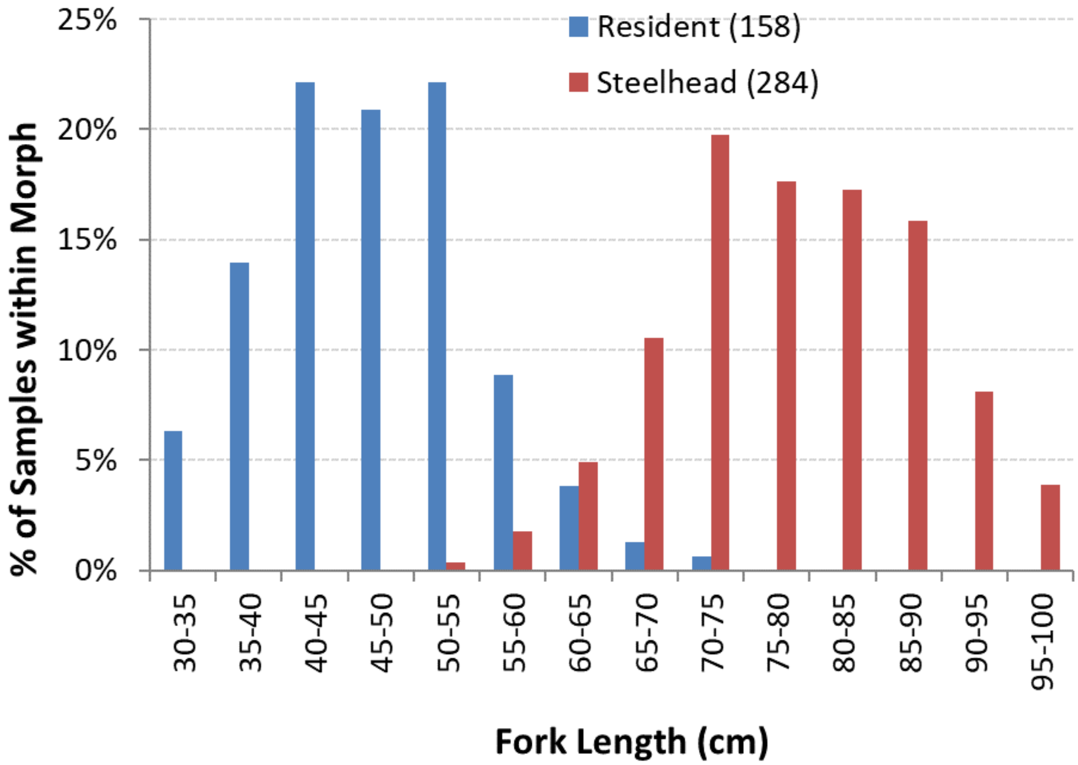

Figure 2.3. Comparison of size distribution of resident rainbow trout and steelhead in the Cheakamus River based on collection of 388 scales between 2009 and 2018.

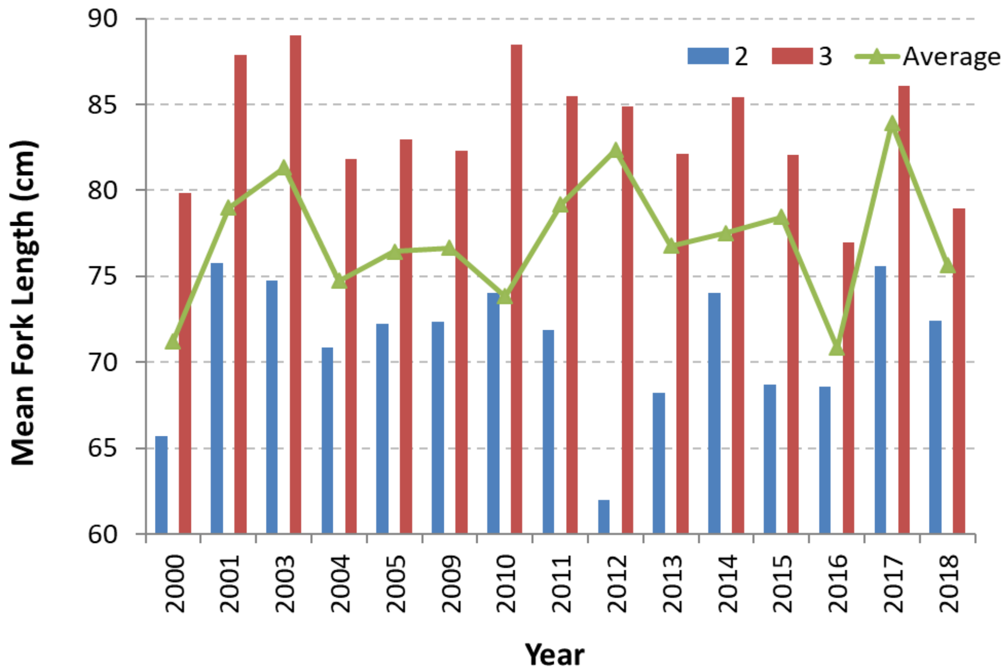

Figure 2.4. Mean size of returning steelhead spawners by ocean age as determined during scale collection.

Ocean Age

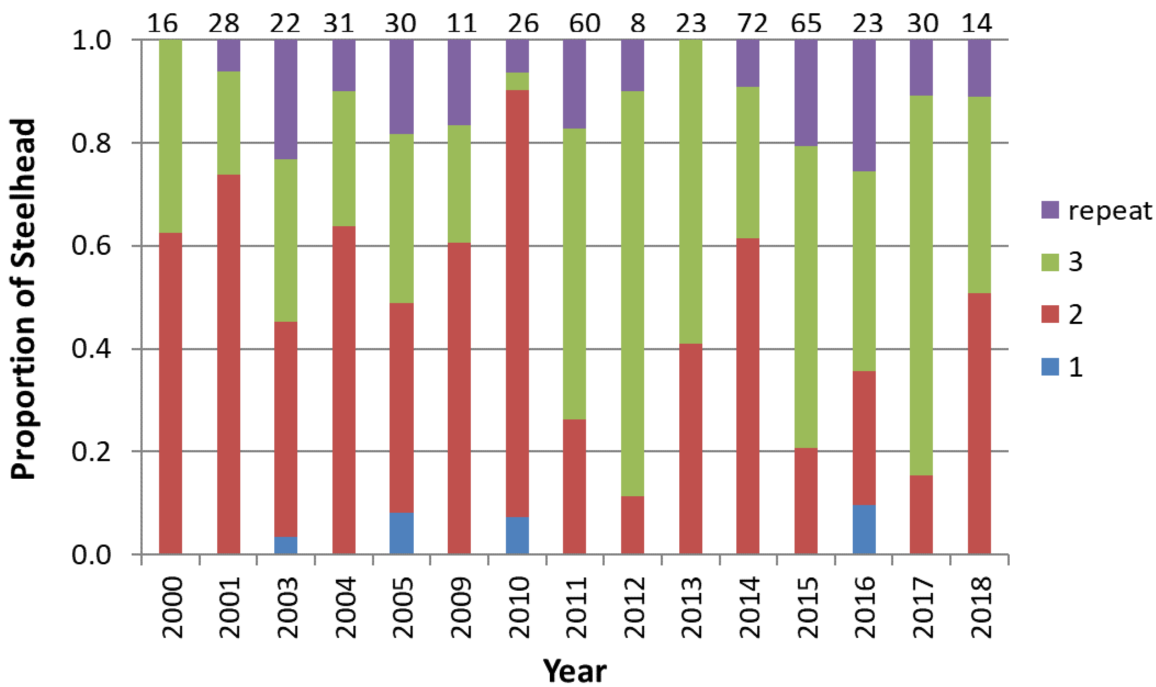

Figure 2.5. Proportion of steelhead in the Cheakamus River that spent 1 to 3 years in the ocean or were repeat spawners as determined by scales collected from anglers. Text at the top of the plot shows mean size of returning spawners in each year.

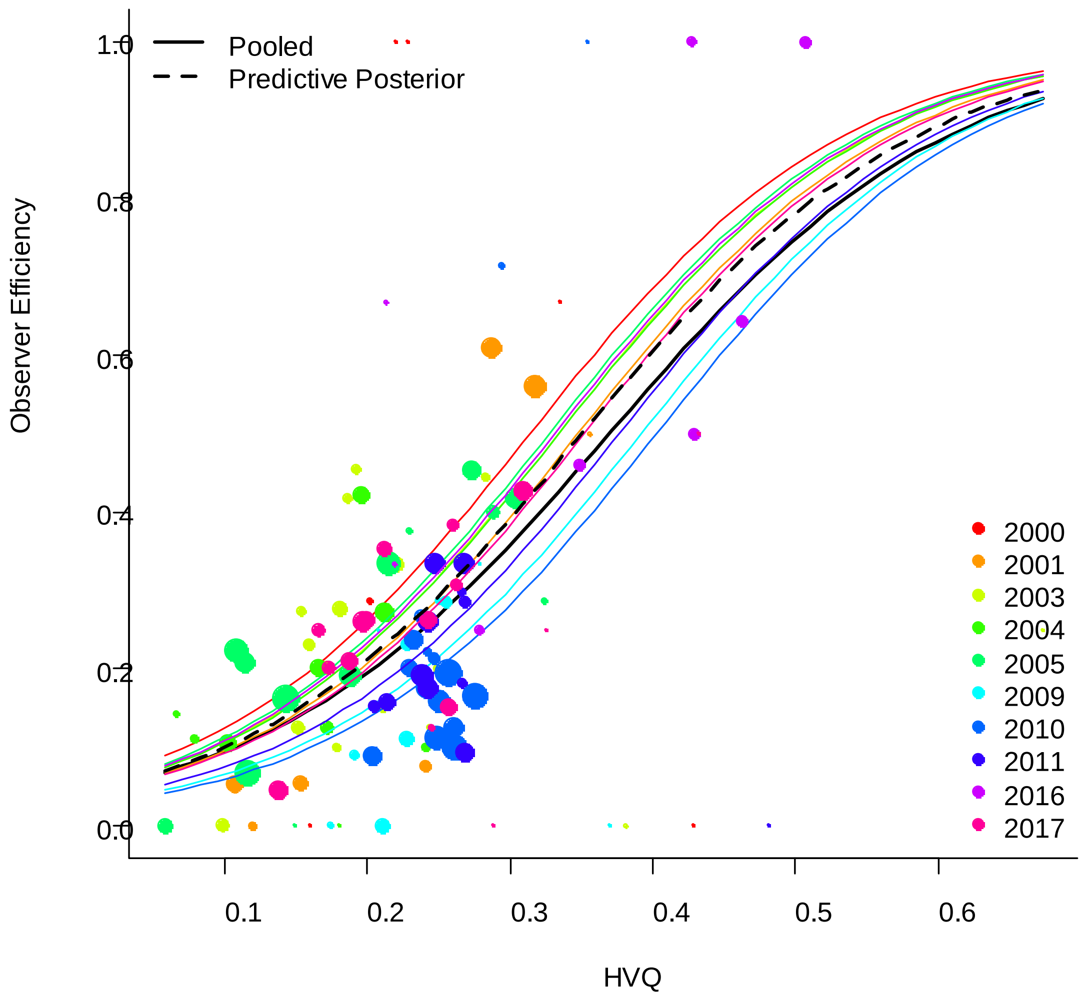

Figure 2.6. Relationship between the ratio of horizontal visibility to discharge (HV/Q) and observer efficiency (pCap) determined based on the number of tagged steelhead resighted (r) compared to the number known to be in the survey area (R). The size of each point reflects the number of tagged fish present in the survey area. The lines show the estimated relationship from the hierarchical Bayesian model (HBM) which allows both the intercept of the relationship to vary across years (model HBM_b0). The solid black line shows the relationship based on the pooled model (one relationship fit to all years) and the dashed black line shows the expected relationship in each year telemetry was conducted based on the HBM. See appendix A2 for additional details.

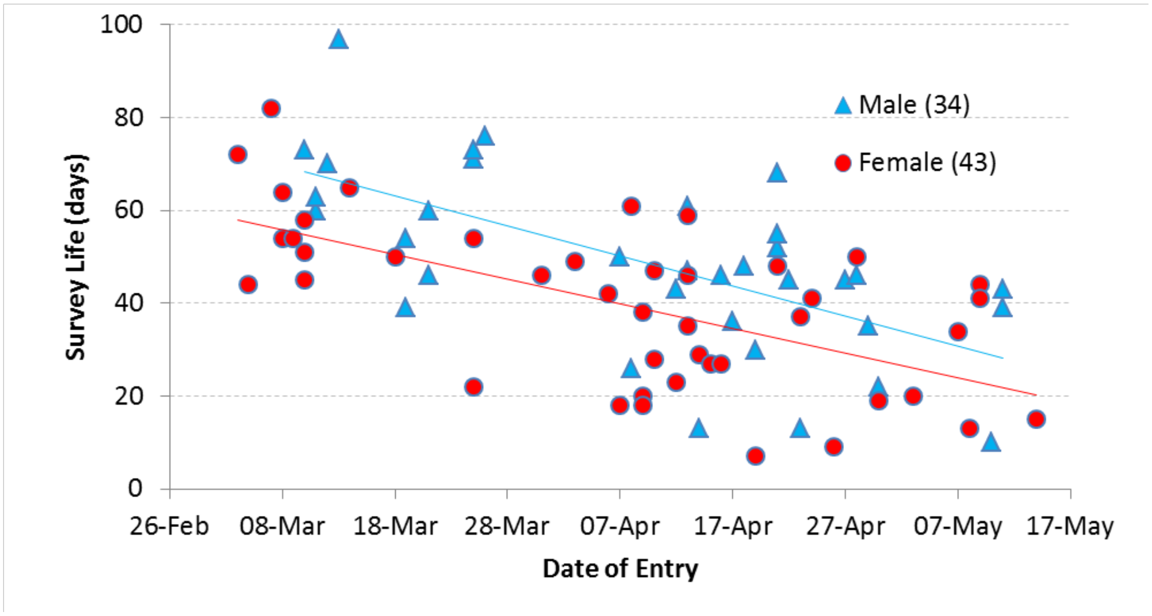

Figure 2.7. Relationship between date of entry and duration of time spent in survey area (survey life) for male and female steelhead in the Cheakamus River based on data from all years telemetry was conducted. Numbers in parentheses in the legend denote the sample size.

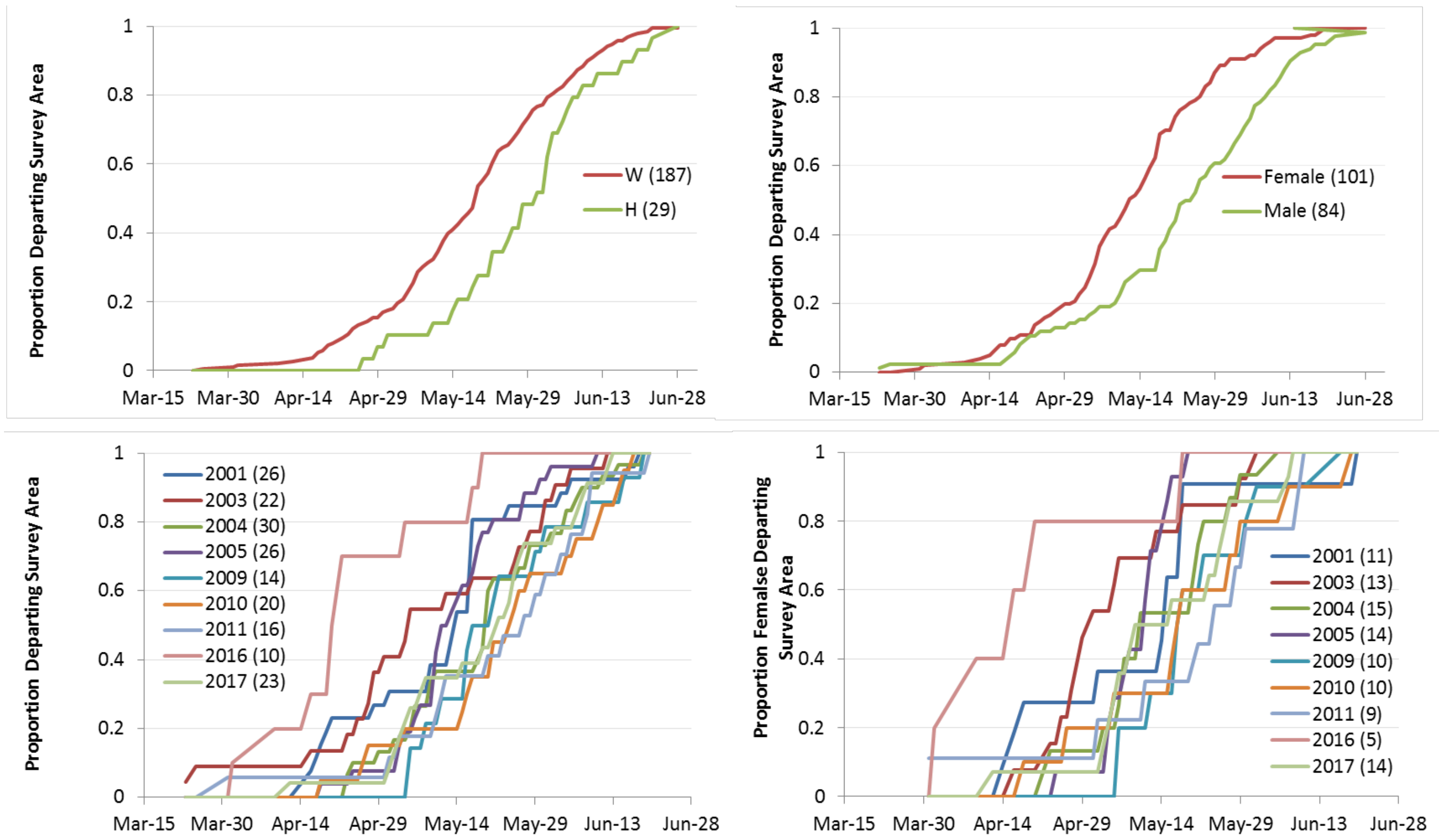

Figure 2.8. Cumulative proportion of radio tagged steelhead departing the survey area by date based on data from all telemetry years. Numbers in parentheses in the legend denote the sample size. Owing to differences in departure timing of wild- and hatchery-origin steelhead, hatchery fish are only included in the Hatchery-Wild comparison plot. Numbers in parentheses in the legends denote sample size.

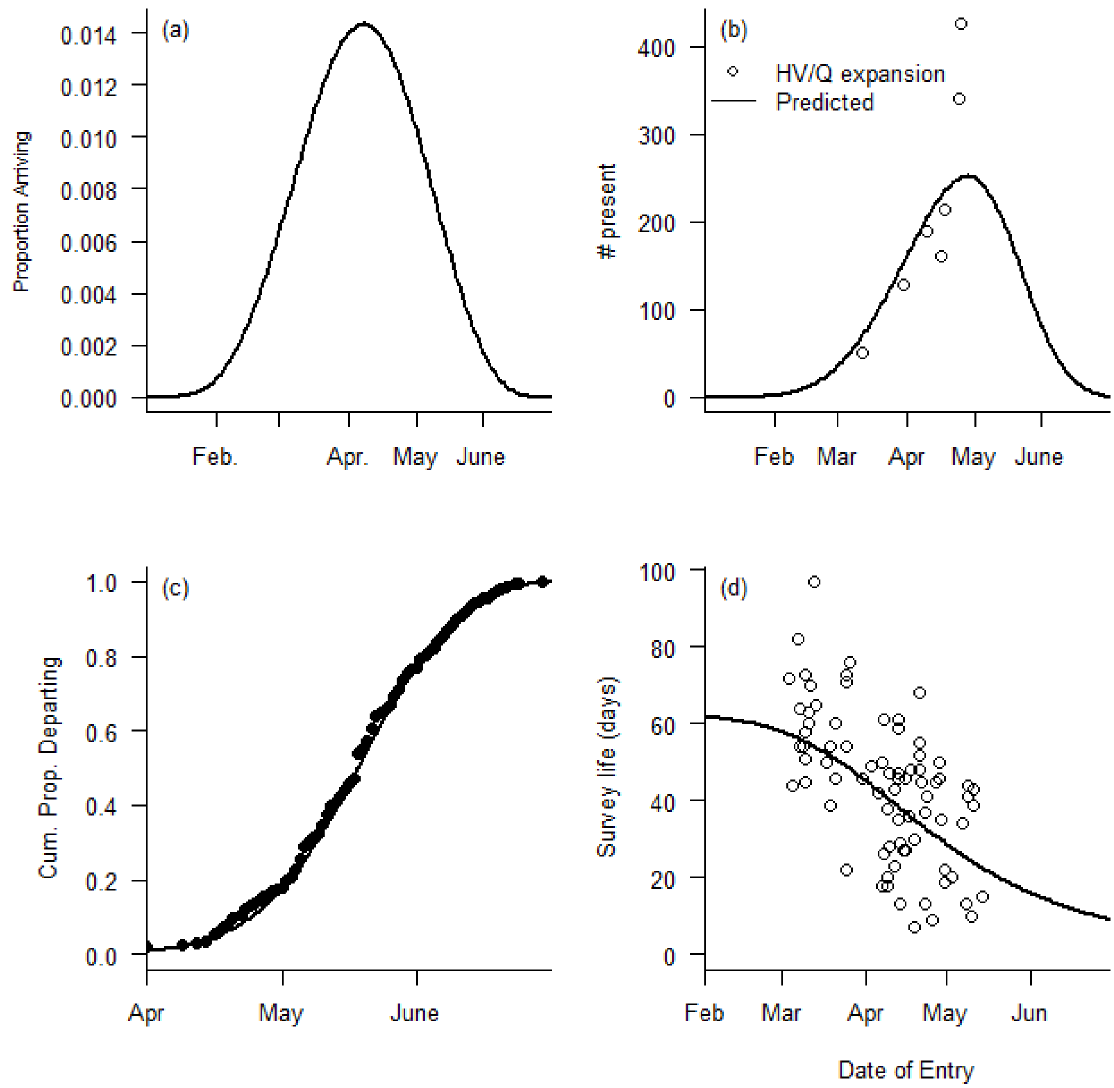

Figure 2.9. Fit of the Steelhead escapement model to the 2018 data. a) shows the predicted proportion of the run arriving by day. b) shows the predicted number present (line) through the run, and the expected numbers present on individual surveys based on detection probability predicted from the ratio of horizontal visibility to discharge (HV/Q). c) shows the predicted (line) and observed (points) departure schedule (data from 2001-2017). d) shows the predicted and observed survey life – date of entry relationship (data from 2001-2017). e) shows the predicted detection probability by survey date based on the p-HV/Q model (lines), and estimates of detection probability based 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 2000-2017 (r/R, colored points with size proportional to number of tags present during swims).

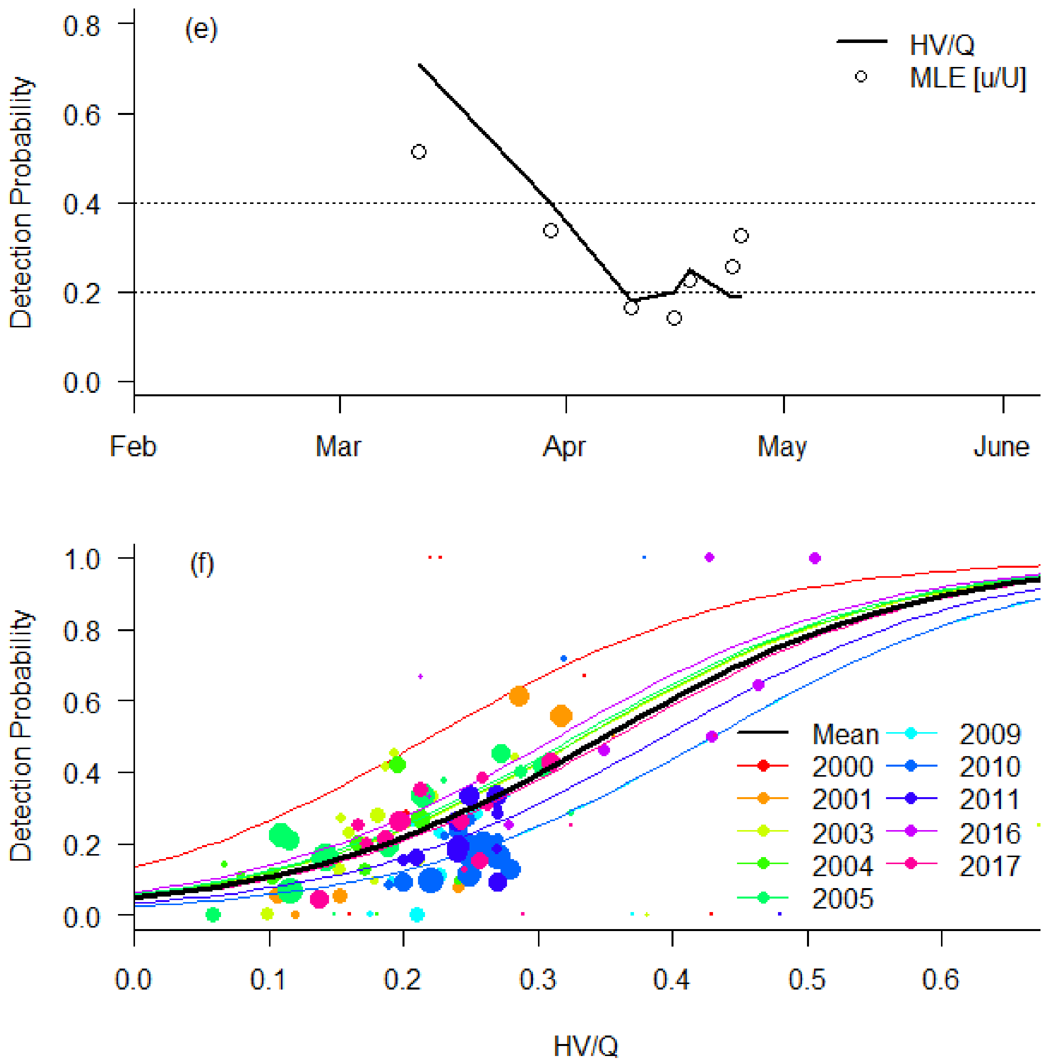

Figure 2.9. Con't.

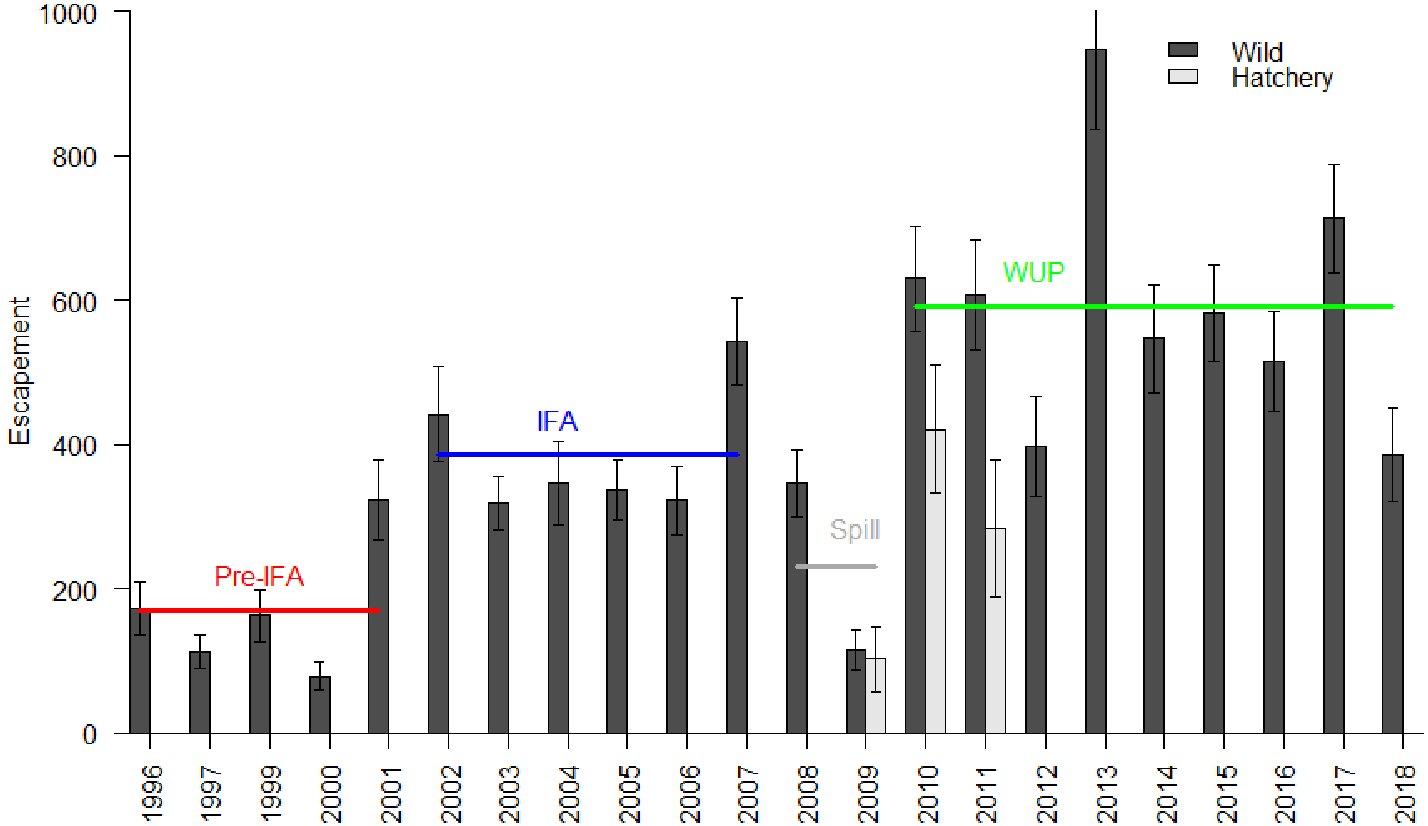

Figure 2.10. The Steelhead escapement trend in the Cheakamus River, 1996-2018 showing abundance of returns that reared as juveniles in the river before and after the Interim Flow Agreement (IFA) and Water Use Plans (WUP) were implemented and the year that the sodium hydroxide spill occurred (Pre- and Post-Spill). The height of the bars and error bars show the most likely escapement estimates and 80% credible intervals, respectively.

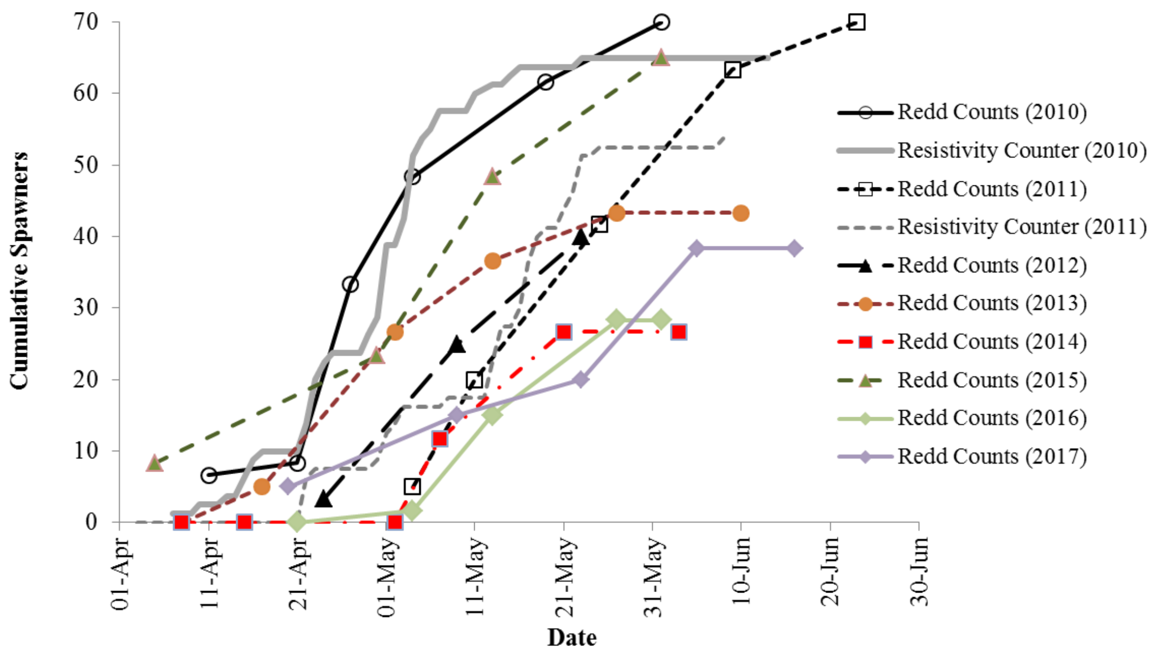

Figure 2.11. Comparison of Steelhead run-timing in Brohm River based on redd counts (expanded to spawners) and net cumulative arrivals based on a resistivity counter near the mouth. Resistivity counter data from 2012 and 2013 were not available.

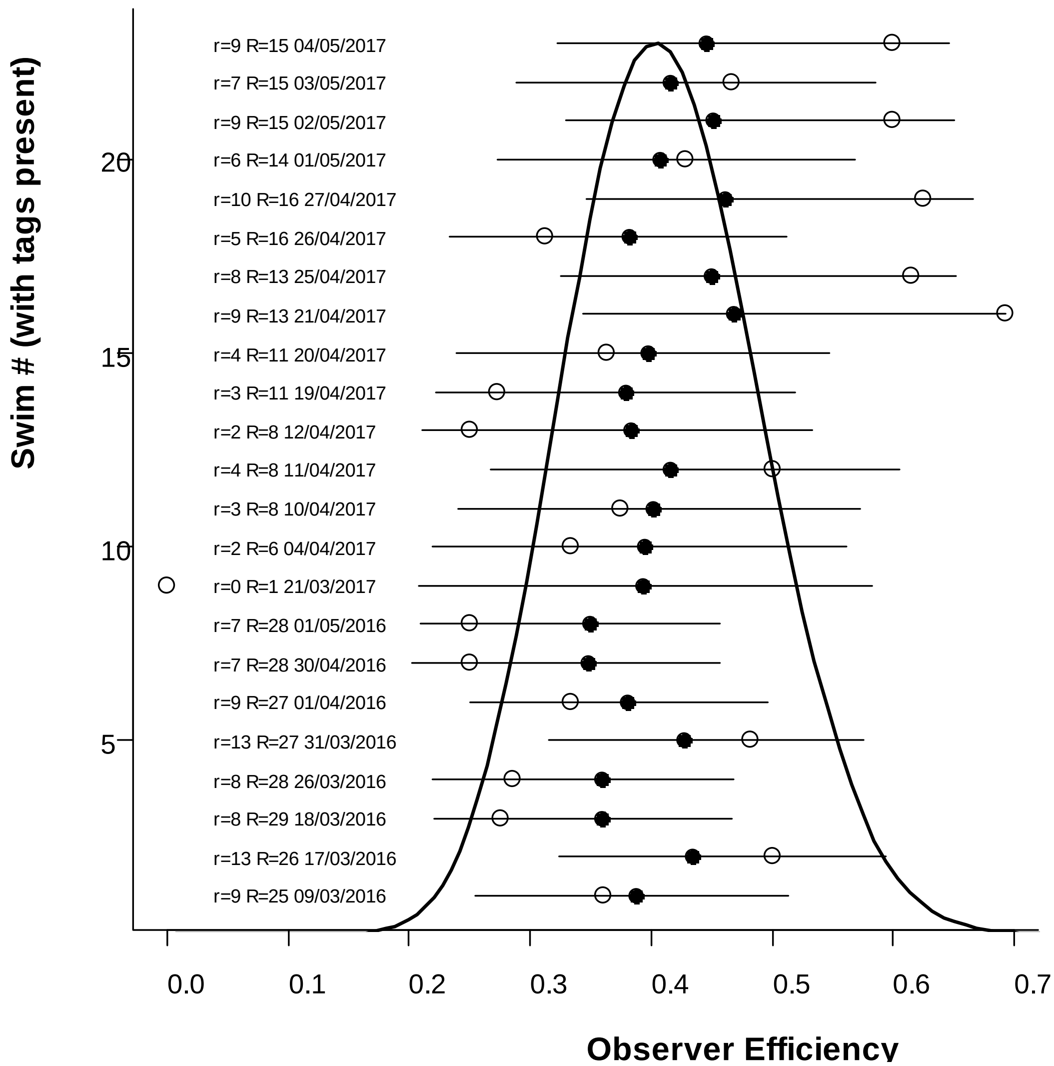

Figure 2.12. Detection probability for resident rainbow trout in the Cheakamus River. Open circles show the swim-specific condition estimates determined as the ratio of tags observed (r) to tags present (R, see text on right). Filled points show the shrunken swim-specific mean estimates from the hierarchical Bayesian model (HBM). with 95% credible intervals (horizontal lines). The distribution is the mean hyper-distribution for detection probability estimates as estimated by the HBM.

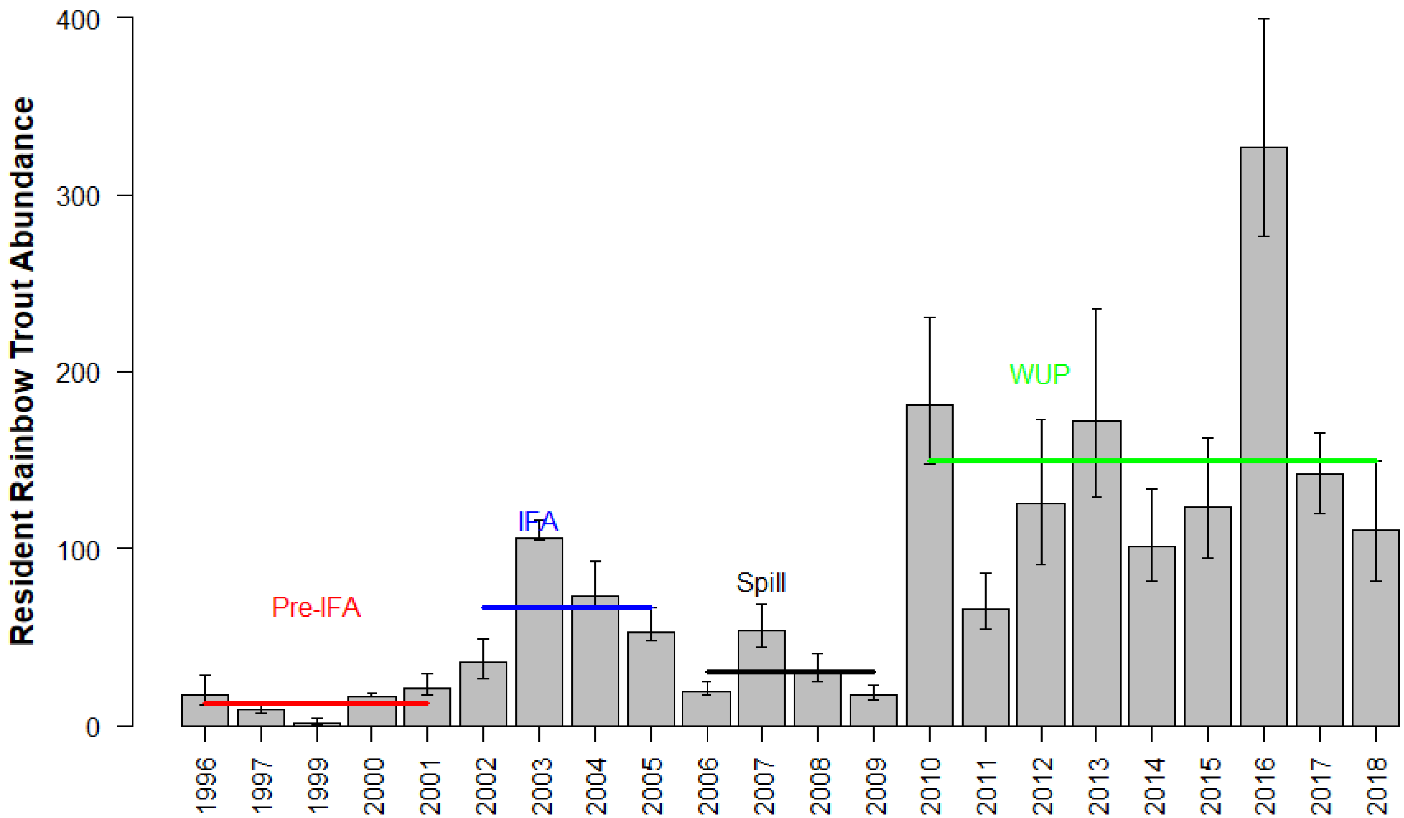

Figure 2.13. Resident rainbow trout abundance estimates in the Cheakamus River upstream of the Cheekye River confluence. The height of bars and error bars represent the mean and 95% credible intervals for annual estimates. Assuming a minimum age of 4 yrs, old, the average abundance for resident trout rearing in the Cheakamus River prior to the Instream Flow Agreement (pre-IFA), during the IFA period (IFA), during the period effected by the CN spill (Spill), and during the WUP period (WUP) are shown by red, blue, black, and green horizontal lines, respectively.

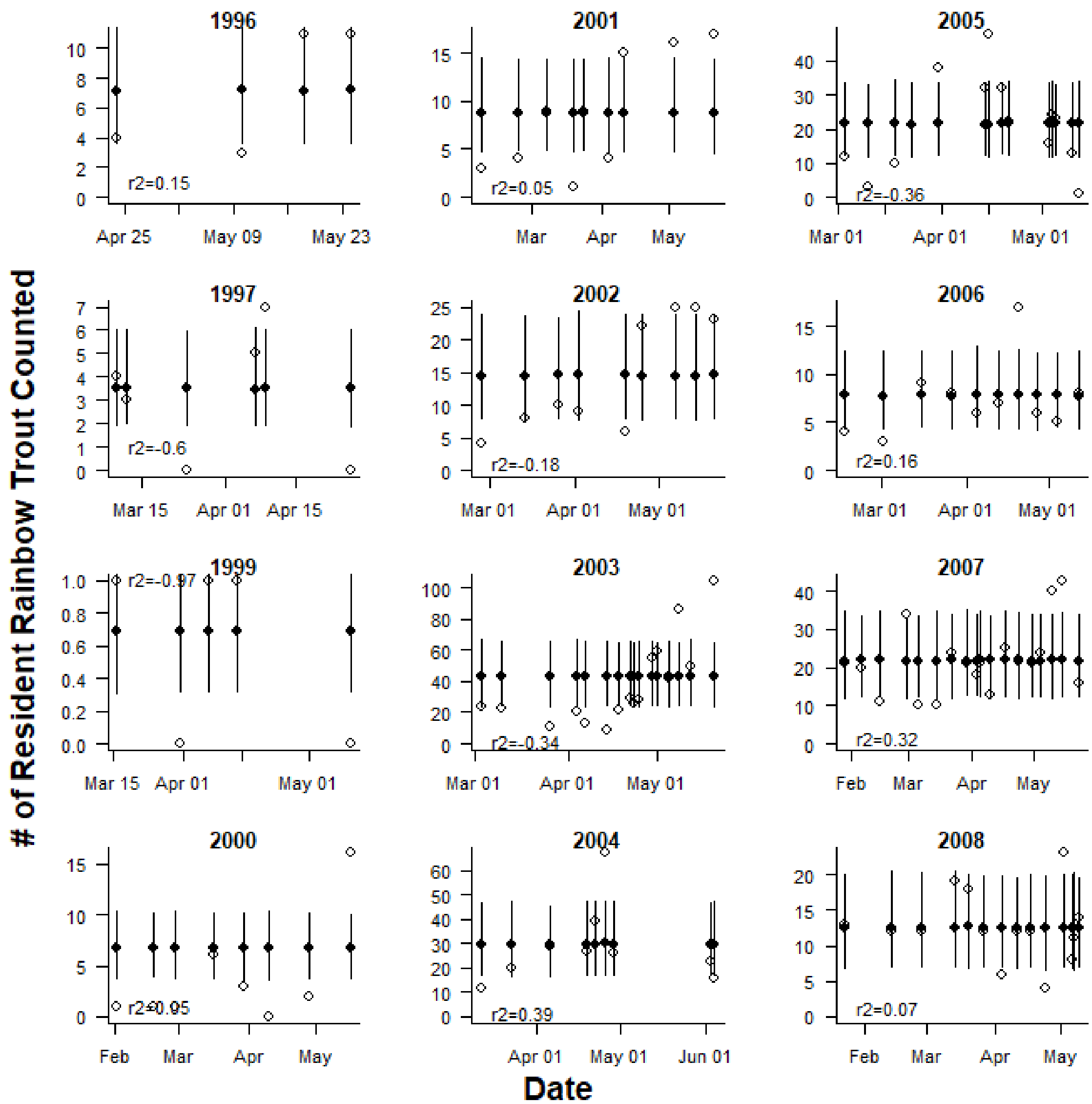

Figure 2.14. Comparison of predicted and observed resident rainbow trout abundance in the Cheakamus River. As the model predicts that abundance doesn't change over the swim survey period in each year, the mean and 95% credible intervals of abundance (solid points and vertical lines) remain constant across surveys in each year. The open points show the resident trout counts expanded by the detection probability estimated for each survey as drawn from the hyper-distribution (see Fig. 2.12).

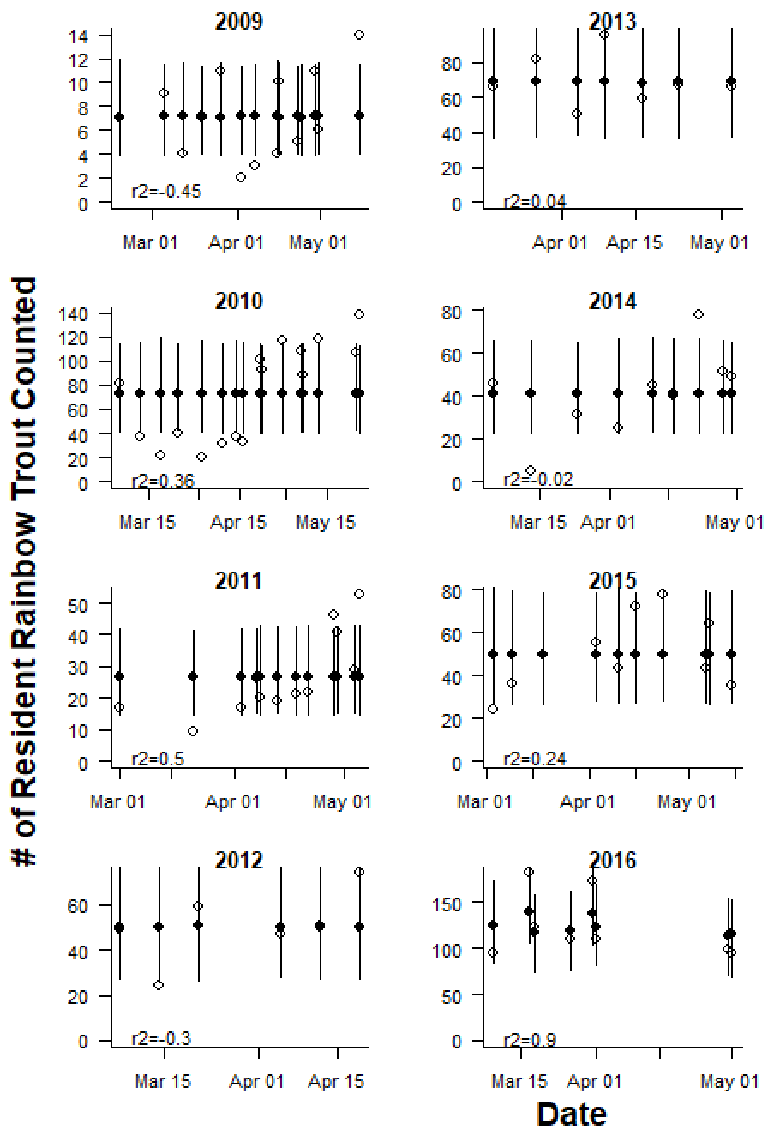

Figure 2.14. Con't.

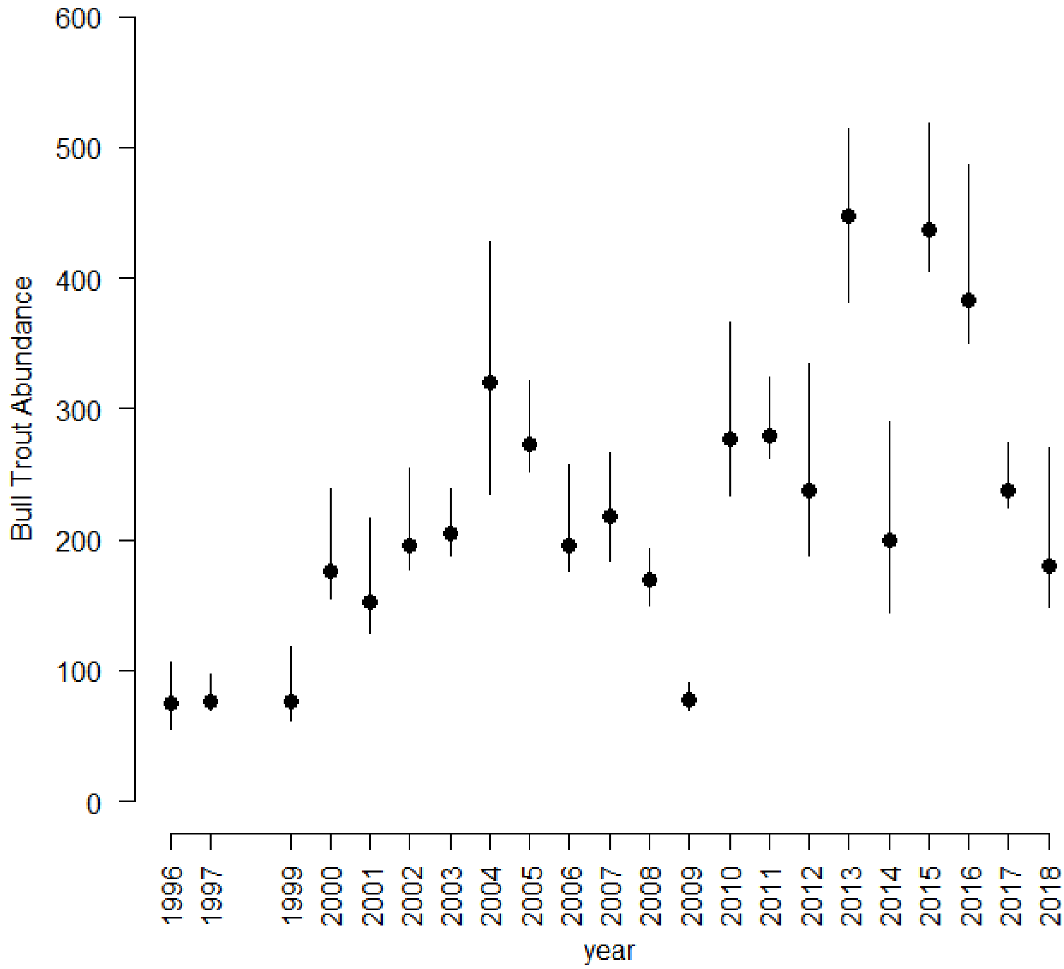

Figure 2.15. Estimates of bull trout abundance in the Cheakamus River survey area, 1996-2018. Points and vertical lines denote the mean and 95% credible intervals of the annual posterior distributions of abundance.

Table 3.1. Summary of juvenile Steelhead sampling effort in spring and fall of 2018 in the Cheakamus River. 'EF' and 'SN' denote electrofishing and snorkeling sampling gear types, respectively.

Season	# Index Sites EF	SN	Total	Sampled Length (m)	Useable Length (m)	Proportion Sampled
Spring	80	112	192	7,856	46,197	0.17
Fall	107		107	3,236	46,197	0.07

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 (mm)	2008			2009			2010			2011			2012			2013			2014			2015			2016			2017		
	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+
<45							2																							
45-49							6															11						5		
50-54							8						1						3			7			1			5		
55-59							3						2						5			7			6			6		
60-64							1						5			5			8			6			4			11	1	
65-69							2	1						1		2			1			4			6			3	1	
70-74					1		1	3			2			1		3	1		1	3		3	5		5	1		5	3	
75-79	2				2		1	3			1						4			4			2		1	3			6	
80-84		1			3			4			3						4			1			5		2	3			6	
85-89		2			6			2			3			1			4			7			8		1	4			7	
90-94		4			4			5			3			3			6			4			3			5			6	
95-99		3			4			3			5						4			6			8			3			6	
100-104		1			4			3			4						5			4			7			8			8	
105-109					4			3	1					1			7			5			6			6			10	
110-114						2		1			1			1			3			4			3			5			6	
115-119									1		1			1	1		2	4		2	2		1			4	1		3	
120-124						1			1						1		1	1		2	3		4	3		1	3		1	4
125-129			1			2			2			4			1		1	2			4			5			1			1
130-134			1			3			6			1			3			6			2		1	3			2			1
135-139																		5			6		1	5			3			4
140-144									1			2		1	2			6			5			7			2		1	1
145-149			1												2			2			4			3			1			2
150-154						1									3			5			1			3			2			3
155-159						1						1			3			2									2			2
160-164															2			2						2						1
165-169																		1									1			2
170-174									1															1						
175-179																														
180-184																														
185-190			1																					1						
>190																								1						
Total	2	11	4	0	28	10	24	28	13	0	23	8	8	10	18	10	42	36	18	42	27	48	54	34	26	43	18	35	65	21

Table 3.4. Con't.

b) Brohm – Spring

Fork Length (mm)	2009			2010			2011			2012			2013			2014			2015			2016			2017		
	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+
<45																											
45-49							5																		3		
50-54				2			4			5			5						6			1			5		
55-59	1			1			4			2			2						7			6			5		
60-64				9			4			5			6			6			9			6			5		
65-69				4			2			4			4			5			7			2			5		
70-74	1			3				1		4			3			5			7			8			4		
75-79		1		1						2			2			5			3			7	1		1		
80-84					2		1	1			4			5		1	2		2	1		7			1		
85-89		3			1		1	6		1	2		1	2		1	6		2	4		4					
90-94		2			2			6		1	3			4			6			6		1	4		1	2	
95-99		4			2			4		1	5			5			5			8			1			3	
100-104					3			3	1	2	8		1	5			9			8			3			1	
105-109		1			4			6			3			6			1			2			2			3	
110-114		1			1				1		4			5			3	1		7			3			2	
115-119					1			5	1		3			4			2	1		1			3			2	1
120-124		2						2	8		4			3				2		1	1		4			1	1
125-129					3	1			1			4			5		1	1			2		1			1	1
130-134									4			2			2						1						
135-139		1							7			1		1	2			1			1						
140-144									6			6			5						4						
145-149			2						3			1			1												
150-154			1						1									1			1						1
155-159		1	1						2			1			1						1			1			2
160-164			1						2			1			1									1			
165-169			1									1			2						1						
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	43	38	12	42	23	2	30	15	6

Table 3.4. Con't.

c) Cheakamus – 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																		
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

Fork Length	2014			2015			2016			2017			2018		
(mm)	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+
<45															
45-49	1			4			1			8			24		
50-54	9			6			14			8			11		
55-59	7			7			11			13			12		
60-64	9			7			14	1		11			10		
65-69	11			5	1		13			8			13		
70-74	8	2		6	3		9	1		8	1		14		
75-79	2	2			5		9	5		1	1		15	3	
80-84		5			9		3	9			3		5		
85-89		3			3		2	4			4			5	
90-94		2			6			5			12				
95-99		13			2			3			13			8	
100-104		13			5			4			13			8	
105-109		8			6			3			11			7	
110-114		10			6			5	1		16			4	
115-119		4	2		2			5	2		11	1		7	
120-124		4	5		1				4		8	4		4	
125-129		1	5			1			2		4	6	1	4	1
130-134			6						5			9			3
135-139			6			3			3			3			1
140-144			9						2			3			
145-149			6						1						1
150-154			3			1			2			3			1
155-159			3			1						2			1
160-164			1			1						3			
165-169			1									1			
170-174												1			
175-179															
180-184															
185-190															
>190															
Total	47	67	47	39	49	7	76	45	22	57	97	36	105	50	8

Table 3.4. Con't.

d) Cheakamus – Spring

Fork Length (mm)	2008			2009			2010			2011			2012			2013			2014			2015			2016			2017			2018		
	0+	1+	2+	0+	1+	2+	0+	1+	2+	0+	1+	2+	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																		2					
50-54				5			2			3			6												2			8			9		
55-59				3			6			4			9			2			3			7			2			13			6		
60-64				6			3	1		7			6			9			5			5			8			16			12		
65-69				2			6	1		6			1			8			6			7			10			9			11		
70-74				6			6	2		6			6			6			7	2		12			7	2		11	3		28		
75-79				3			6	4		7	1		7			11	2		5	1		7			6	2		12	1		8		
80-84		1		6	1		1	5		6	1		3			10			4	2		12	2		4	2		12	1		12	5	
85-89	1			3			2	11		5	1		9	1		5	1		5	4		8	3		2	12		10	4		6	3	
90-94		7		7	2			10		6	1		4	1		6	3		2	4		3	4			10		7	4		7	6	
95-99		3		1	2		1	11		5	3		1	2	1		3		3	4			5			4		3	9		1		
100-104		1			1			7		1	4		3	3			6			3			5			10		1	11			5	
105-109		1			3			12		2	6		2	2			7			6			3			1			5			4	
110-114					2			5			6		1	4		1	8			3			6			4			2			3	
115-119					6			5			4	1		1			3			5			3			4			2			3	
120-124					1			4	1		5	3		8			8			1			6						3			4	
125-129					7	1		1	1		2	1					2			3			4	1						1		2	
130-134		3			4			1			2	2		1	3		5			2	1		2	2						4		1	2
135-139		3	1		7	2			1		3	2		1				1			1		1	1						4			1
140-144		4			1	2		1	2			2		2	1			3			1			3						3		1	1
145-149		3	4		1	1			4			1		2	2		1	7			1			4						1			1
150-154		1	2			1			2			4	1		2									2						1			1
155-159			4			3			4						2									1						1			
160-164		1	1			1						1			1			1						2									1
165-169		1	1			1			1			5			1						1			2						1			1
170-174												1			1																		
175-179						1			1			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	61	44	19	41	51	0	104	45	16	100	37	9

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**		
	0+	**1+**	**2+**	**0+**	**1+**	**2+**
Year		**Fall**			**Fall**	
2008	78	93	138	68	107	149
2009		90	127	56	105	136
2010	52	91	129	59	106	142
2011		91	137	51	105	136
2012	55	94	136	55	92	127
2013	56	92	129	56	84	129
2014	56	96	133	54	100	136
2015	58	97	141	55	84	146
2016	55	95	132	56	87	131
2017	53	91	136	54	104	137
2018		No sampling		54	101	133
Avg	58	93	134	55	97	135
		Spring			**Spring**	
2008				88	116	154
2009	67	105	158	63	115	157
2010	68	101	128	70	97	143
2011	57	97	133	70	106	151
2012	69	112	151	69	114	150
2013	66	101	143	71	109	150
2014	60	95	129	62	91	132
2015	71	103	137	70	107	148
2016	75	103	162	71	96	NA
2017	72	106	133	69	102	142
2018		No sampling		69	107	149
Avg	67	103	141	68	104	147

Table 3.6. Total number of juvenile Steelhead captured by electrofishing (EF) or observed by snorkelling (SN) at index sites in spring and fall of 2018 in the Cheakamus River.

		Age			
Season	**Gear**	**0+**	**1+**	**2+**	**0+ - 2+**
Spring	EF	1,318	29	6	1,353
	SN	1,979	800	182	2,961
Fall	EF	3,414	72	9	3,495

Table 3.7. Summary of effort (KM of shoreline sampled by electrofishing (EF) and snorkeling (SN) and catch per effort in the Brohm, Cheakamus, and Cheekeye Rivers over the study period.

						Catch Per KM						
			KM Sampled			EF				SN		
River	**Season**	**Year**	**EF**	**SN**		**0+**	**1+**	**2+**		**0+**	**1+**	**2+**
Brohm	fall	2008	0.13			1,488	512	291				
		2009	0.39			1,646	510	249				
		2010	0.55			1,501	385	339				
		2011	0.30			1,547	356	158				
		2012	0.38			2,406	453	276				
		2013	0.46			1,175	600	121				
		2014	0.45			1,183	680	208				
		2015	0.47			1,979	350	152				
		2016	0.45			1,696	493	92				
		2017	0.45			2,830	700	141				
	spring	2009	0.00	0.40						73	590	125
		2010	0.30	0.50		292	193	23		277	836	311
		2011	0.33	0.50		317	178	86		50	182	288
		2012	0.37	0.81		189	90	16		46	639	138
		2013	0.44	0.72		286	99	27		61	406	154
		2014	0.41	0.75		307	162	60		85	539	257
		2015	0.46	0.80		153	90	24		162	190	179
		2016	0.46	0.75		292	54	4		239	248	136
		2017	0.45	0.75		148	40	9		171	353	76
Cheakamus	fall	2007	0.48			2,118	77	8				
		2008	1.13			1,550	85	32				
		2009	2.55			642	38	9				
		2010	3.00			483	20	8				
		2011	2.99			2,322	38	7				
		2012	2.76			858	153	13				
		2013	3.54			1,306	42	10				
		2014	3.80			981	77	23				
		2015	3.21			716	65	3				
		2016	3.39			1,369	25	8				
		2017	3.76			2,028	57	14				
		2018	3.24			1,055	22	3				
	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		474	50	2		449	398	50
		2015	2.71	6.83		185	25	6		119	86	25
		2016	1.73	5.07		149	24	0		314	209	22
		2017	2.88	6.82		416	19	5		334	149	33
		2018	2.33	5.53		566	12	3		358	145	33
Cheekeye	fall	2016	0.90			540	61	16				

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

Cheakamus Age-1+ Electrofishing					
Year	**Season**	**Marks**	**Recaps**	**θ**	**CV θ**
2007	Fall	11	1	0.09	0.95
2007	Fall	13	0	0.00	
2007	Fall	4	0	0.00	
2007	Fall	52	6	0.12	0.38
2007	Fall	20	2	0.10	0.67
2007	Fall	17	3	0.18	0.52
2008	Fall	2	0	0.00	
2008	Fall	4	0	0.00	
2008	Spring	19	5	0.26	0.38
2008	Spring	13	1	0.08	0.96
2008	Spring	18	3	0.17	0.53
2008	Spring	1	0	0.00	
2008	Spring	34	10	0.29	0.27
2008	Spring	9	1	0.11	0.94
2008	Spring	12	1	0.08	0.96
2008	Spring	15	0	0.00	
2009	Fall	2	2	1.00	0.00
2009	Fall	3	0	0.00	
2009	Fall	1	0	0.00	
2009	Fall	3	1	0.33	0.82
2009	Fall	1	0	0.00	
2009	Fall	5	0	0.00	
2009	Fall	2	2	1.00	0.00
2009	Fall	9	2	0.22	0.62
2009	Fall	10	4	0.40	0.39
2009	Fall	7	0	0.00	
2009	Spring	2	1	0.50	0.71
2010	Spring	40	6	0.15	0.38
2010	Spring	39	4	0.10	0.47
2010	Spring	15	4	0.27	0.43
2010	Spring	19	3	0.16	0.53
2010	Fall	11	1	0.09	0.95
2010	Fall	5	0	0.00	
2010	Fall	16	7	0.44	0.28
2010	Fall	16	1	0.06	0.97
2011	Fall	8	1	0.13	0.94
2011	Fall	6	0	0.00	
2011	Fall	3	0	0.00	
2011	Fall	1	0	0.00	
2013	Fall	1	0	0	
2013	Fall	1	0	0	
2013	Fall	1	0	0	
2013	Fall	3	2	0.66667	0.41
2013	Fall	1	0	0	
2013	Fall	1	0	0	

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 the Cheakamus River in fall and spring of 2018. Note index sites used in the estimation are specific to river, year, and season, while mark-recapture data is aggregated across years and seasons for both gear types and among rivers in the case of snorkeling only.

				Index Sites			Mark Recapture		
River	**Year**	**Season**	**Age**	**EF**	**SN**	**Total**	**EF**	**SN**	**Total**
Cheakamus	2018	Spring	0	80	69	149	57	20	77
			1-2	80	111	191	45	20	65
		Fall	0	107		107	57		57

Table 3.11. 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 3.11. 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 3.11. Con't.

River	Year	Season	Age	Mean	Median	CV	LCL	UCL
Cheakamus	2014	Fall	0+	153.6	151.1	0.13	120.7	199.7
	2015	Spring	0+	23.2	22.9	0.12	18.5	29.7
			1+	7.1	7.0	0.10	5.9	8.5
			2+	2.0	2.0	0.09	1.7	2.4
Brohm	2014	Fall	0+	15.0	14.8	0.13	11.7	19.6
			1+	6.0	5.9	0.12	4.8	7.4
			2+	1.8	1.8	0.15	1.4	2.5
	2015	Spring	0+	2.0	1.9	0.18	1.4	2.7
			1+	0.9	0.8	0.11	0.7	1.1
			2+	0.6	0.6	0.13	0.5	0.8
Cheakamus	2015	Fall	0+	146.6	141.4	0.22	98.8	222.0
	2016	Spring	0+	33.8	32.9	0.18	24.5	48.2
			1+	14.2	14.1	0.11	11.5	17.9
			2+	1.6	1.6	0.10	1.3	1.9
Brohm	2015	Fall	0+	24.4	24.3	0.11	19.7	30.1
			1+	3.1	3.1	0.15	2.4	4.2
			2+	1.3	1.3	0.17	1.0	1.8
	2016	Spring	0+	3.7	3.6	0.17	2.7	5.1
			1+	0.9	0.9	0.11	0.7	1.1
			2+	0.4	0.4	0.17	0.3	0.6
Cheakamus	2016	Fall	0+	241.2	237.2	0.14	184.3	322.4
	2017	Spring	0+	57.2	56.7	0.10	47.9	69.6
			1+	10.5	10.4	0.09	8.8	12.4
			2+	2.5	2.4	0.09	2.1	2.9
Brohm	2016	Fall	0+	21.2	21.0	0.11	17.2	26.2
			1+	4.4	4.3	0.14	3.4	5.7
			2+	0.8	0.8	0.21	0.6	1.2
	2017	Spring	0+	1.9	1.8	0.18	1.3	2.6
			1+	1.2	1.1	0.12	0.9	1.5
			2+	0.3	0.3	0.13	0.2	0.4

Table 3.11. Con't.

River	Year	Season	Age	Mean	Median	CV	LCL	UCL
Cheakamus	2017	Fall	0+	337.5	332.8	0.14	259.9	441.6
Brohm	2017	Fall	0+	37.9	35.9	0.27	25.2	63.9
			1+	6.2	6.2	0.13	4.9	8.0
			2+	1.3	1.2	0.17	0.9	1.7
Cheakamus	2018	Spring	0+	81.1	79.4	0.16	61.5	111.3
			1+	9.7	9.6	0.11	7.9	12.0
			2+	2.4	2.4	0.10	2.0	2.9
	2018	Fall	0+	178.4	175.2	0.14	137.4	237.5

Table 3.12. 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. 0+-1+ survival rates in years effected by high and moderate pink salmon abundance are highlighted in pink and light pink, respectively.

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	789		
	0+	Fall-08	236.5	30%	
	0+	Spring-09	48.6	21%	
	1+	Spring-10	18.3	38%	8%
2009	Eggs	Spring-09	500		
	0+	Fall-09	97.7	20%	
	0+	Spring-10	22.0	22%	
	1+	Spring-11	3.5	16%	4%
2010	Eggs	Spring-10	1,477		
	0+	Fall-10	70.0	5%	
	0+	Spring-11	31.9	46%	
	1+	Spring-12	19.6	61%	28%
2011	Eggs	Spring-11	2,642		
	0+	Fall-11	389.4	15%	
	0+	Spring-12	87.3	22%	
	1+	Spring-13	11.56	13%	3%
2012	Eggs	Spring-12	1,266		
	0+	Fall-12	150.3	12%	
	0+	Spring-13	48.9	33%	
	1+	Spring-14	45.6	93%	30%
2013	Eggs	Spring-13	2,699		
	0+	Fall-13	246.7	9%	
	0+	Spring-14	52.5	21%	
	1+	Spring-15	7.0	13%	3%
2014	Eggs	Spring-14	1,230		
	0+	Fall-14	151.1	12%	
	0+	Spring-15	22.9	15%	
	1+	Spring-16	14.20	62%	9%
2015	Eggs	Spring-15	1,472		
	0+	Fall-15	141.4	10%	
	0+	Spring-16	32.9	23%	
	1+	Spring-17	10.5	32%	7%
2016	Eggs	Spring-16	1,351		
	0+	Fall-16	237.2	18%	
	0+	Spring-17	56.7	24%	
	1+	Spring-18	9.6	17%	4%
2017	Eggs	Spring-17	1,824		
	0+	Fall-17	332.8	18%	
	0+	Spring-18	79.4	24%	
2018	Eggs	Spring-18	496		
	0+	Fall-18	175.2	35%	

Table 3.12. 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	5.9	154%		
		1+	Spring-15	0.8	14%	22%	5%
	2014	0+	Fall-14	14.8			
		0+	Spring-15	1.9	13%		
		1+	Fall-15	3.10	161%		
		1+	Spring-16	0.89	29%	46%	6%
	2015	0+	Fall-15	24.27			
		0+	Spring-16	3.61	15%		
		1+	Fall-16	4.33	120%		
		1+	Spring-17	1.1	26%	32%	5%
	2016	0+	Fall-16	21.0			
		0+	Spring-17	1.8	9%		
		1+	Spring-18	NA	NA	NA	NA

Table 3.13. Comparison of Steelhead smolt production estimates for the Cheakamus River from 2009-2017 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**	**2015**	**2016**	**2017**
Juvenile Survey Parr Abundance									
Age 1 Parr (--> 2 Yr Smolt)	5,070	14,310	2,410	10,830	8,520	32,850	4,940	10,560	6,330
Age 2 Parr (--> 3 Yr Smolt)	1,560	2,640	1,610	2,770	1,670	2,760	1,160	1,050	1,670
RST Estimates of Smolts									
Total Smolts	7,197	4,974	5,518	2,208	4,455	10,107	2,458	4,919	6,266
% 2 Yr Smolts	75%	49%	56%	33%	55%	21%	59%	79%	28%
% 3 Yr Smolts	23%	44%	43%	61%	45%	63%	41%	13%	63%
% 4 Yr Smolts	2%	3%	2%	6%	0%	16%	0%	5%	9%
2 Yr Smolts	5,369	2,452	3,084	738	2,471	2,122	1,460	3,884	1,772
3 Yr Smolts	1,663	2,179	2,348	1,346	1,984	6,367	998	656	3,936
4 Yr Smolts	163	143	86	124	0	1,617	0	234	557
RST 3 Yr Smolt / Juvenile Survey 2+ Parr Ratio	1.07	0.83	1.46	0.49	1.19	2.31	0.86	0.62	2.36
% Difference (100*(2+ parr - 3 yr smolt)/3 yr smolt)	-6%	21%	-31%	106%	-16%	-57%	16%	60%	-58%

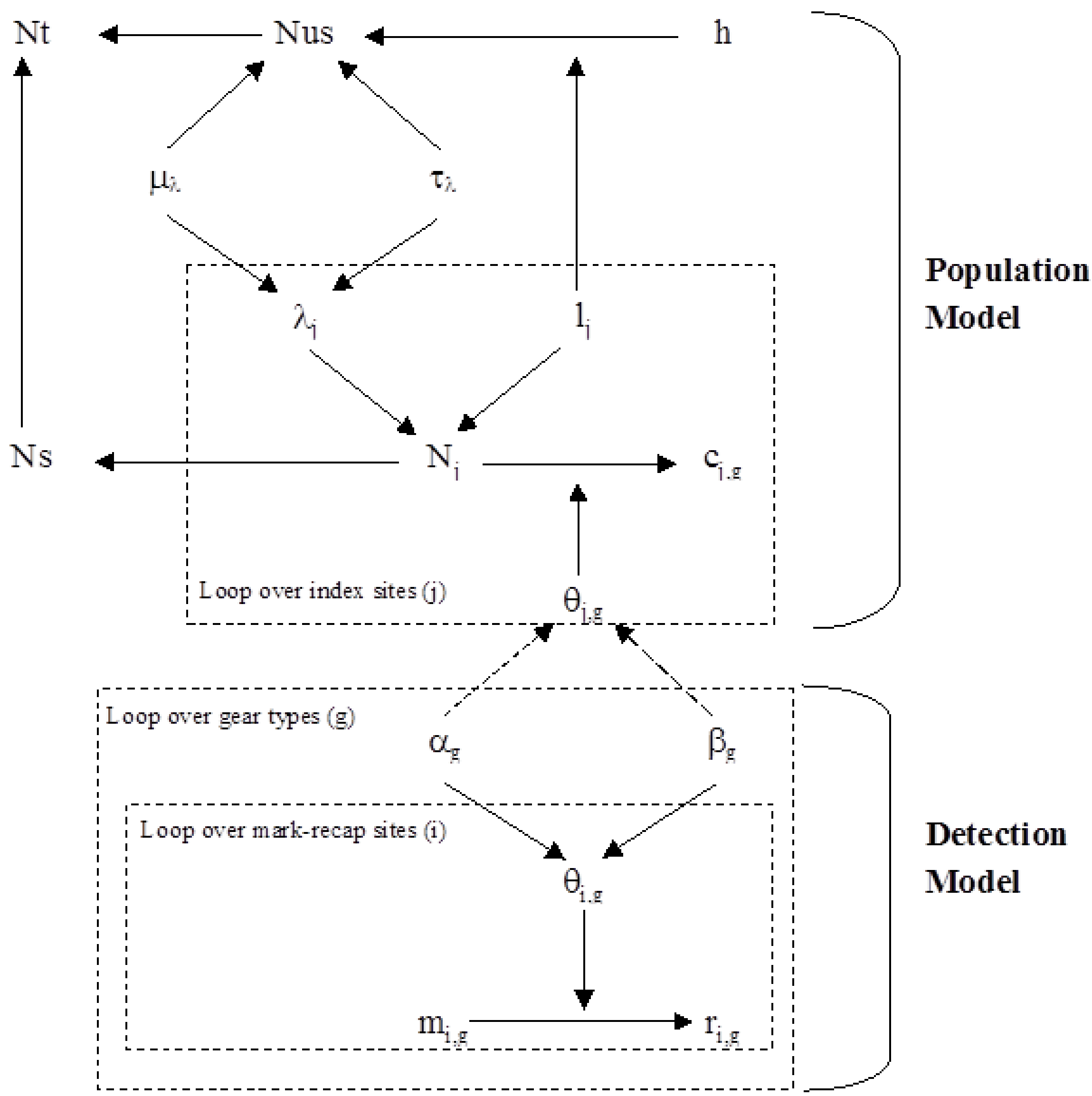

Figure 3.1. Graphical representation of the two-phase hierarchical Bayesian model to estimate juvenile Steelhead abundance in the Cheakamus River. See Table 3.2 for definition of model variables. Arrows indicate conditional dependencies between the variables. The dashed arrows indicate that the hyper-parameters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

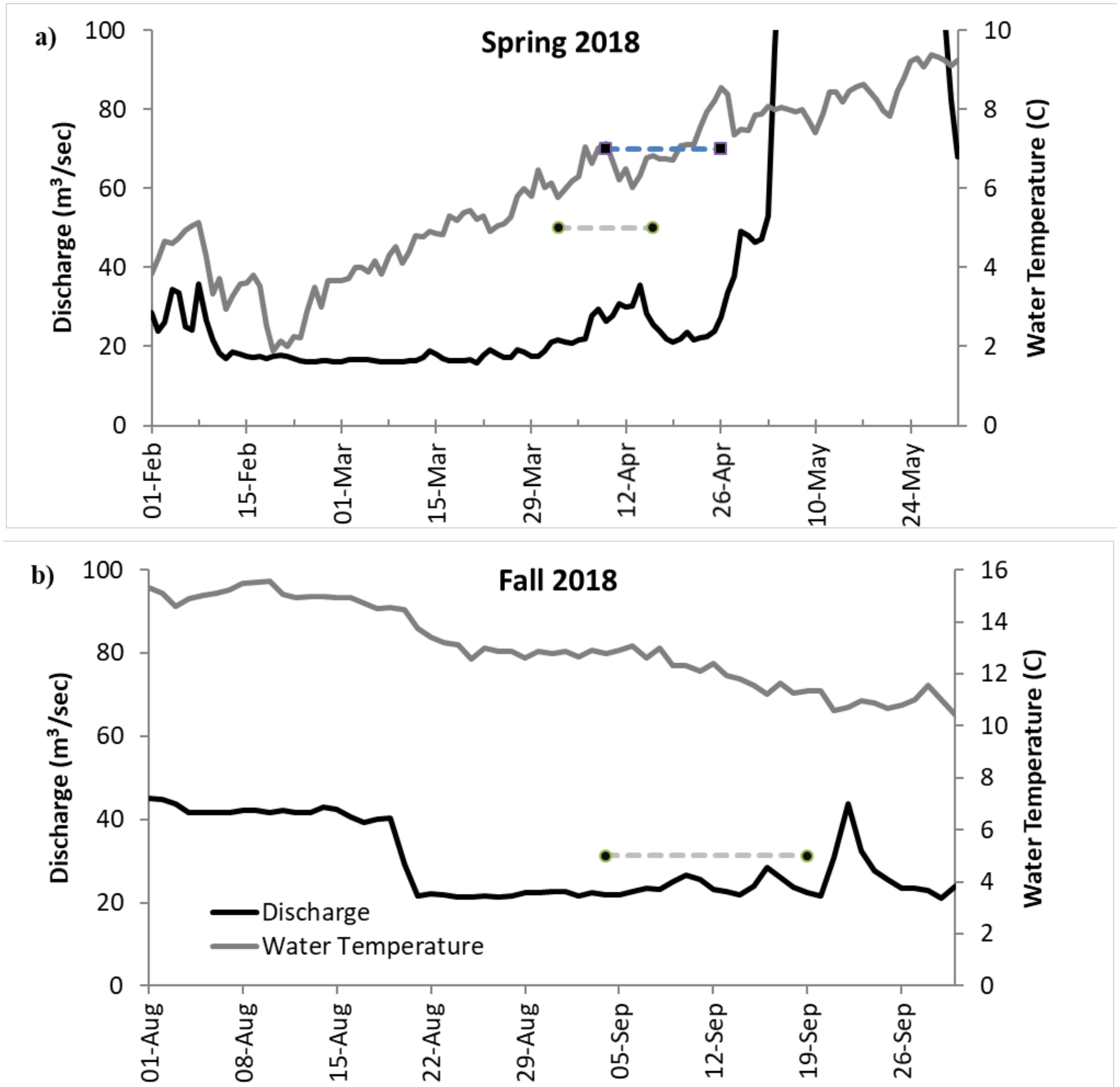

Figure 3.2. Discharge and water temperature at the Brackendale gauge (near Rotary Screw Trap) in the Cheakamus River during the spring (a) and fall (b) of 2018 sampling periods. The horizontal lines show the fish sampling periods. In a), horizontal lines with circles and squares denote snorkeling and electrofishing sampling periods, respectively.

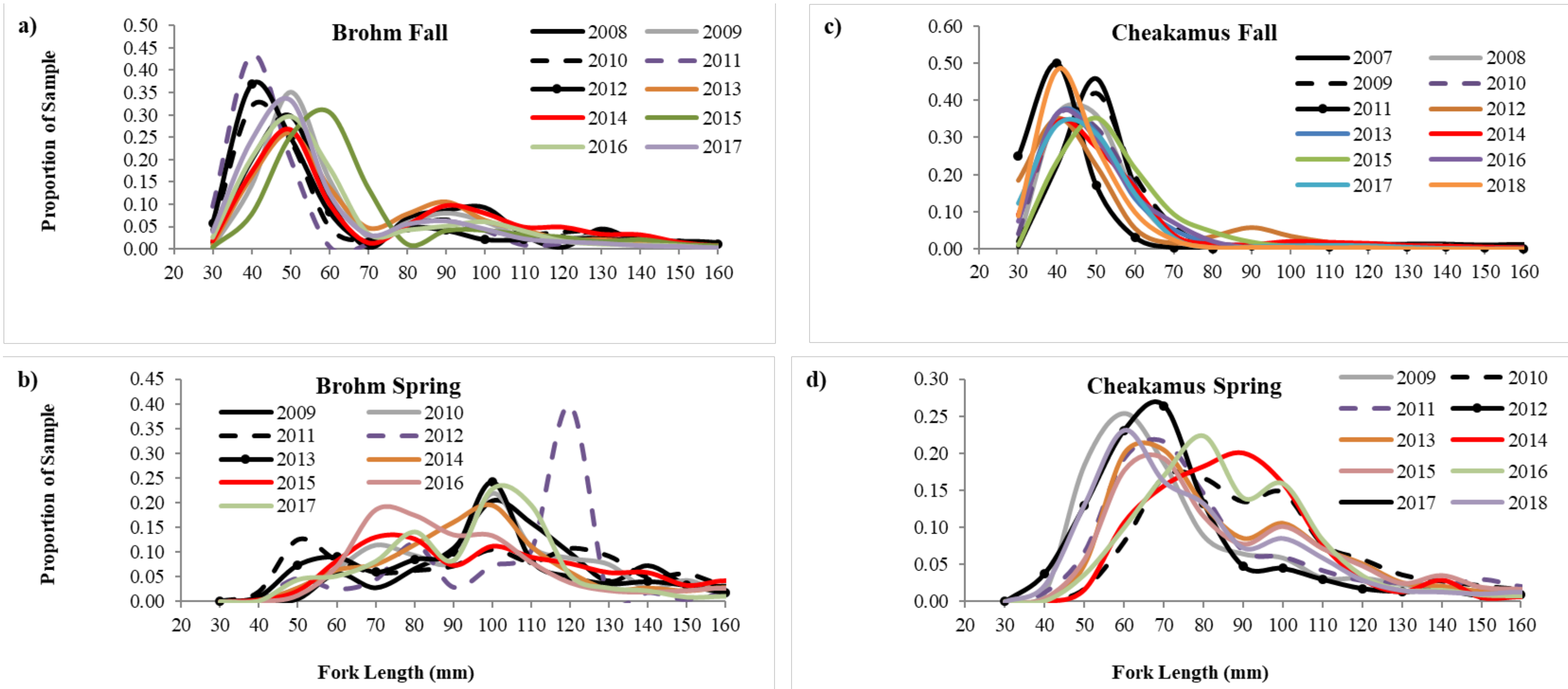

Figure 3.3. Interannual comparisons of length frequency distributions for juvenile Steelhead between years within rivers and seasons. Distributions from fall samples are based on electrofishing only while distributions for spring samples are based on electrofishing and snorkelling for all Cheakamus River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

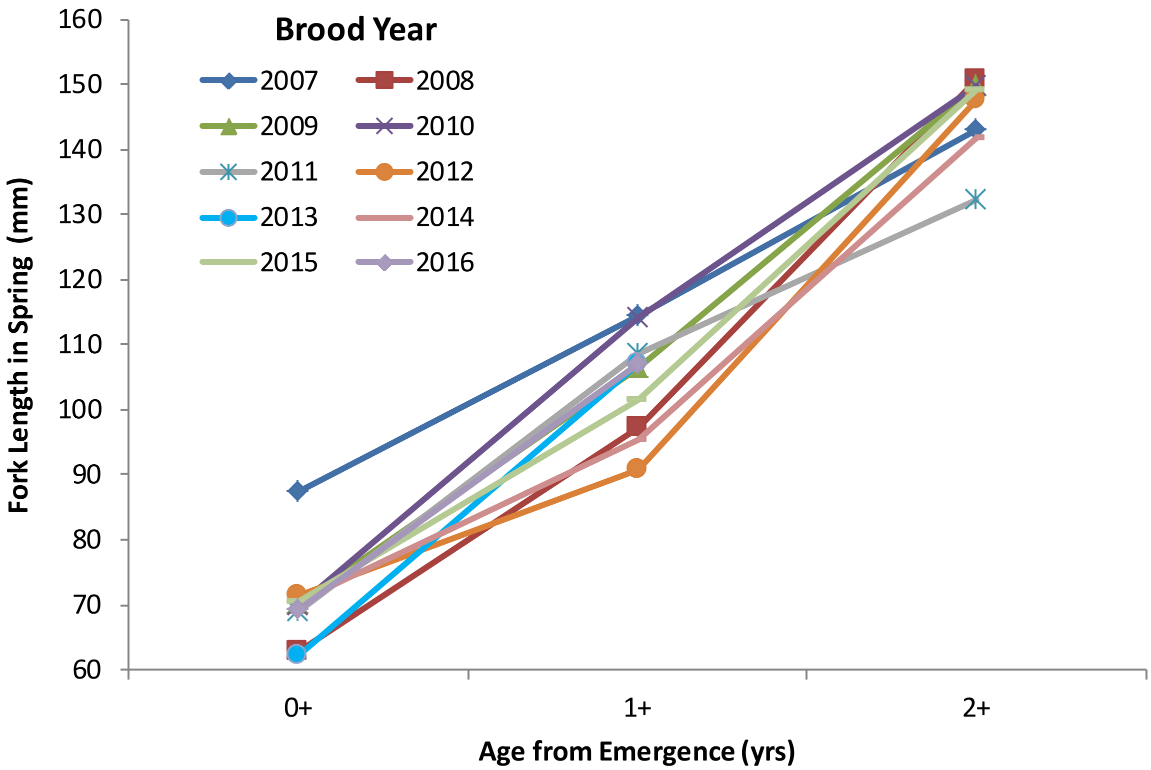

Figure 3.4. Mean size-at-age in spring by brood year for Cheakamus River juvenile Steelhead based on spring samples.

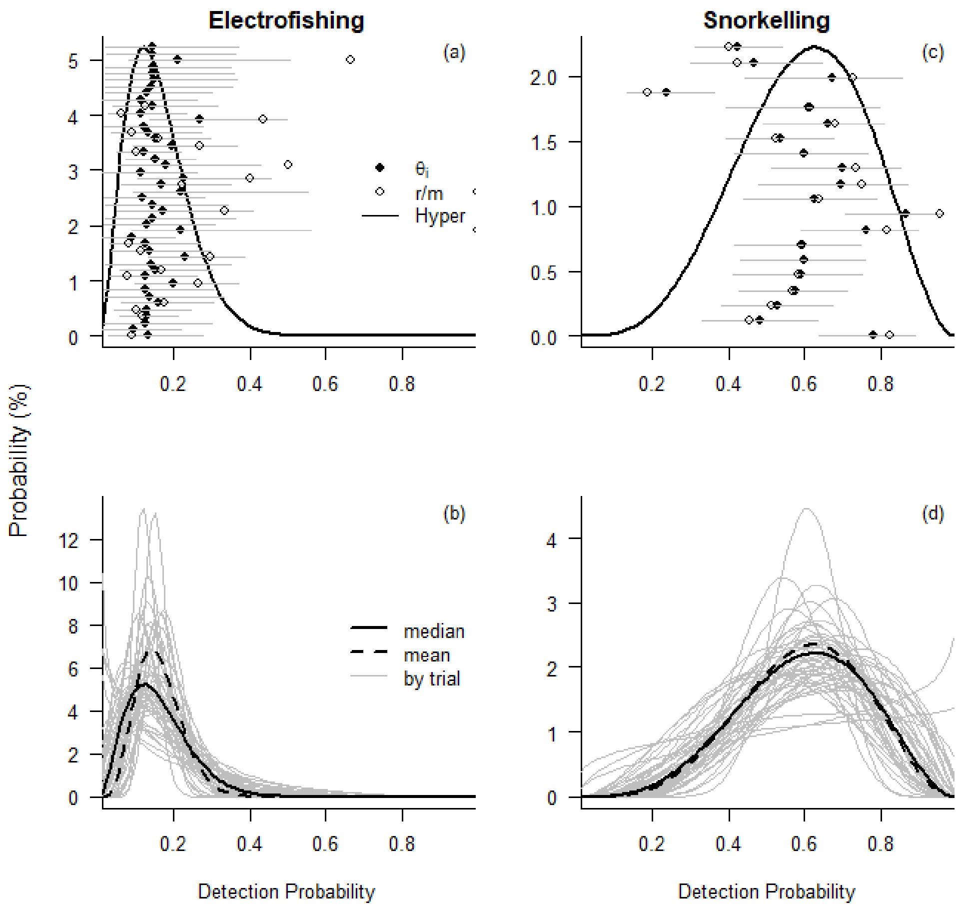

Figure 3.5. Graphical representation of output from the hierarchical Bayesian model that estimates juvenile Steelhead abundance showing results for age 1+ fish in the Cheakamus River in spring 2018. a) and c) show the median hyper-distribution for detection probability, the median estimates of site-specific 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.

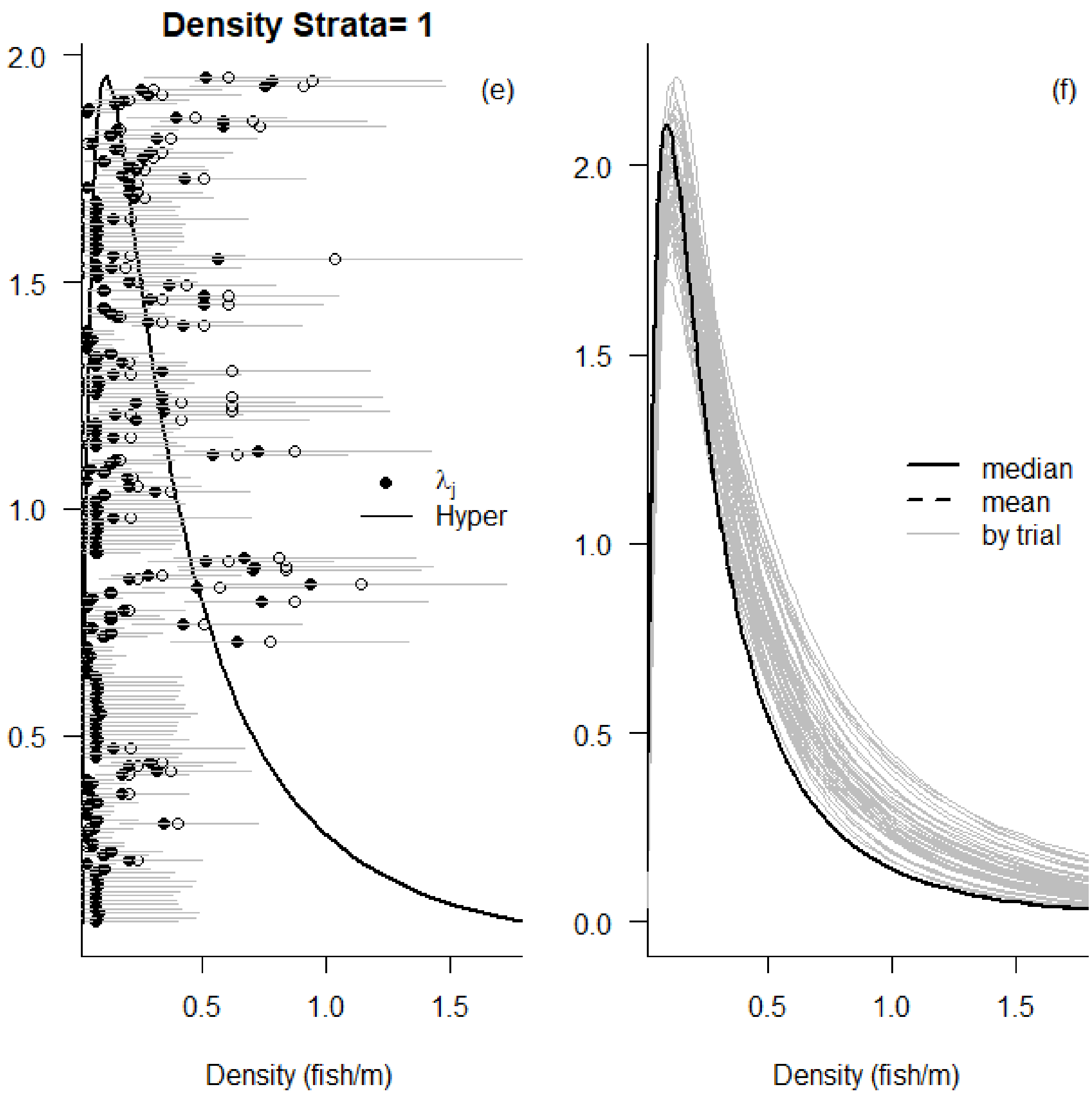

Figure 3.5. Con't.

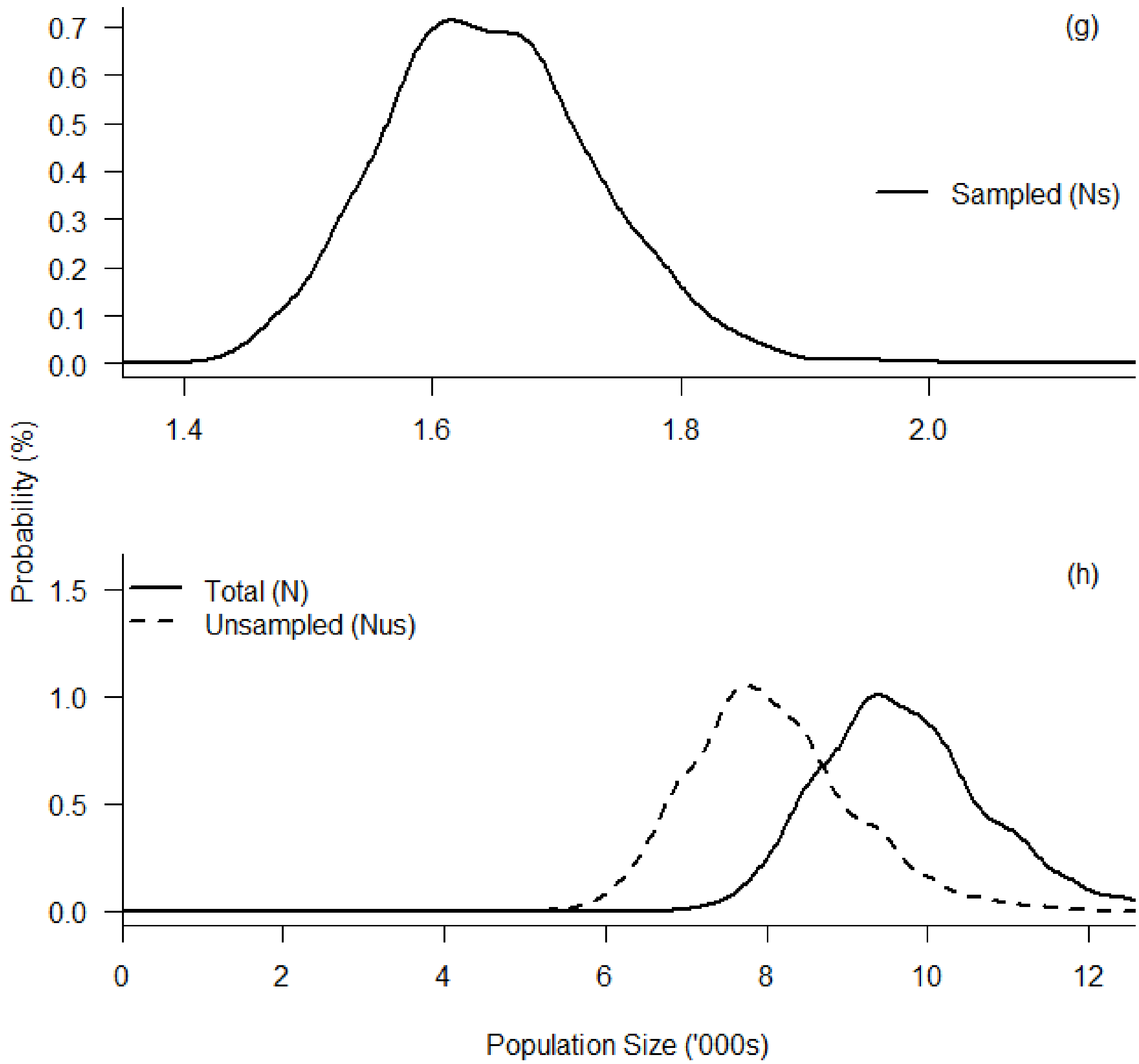

Figure 3.5. Con't.

a) Cheakamus River

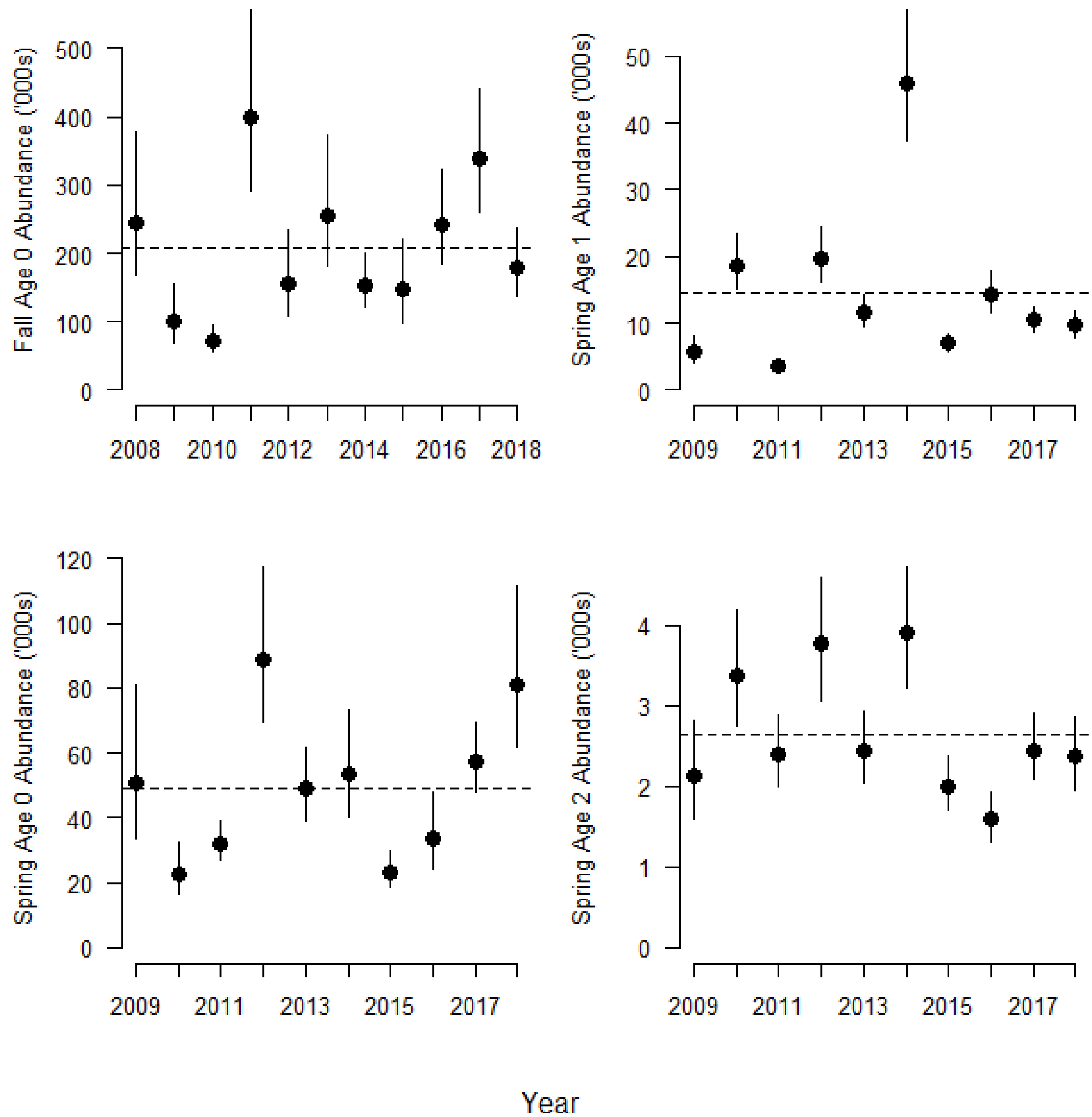

Figure 3.6. Juvenile steelhead abundance estimates in Cheakamus (a) and Brohm (b) Rivers. The height of bars and error bars represent median values and the 95% credible intervals from the HBM (see Table 3.11).

b) Brohm River

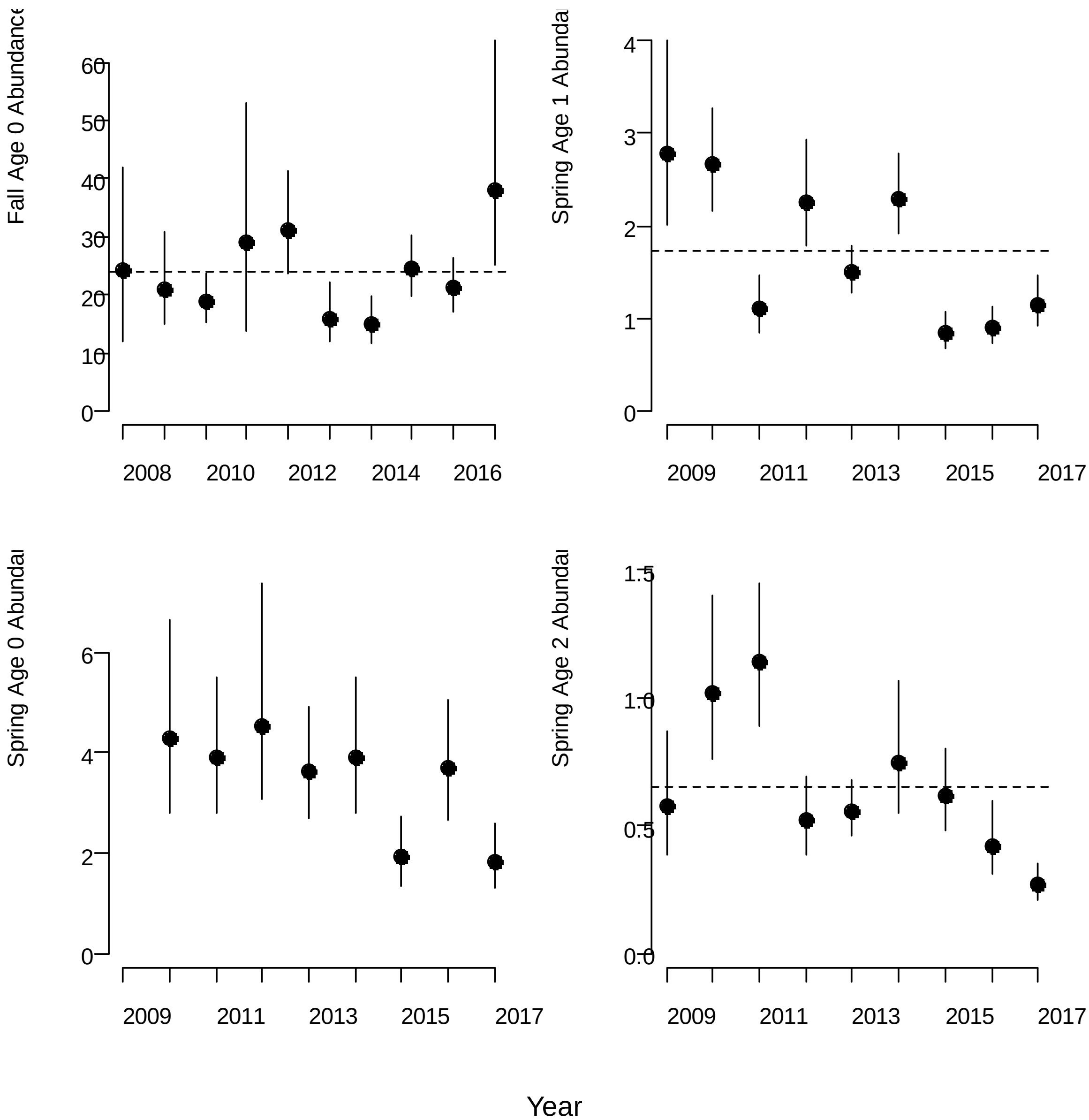

Figure 3.6. Con't.

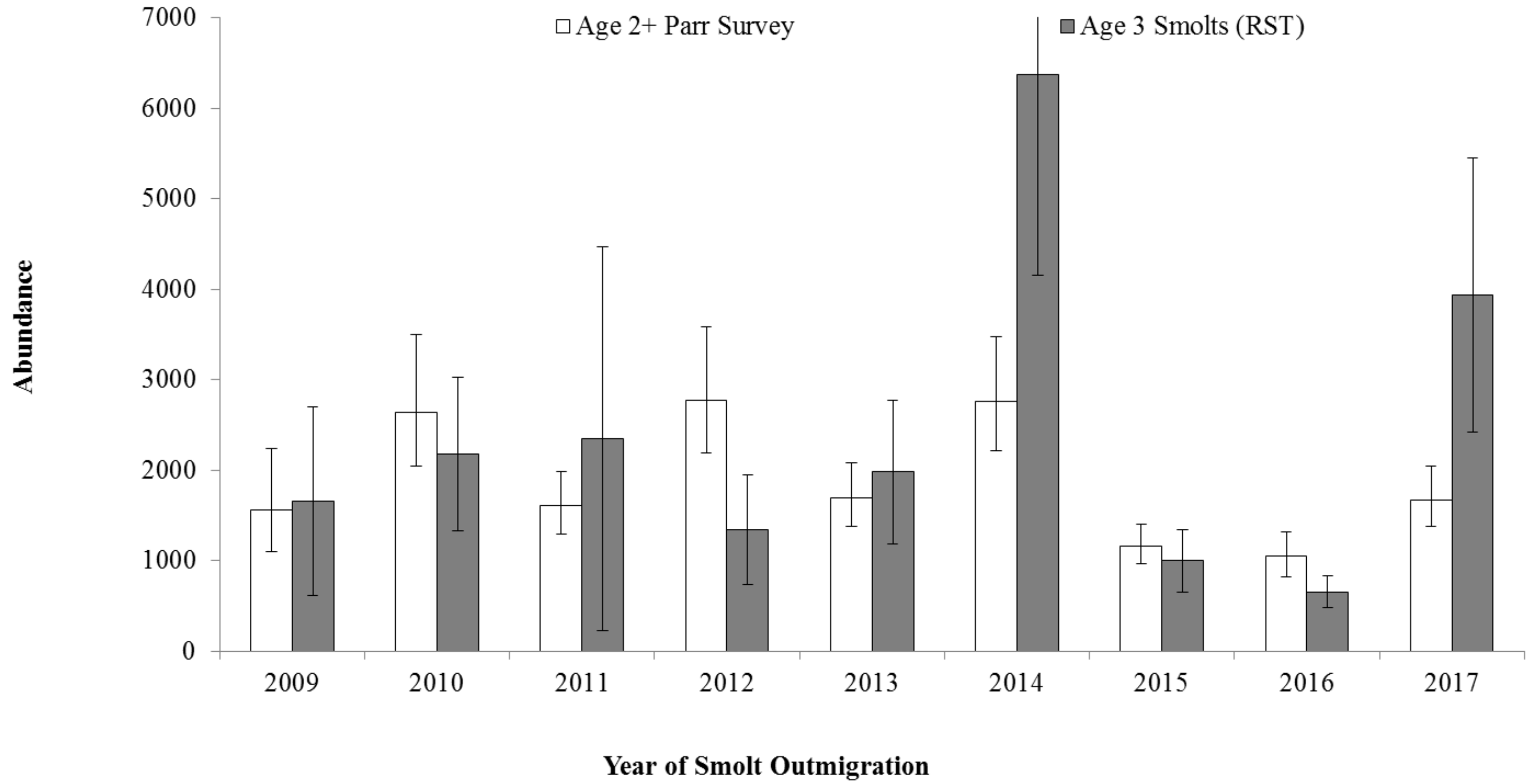

Figure 3.7. Comparison of abundance estimates of age 2 Steelhead parr in the Cheakamus River above the Rotary Screw Trap (RST) in 2009-2017 based on juvenile surveys (based on HBM results developed in this report) with abundance of 3 year smolts at the RST in the same year (based on the Bayesian spline non-diagonal model). Error bars denote 95% confidence limits.

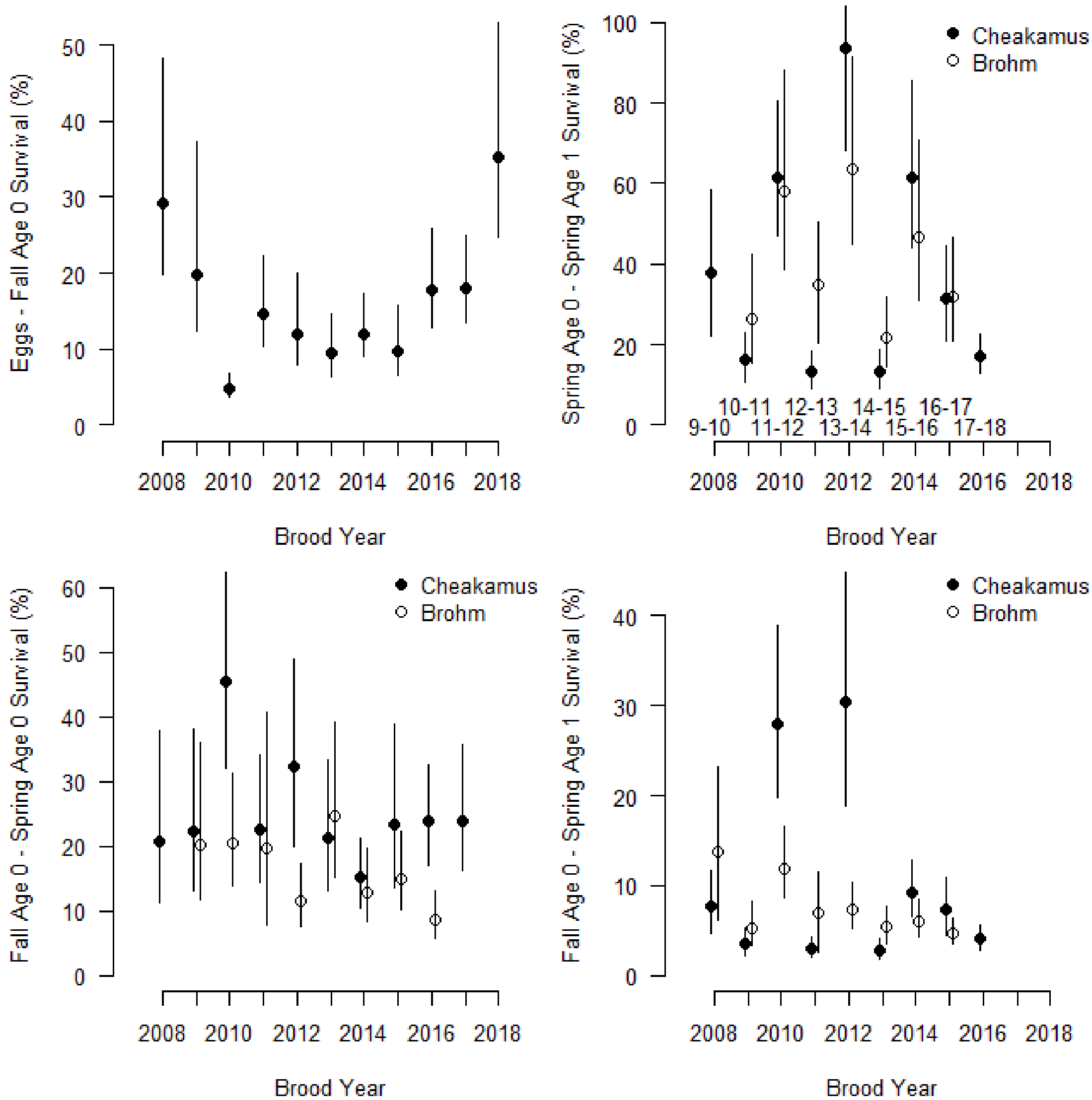

Figure 3.8. Survival by Steelhead life stage in Cheakamus and Brohm Rivers by brood year. Points and vertical lines denote means and 95% credible intervals, respectively.

Appendix A1. Comparison of estimates of steelhead ages determined from scales of returning spawners from different readers

A1.1 Introduction

Data from the Cheakamus steelhead monitoring program has shown an increase in the age of returning steelhead. Based on scales collected prior to 2011 (2000-2010), 72% of smolts spent two winters in the river leaving as 2-year smolts, compared to 40% based on scales collected after 2010 (2011-2017). The population has therefore shifted to one dominated by 2-year smolts to one dominated by 3-year smolts. There has also been an increase in ocean age, with 60% of spawners spending two winters at seas based on scales collected prior to 2011, compare to 32% based on scales collected after 2010. Increases in freshwater and ocean ages have of course led to an increase in the total age of the population. Prior to 2011 the percentage of returning steelhead aged 4, 5, and 6 years was 57%, 31%, and 11%, compared to 11%, 57%, and 31% based on scales collected after 2010, respectively. Changes in freshwater age may be indicative of changes in habitat or juvenile density (both potentially effected by flow), and accuracy in total age estimates over time is needed to correctly assign the brood year (birth year) of returning steelhead needed for the stock-recruit analysis.

Thus, consistency and accuracy in ageing is important to interpretation of Cheakamus steelhead data. However, estimating freshwater and ocean ages of steelhead from reading scales can be challenging because assignment of annuli based on examination of circulii can be quite subjective. Don McCubbing of Instream Fisheries Research (IFR) conducted or supervised the ageing of Cheakamus steelhead scales collected between 2000 and 2013. Beginning in 2014 this work was conducted by other IFR staff no longer under his supervision. In this supplement we compare ages independently assigned by different readers to establish whether the trends in freshwater and ocean ages described above are real, or instead potentially caused by a bias in more recent estimates owing to the change in personnel reading scales for IFR.

A1.2 Methods

We compared freshwater, ocean, and total ages for steelhead, and total ages for resident rainbow trout based on the original IFR reads (supervised by McCubbing up to 2013) with those from two different scale readers. The analysis is based on 286 scales collected from fish angled in the Cheakamus River between 2014 and 2016. Age estimates were independently determined for each fish by Mike Stamford (MS) and Jennifer Buchanan (JS) and compared to the original IFR estimates. Mike Stamford has considerable experience ageing freshwater fish from scales and otoliths, but had no previous experience ageing mykiss from the Cheakamus River. Jennifer Buchanan has approximately 1 year of experience ageing scales for many different species of fish. Primarily, her experience with adult steelhead comes from samples taken on both the Keogh and Cheakamus river systems.

Scale samples were read independently by MS and JS. Samples were photographed in advance so that each reader was using the exact same medium for determining age. Scales were viewed as a whole and at a higher magnification to examine finer details in the centre of the scale. Scales were photographed at the highest magnification that would fit the entire scale in a single frame (usually a 10X magnification) and a higher magnification images just of the centre (30X). Some resident samples could be fully photographed at 30X magnification. The ages of scales determined independently from each reader were compared. Readers reviewed scales where their ages did not agree and came to a consensus when possible.

We also compared the morph classification of mykiss that were angled (resident rainbow or steelhead) based on examination of external characteristics at the time of capture (size, coloration, spotting pattern, presence of sea lice) with classifications based on examination of scales. The assumption in doing this is that the scale classification of morph will be more accurate. We also compared the percentage of fish classified as resident among scale readers to evaluate how variable this determination is.

A1.3 Results

There was complete agreement in total age estimates for steelhead for 50% of the scale reads between IFR and MS, 54% between IFR and JB, and 73% between MS and JB (Table A1.1). It is likely that the better agreement for MS and JB reads was due to initial discussions about scale characteristics prior conducting their independent reads. The discrepancy in total ages of steelhead among readers was caused mainly by greater discrepancies in freshwater age estimates. The percentage of scales assigned the same freshwater ages ranged from 54% and 57% based on IFR vs. MS and IFR vs. JB comparisons, and 74% and 77% for ocean ages, respectively (Table A1.2). Discrepancies among readers in freshwater age were generally centered near zero with no tendency for under- or over-aging (Table A1.3a). When using data from all years, the freshwater age proportions were relatively consistent among readers (Table A1.4a, ’14-’16). However, when we examined the data by year there was quite a bit of variation in freshwater age structure among readers in some cases. For example in 2014, IFR estimated 81% of smolts were 3 years old compared to 55% and 44% for MS and JB (Table A1.4a). In 2016, MS estimated 22% age 4 year smolts compared to 4% for IFR and JB.

Discrepancies in ocean ages for steelhead were smaller than for freshwater ages with no tendency for over- or under-aging among readers (Tables A1.3b and A1.4b). We did note that ocean age estimates from IFR in 2016 showed a higher proportion of ocean age 3 fish (79%) compared to MS (57%) and JB (64%) relative to other years (Table A1.4b). The high estimate of ocean age 3 fish in 2016 from the original IFR reads was one of the motivations for conducting this ageing analysis, and this comparison suggests that ocean age was overestimated by IFR in this case.

Resident rainbow trout showed the largest discrepancies in age estimates among readers. There were considerable discrepancies between IFR estimates compared to estimates from MS or JB (24-36% correct, Table A1.2). As for steelhead, MS and JB resident rainbow ages showed better agreement (48%), the but the level of agreement for resident rainbow trout age was low relative to their agreement on steelhead. JB estimates of resident rainbow trout age tended to be lower compared to other readers. As a result, the proportion of younger fish was higher based on JB reads (e.g. 71%-76% $\leq$ age 5 years, Table A1.5).

Assuming scale-based assessment of morph is more accurate than field-based assessment, there was moderate error in field-based assignment of mykiss morph. Using data from all three years (2014-2016), 17% of mykiss classified as resident rainbow trout in the field were actually steelhead based on scale reads, while only 4% of mykiss classified as steelhead in the field were actually resident rainbow trout (Table A1.6). The low classification error rate for steelhead was consistent among years. In contrast, classification error for resident rainbow trout increased over time with the lowest value of 3% in 2014, and the highest value of 30% in 2016. It is likely this error is partly determined by the degree of overlap in size distributions of the two morphs (Table A1.7).

In 2014 there was limited overlap largely due to the smaller size distribution of residents. In 2015 there was a higher proportion of larger residents, and in 2016 there was a higher proportion of smaller steelhead. There were five fish less than 500 mm that were classified as steelhead based on scale reads in 2016. Fork length was likely incorrectly recorded for one fish which was a repeat spawner with a total age of 6. The other fish assigned a steelhead morph via a scale read was not aged. The 3 remaining fish had spent only one sea winter at sea. Discrepancies between field- and scale-based morph assignments could also be due to uncertainty in morph assignment based on scale reads. A conclusive determination of morph can only be done using otolith microchemistry. In the absence of this information we cannot determine if scale reads are 100% accurate with regards to morph classification. Regardless, there is a relatively consistent classification of the resident morph among readers. Based on using all scales from 2014 to 2016, MS, JB, and IFR estimated that 24%, 29%, and 29% of samples were resident rainbow trout, respectively (Table A1.8).

A1.4 Discussion

There was better agreement in steelhead and resident rainbow trout ages between the two biologists involved in the 2014-2016 age comparison (MS, JB) compared to the extent of agreement between these biologists and the original IFR reads. As mentioned above, this likely occurred because MS and JB discussed scale characteristics and interpretation prior to conducting their independent reads. This highlights the need to carefully review protocols each year prior conducting the age analysis. This analysis has provided a large reference set of scales (with digital pictures) with a consensus age from MS and JB. Prior to conducting reads in future years, we recommend that the IFR reader (JS) review the reference collection to ensure consistency with past estimates. Estimates of age for 2014-2016 used in the long-term assessment will be based on the consensus MS and JB ages.

Discrepancies among readers were greatest for resident rainbow trout ages, intermediate for steelhead freshwater ages, and lowest for ocean ages. This pattern was likely driven by challenges in observing annuli in freshwater caused by relatively short periods of good growth which separate winter checks. In addition, defining the first winter check can be very challenging owing to the limited time between when recently emerged fry begin developing scales and when the winter-low growth period begins.

Most importantly, this age comparison did not raise any red flags regarding the trend in freshwater and ocean age for Cheakamus steelhead before and after 2010. While the repeatability of IFR estimates of freshwater age with MB and JS was only moderate (56-57%), there was no tendency for IFR estimates to be too high (except in 2014), which would lead to the mistaken conclusion that smolt age has increased since 2010 as seen in the data. The long-term age data also shows an increase in ocean age. This analysis showed little discrepancy in ocean age estimates among readers and no tendency for IFR to overestimate ocean age except in 2016. We therefore conclude that the observed shift in age structure for the Cheakamus steelhead population after 2010 is real and not an artefact of ageing error.

Table A1.1. Contingency tables summarizing steelhead total age estimates from the original Instream Fisheries Research reads (IFR) with those from two independent readers (MS, JB). Cells shows the number of steelhead assigned an age by each reader, with the diagonal cells highlighted in grey showing the number of fish where the same ages were assigned by both readers. Statistics to the right of each table show the percentage of fish that were assigned the same age by both readers (correct) and the percentage that were over- or under-aged by IFR relative to the other readers (IFR vs. MS, IFR vs. JB), or over- or under-aged by MS relative to JB (MS vs. JB).

		MS						
		4	**5**	**6**	**7**			
IFR	**4**	11	8	5	2		IFR vs. MS	
	5	18	61	32	5		correct	50%
	6	5	13	21	4		over	19%
	7	0	0	0	0		under	30%
		JB						
		4	**5**	**6**	**7**			
IFR	**4**	13	7	6	0		IFR vs. JB	
	5	17	60	32	3		correct	54%
	6	6	11	25	1		over	19%
	7	0	0	0	0		under	27%
		JB						
		4	**5**	**6**	**7**			
MS	**4**	25	4	4	0		MS vs. JB	
	5	10	61	10	0		correct	73%
	6	0	12	42	1		over	16%
	7	0	1	6	3		under	11%

Table A1.2. Comparison of precision of age estimates for resident rainbow trout (RES) and for steelhead (SHA) based on scales collected between 2014 and 2016. Sample size (# of scales aged) and the percentage of scales with 0-4 year differences among agers (IFR, MS, JB) are shown. The 0 yr. age difference column identifies the percentage of scales that were assigned the same age by both readers.

Morph	Age	Comparison	Sample	Percentage of Sample by Age Difference				
	Type		Size	0	1	2	3	4
RES	Fresh	MS-JB	89	48	31	11	8	1
RES	Fresh	IFR-MS	75	36	43	13	3	5
RES	Fresh	IFR-JB	75	24	45	19	8	3
SHA	Fresh	MS-JB	180	74	22	3	0	0
SHA	Fresh	IFR-MS	149	54	40	4	1	1
SHA	Fresh	IFR-JB	148	57	40	1	1	1
SHA	Ocean	MS-JB	187	85	12	2	1	0
SHA	Ocean	IFR-MS	193	74	22	4	0	0
SHA	Ocean	IFR-JB	187	77	17	5	1	0
SHA	Total	MS-JB	180	73	24	3	0	0
SHA	Total	IFR-MS	187	50	40	9	1	0
SHA	Total	IFR-JB	181	54	38	8	0	0

Table A1.3. Contingency tables summarizing steelhead freshwater (a) and ocean (b) age estimates from Instream Fisheries Research (IFR) and two independent readers (MS, JB) based on all samples (2014-2016). See caption for Table A1 for details.

a) Freshwater ages

		MS					
		2	**3**	**4**		IFR vs. MS	
IFR	**2**	24	26	5		correct	56%
	3	28	55	5		over	19%
	4	0	0	1		under	25%
		JB					
		2	**3**	**4**		IFR vs. JB	
IFR	**2**	31	24	1		correct	58%
	3	33	52	2		over	23%
	4	0	0	1		under	19%
		JB					
		2	**3**	**4**		MS vs. JB	
MS	**2**	55	10	1		correct	77%
	3	19	75	0		over	16%
	4	1	8	3		under	6%

Table A1.3. Con't.

b) Ocean ages

		MS						
		1	**2**	**3**	**4**		IFR vs. MS	
IFR	**1**	1	3	1	0		correct	76%
	2	0	64	12	1		over	12%
	3	1	21	78	4		under	11%
	4	0	0	1	0			

		JB						
		1	**2**	**3**	**4**		IFR vs. JB	
IFR	**1**	1	2	2	0		correct	80%
	2	0	59	14	2		over	7%
	3	0	12	84	2		under	12%
	4	0	1	0	0			

		JB						
		1	**2**	**3**	**4**		MS vs. JB	
MS	**1**	1	0	1	0		correct	87%
	2	0	71	15	0		over	3%
	3	0	2	82	3		under	11%
	4	0	0	3	1			

Table A1.4. Proportion of steelhead in each freshwater (a) and ocean (b) age class by year and reader.

a) Freshwater

'14-'16	Freshwater Age		
	2	**3**	**4**
IFR	38%	61%	1%
MS	39%	54%	6%
JB	44%	54%	2%
2014	**Freshwater Age**		
	2	**3**	**4**
IFR	19%	81%	0%
MS	40%	55%	5%
JB	56%	44%	0%
2015	**Freshwater Age**		
	2	**3**	**4**
IFR	59%	41%	0%
MS	40%	55%	5%
JB	37%	60%	3%
2016	**Freshwater Age**		
	2	**3**	**4**
IFR	43%	52%	4%
MS	19%	59%	22%
JB	31%	65%	4%

Table A1.4. Con`t.

b) Ocean

'14-'16	**Ocean Age**			
	1	**2**	**3**	**4**
IFR	5%	62%	32%	0%
MS	0%	70%	27%	3%
JB	0%	66%	32%	3%
2014	**Ocean Age**			
	1	**2**	**3**	**4**
IFR	5%	62%	32%	0%
MS	0%	70%	27%	3%
JB	0%	66%	32%	3%
2015	**Ocean Age**			
	1	**2**	**3**	**4**
IFR	1%	29%	70%	0%
MS	1%	29%	68%	2%
JB	1%	22%	76%	1%
2016	**Ocean Age**			
	1	**2**	**3**	**4**
IFR	0%	18%	79%	4%
MS	4%	36%	57%	4%
JB	0%	32%	64%	4%

Table A1.5. Summary of the percentage of resident rainbow trout in each age class by year and reader.

2014	Total Age						
	3	**4**	**5**	**6**	**7**	**8**	**9**
IFR	0%	29%	24%	39%	8%	0%	0%
MS	3%	33%	14%	39%	11%	0%	0%
JB	15%	32%	24%	24%	5%	0%	0%
2015	**Total Age**						
	3	**4**	**5**	**6**	**7**	**8**	**9**
IFR	0%	28%	28%	33%	11%	0%	0%
MS	0%	40%	10%	20%	20%	10%	0%
JB	5%	24%	48%	10%	14%	0%	0%
2016	**Total Age**						
	3	**4**	**5**	**6**	**7**	**8**	**9**
IFR	0%	22%	30%	35%	4%	4%	4%
MS	0%	40%	10%	20%	20%	10%	0%
JB	0%	41%	29%	12%	18%	0%	0%

Table A1.6. Comparison of mykiss morph assignment based on examination of external characteristics at the time of capture (field) and based on scales (Scale). 'RES' and 'SHA' denote resident rainbow trout and steelhead morphs, respectively. The field error rate is the percentage of fish assigned a 'RES' or 'SHA' in the field that were classified as the other morph based on examination of scales. Results are shown for all years combined and for each year separately.

						Field Error Rate
'14-'16			**Scale**			
		RES	SHA	Total		
Field	RES	73	15	88		17%
	SHA	8	186	194		4%
2014			**Scale**			
		RES	SHA	Total		
Field	RES	36	1	37		3%
	SHA	4	79	83		5%
2015			**Scale**			
		RES	SHA	Total		
Field	RES	18	6	24		25%
	SHA	4	79	83		5%
2016		**Scale**				
		RES	SHA	Total		
Field	RES	19	8	27		30%
	SHA	0	28	28		0%

Table A1.7. Comparison of size distributions for mykiss assigned resident rainbow trout (RES) or steelhead (SHA) morphs based on scale reads by year.

Fork	2014		2015		2016	
Length (mm)	**RES**	**SHA**	**RES**	**SHA**	**RES**	**SHA**
300-325	3					1
325-350	1		2			
350-375	4		1		1	
375-400			2		4	
400-425	3		2		1	2
425-450	5				2	
450-475	4		2		2	2
475-500	1		2		2	
500-525	6		2	1	2	1
525-550	3		1	1	3	
550-575	3	1			1	1
575-600		2	1			
600-625			1	3	1	
625-650	2	2		5		
650-675	1	5	1	1		4
675-700		8		4		
700-725		9	1	7		2
725-750		8	1	11		3
750-775	1	9		5		5
775-800		2		7		4
800-825		8	1	5		4
825-850		6		9		3
850-875		4		12		4
875-900		5		2		
900-925		3		4		
925-950		3	1	3		
950-975		3		4		
975-1000				1		

Table A1.8. The proportion of scale samples assigned resident rainbow trout (RES) or steelhead (SHA) morphs and the percentage that were resident. Results are based on all scales collected between 2014 and 2016.

	MS	JB	IFR
RES	67	79	79
SHA	218	198	194
Total	285	277	273
% RES	24%	29%	29%

Appendix A2. Examination of interannual variation in the relationship between river conditions and diver observer efficiency

Table A2.1. WinBugs source code for estimating parameters predicting observer efficiency as a function of ratio of horizontal visibility to discharge.

```
#Priors for means of hyper-distributions for pCap-HVQ relationship
mu_alpha~dnorm(0,1.0E-03)            #mean of intercept
mu_beta~dnorm(0,1.0E-03)             #mean of slope

#Priors for precision of hyper-distributions for pCap-HVQ relationship
tau_alpha~dgamma(0.01,0.01)          #precision of intercept
tau_beta~dgamma(0.01,0.01)           #precision of slope

#Convert precision to standard deviation (for output only
sd_alpha<-pow(1/tau_alpha,0.5)
sd_beta<-pow(1/tau_beta,0.5)

#Predict intercept and slope for each year based on hyper-parameter means and annual
#deviates (e.g. annual random effects)
for(iyr in 1:Nyrs){
	alpha_dev[iyr]~dnorm(0,tau_alpha)		#intercept
	alpha[iyr]<-mu_alpha+alpha_dev[iyr]

	beta_dev[iyr]~dnorm(0,tau_beta)			#slope
	beta[iyr]<-mu_beta+beta_dev[iyr]
}

#Likelihood. Loop across all swims with tags (Nrecs) and compute observer efficiency
#given annual parameters and swim-specific HV/Q
for(i in 1:Nrecs){
	logit(pCap[i])<-alpha[Yr[i]] + beta[Yr[i]]*HVQ[i]
	exp_r[i]<-R[i]*pCap[i] #expected recaps given tagged fish present and pCap
	r[i]~dpois(exp_r[i])	#Poisson likelihood of observed recaps r given expected
}
```

Table A2.2. Comparison of three alternate models for the relationship between the ratio of horizontal visibility to discharge and diver observer efficiency. The pooled model estimates a single relationship (2 parameters) for all the data (all 10 years of available telemetry data). The HBM model allows variation in both the constant and slope parameters across years (a hierarchical model). The HBM_b0 model allows variation in the constant across years but assumes the slope is constant. pD, DIC, and ΔDIC denote the effective number of parameters, the deviance information criteria, and the difference between each models DIC and the lowest DIC value across models.

Model	**pD**	**DIC**	**ΔDIC**
Pooled	2	444.2	12
HBM	8.3	432.5	0.3
HBM_b0	8.2	432.2	0

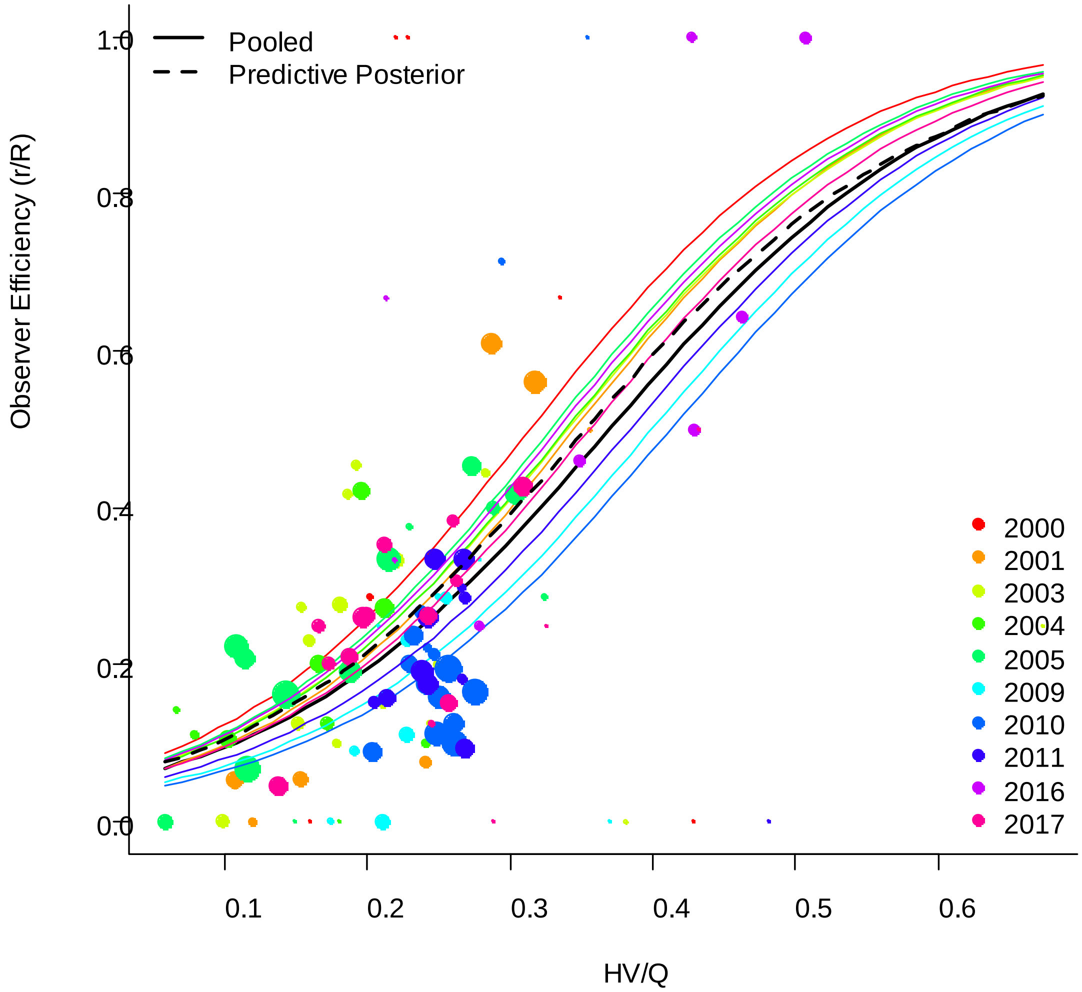

Figure A2.1. Relationship between the ratio of horizontal visibility to discharge (HV/Q) and observer efficiency (pCap) determined based on the number of tagged steelhead resighted (r) compared to the number known to be in the survey area (R). The size of each point reflects the number of tagged fish present in the survey area. The lines show the estimated relationship from the hierarchical Bayesian model which allows both the constant and slope of the relationship to vary across years (model HBM). The solid black line shows the relationship based on the pooled model (one relationship fit to all years) and the dashed black line shows the expected relationship in any year based on the HBM.

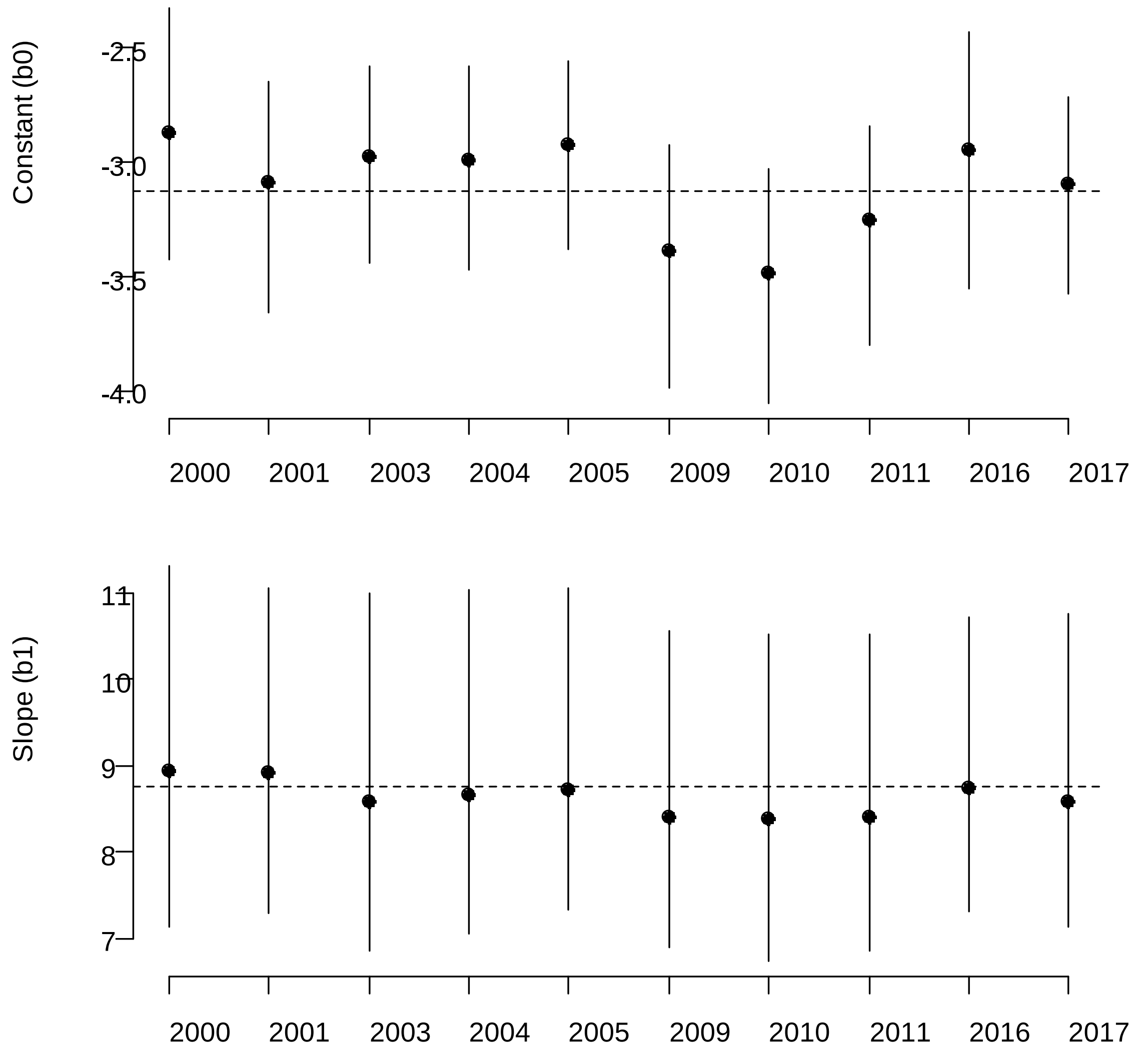

Figure A2.2. Estimates of the constant and slope of the HV/Q-observer efficiency relationship from the HBM model that allows both constant and slope to vary among years (model HBM). Points and vertical lines denote mean estimates and the 80% credible intervals. Dashed horizontal lines show the expected values of the means of hyper-distributions from which annual constant and slope parameters are drawn.

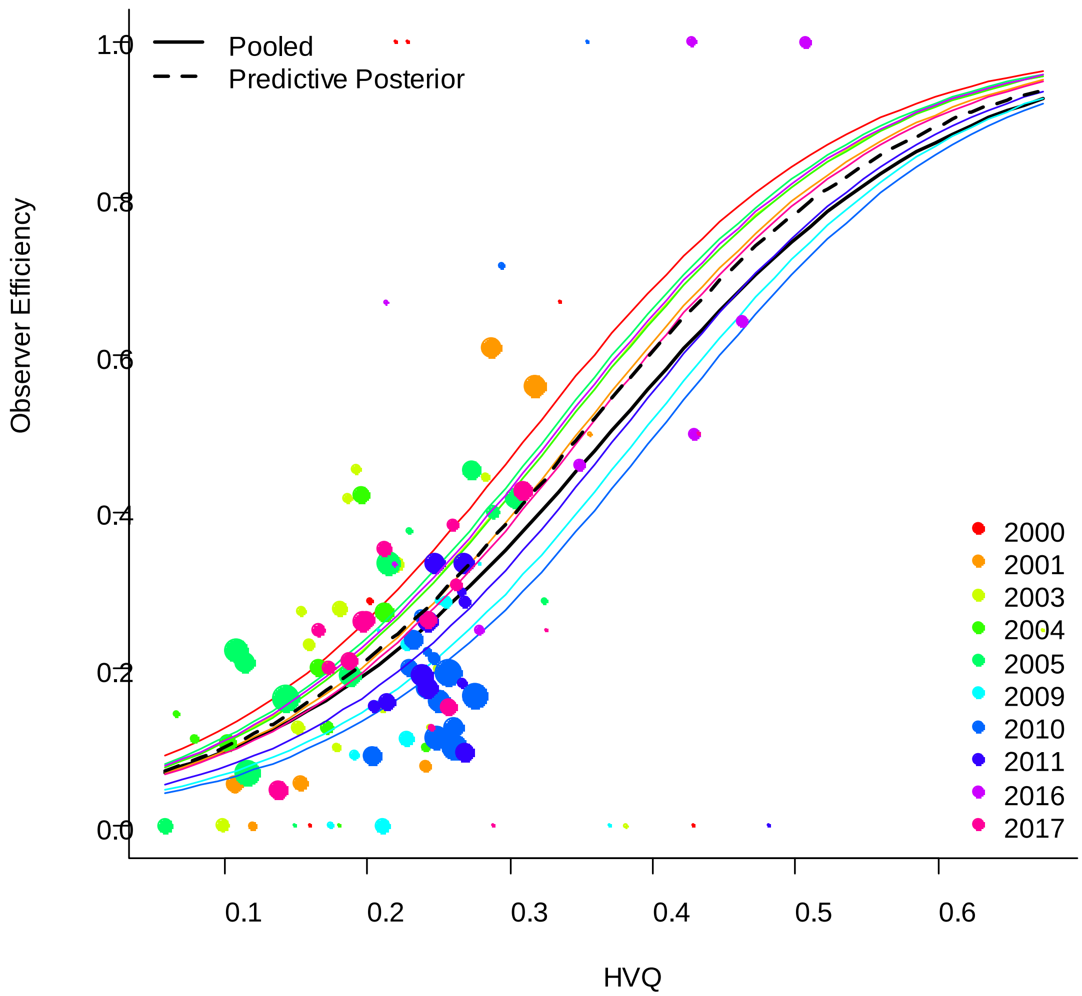

Figure A2.3. Relationship between the ratio of horizontal visibility to discharge (HV/Q) and observer efficiency (pCap) based on the HBM where the constant is allowed to vary across years but the slope is not (HBM_b0). See caption for Figure A1.1 for additional details).

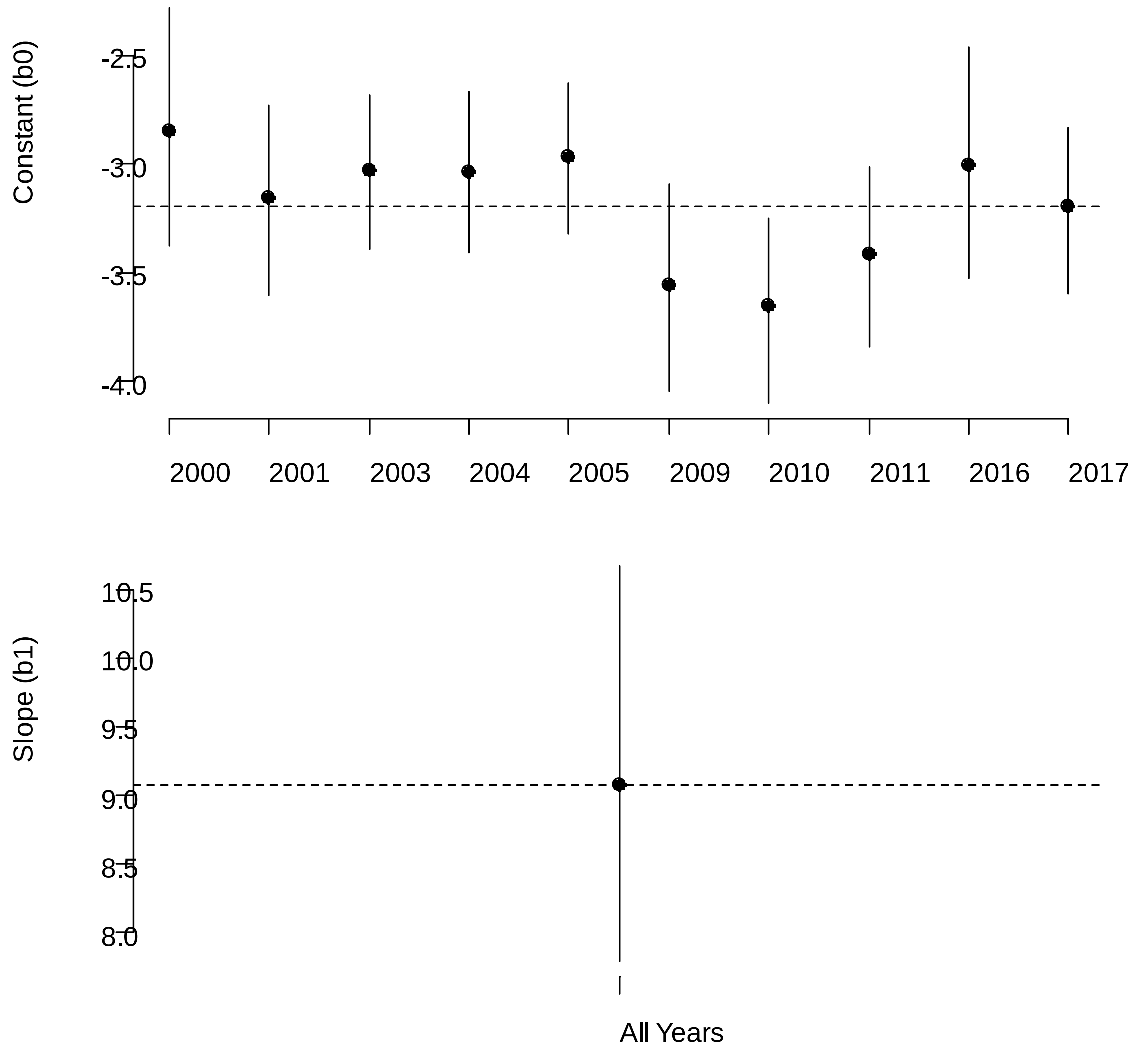

Figure A2.4. Estimates of the constant and slope of the HV/Q-observer efficiency relationship from the HBM model where the constant is allowed to vary across years but the slope is not (HBM_b0). See caption for Figure A1.2 for additional details.

Appendix A3. Source code for resident rainbow trout abundance estimation model

Table A3.1. WinBUGS model used to estimate rainbow trout abundance in the Cheakamus River.

```
##### Estimates of abundance for each year (assumed independent)
for(iyr in 1:Nyrs){
        lgU[iyr]~dunif(lgminU[iyr],8)#unmarked population can't be less than the largest number of unmarked observed
        log(U[iyr])<-lgU[iyr]
        N[iyr]<-U[iyr]+maxR[iyr]      #total abundance (N) is just unmarked abundance estimate + max tags deployed over year
}


#### Model detection probability over swims where tags were present
mu_ltPcap~dnorm(0,1.0E-06)          #Hyper-parameter describing logit normal detection probability
sd_ltPcap~dunif(0.01,5)
tau_ltPcap<-pow(sd_ltPcap,-2)

for(i in 1:N_trecs){     #Loop through all swims where tags are present
        ltPcap[i]~dnorm(mu_ltPcap,tau_ltPcap)       #random draw from detection probability distribution
        logit(Pcap[i])<-ltPcap[i]

        r[t_id[i]]~dbin(Pcap[i],R[t_id[i]])              #likelihood on tags observed given # present (R) and detection

        #Using cut(Pcap[i]) here does not let u[] effect Pcap estimates (and mu_ltPcap and tau_ltPcap estimates)
        pred_u[t_id[i]]<-U[t_YRid[i]]*cut(Pcap[i])

        u[t_id[i]]~dpois(pred_u[t_id[i]])       #Likelihood of observed number of unmarked detected given prediction

        pred_c[t_id[i]] <- pred_u[t_id[i]] + R[t_id[i]]*Pcap[i]        #to compare with observed total count for plot
}
```

Table A3.1. Con't.

```
##### Predict u[] for swims where tags are not present based on random draws from Pcap hyper distribution
for(i in 1:N_ntrecs){
        lt_swPcap[i]~dnorm(mu_ltPcap,tau_ltPcap)            #random draw from hyper distribution

        #using cut(lt_swPcap[i]) does not allow u[] to effect mu_ltPcap and tau_ltPcap parameter estimates)
        logit(swPcap[i])<-cut(lt_swPcap[i])

        pred_u[nt_id[i]]<-U[nt_YRid[i]]*swPcap[i]           #predict unmarked present given abundance and detection
        u[nt_id[i]]~dpois(pred_u[nt_id[i]])                 #liekhood given prediction

        pred_c[nt_id[i]] <- pred_u[nt_id[i]] + R[nt_id[i]]*swPcap[i]          #to compare with observed total count in plots
}
```