Cheakamus Project Water Use Plan

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

Implementation Year 4

Reference: CMSMON-3

Cheakamus River Steelhead Juvenile and Adult Abundance Monitoring

Study Period: Fall 2010 – Spring 2011

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December 1, 2011

Cheakamus River Steelhead
Juvenile and Adult Abundance Monitoring
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Final Report

Prepared for BC Hydro

By

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Abstract

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

Adult Returns

Escapement of steelhead to the Cheakamus River has been conducted annually since 1996 and is determined by combining data from snorkel swim counts and radio telemetry. We conducted a total of 12 swim surveys and radio-tagged 46 fish steelhead in the Cheakamus River in 2011. The tagging study provided an additional year of telemetry data to estimate diver observer efficiency, survey life, and departure timing, which are used in conjunction with count data in a model to estimate escapement. Escapement of steelhead to the Cheakamus River in 2011 was 1071 fish (724 wild-origin, 347 hatchery-origin) with a coefficient of variation (CV) of 0.15. The total rate of return of hatchery-origin smolts released in 2007 and 2008 to mitigate effects of a sodium hydroxide spill was 0.75% and 4.11%. We used information on relative differences in marine survival of hatchery- and wild-origin steelhead from the Cheakamus River based on acoustic tagging (Melnychuck et al. 2009) to estimate a marine survival rate for wild-origin smolts that outmigrated in 2008 of 10.3%. Escapements in 2010 and 2011, even after excluding hatchery-origin spawners, are the highest on record since 1996, largely due to high marine survival of 2008 outmigrants. The high survival of 2008 smolts was very apparent in the age structure of returning adults in 2010 and 2011, with 74% and 68% returning at ocean ages 2 and 3 years, respectively. Returns of wild-origin fish in 2009 were the

lowest on record, likely due to the impact of the sodium hydroxide spill on freshwater juvenile survival. A preliminary stock-recruit relationship indicates that wild-origin steelhead escapement in 2010 and 2011 was more than adequate to fully seed available habitat. Although escapements in 2010 (1144) and 2011 (1071) were similar, egg deposition in 2011 (3.2 million) was two-fold higher owing to the larger size of returning spawners (dominantly ocean age 3 year fish) and higher proportion of females (0.6).

The creel survey and the logbook records from anglers who participated in the tagging program in 2011 documented a total of 993 and 1412 hours of effort, respectively. A total of 167 wild- and 46 hatchery-origin steelhead were landed. Catch per effort in 2010 and 2011 was over 2.5-fold higher than in 2009 due to escapement differences. The proportion of wild-origin steelhead in the catch was 0.43 in 2009, 0.70 in 2010, and 0.78 in 2011. This pattern reflects the declining proportion of hatchery fish in the system over this period due to termination of hatchery stocking as well as the effects of the sodium hydroxide spill and marine survival on wild returns. Hatchery-origin fish returning in 2010 and 2011 were not required to mitigate the effects of reduced recruitment caused by the spill because of higher than expected marine survival rate. However these hatchery-origin fish were available to anglers and contributed to higher catch per effort.

Escapement of steelhead to Brohm River in 2010 and 2011 was estimated based on redd counts and was 70 spawners in both years, compared to estimates from a resistivity counter of 65 and 54 spawners, respectively. Assuming both wild- and hatchery-origin spawners can migrate into Brohm River (as confirmed by radio telemetry in 2011), escapement estimates to Brohm derived from the product of the Cheakamus escapement and the proportion of tagged fish immigrating into Brohm River (~ 6%) were 67 and 70 fish in 2010 and 2011, respectively. These estimates are very close to the redd-based estimates, suggesting that redd counts provide a reliable and highly cost-effective means to determine escapement in Brohm River.

Juvenile Abundance

Estimates of juvenile steelhead abundance in the Cheakamus and Brohm Rivers were derived for fall 2008-2010 and spring 2009-2011 in the Cheakamus River, and fall 2009-2010 and spring 2009-2011 in Brohm River. These values can be used to track abundance and survival rates through time and to relate these patterns to spawning escapement and changes in flow. Fall abundance estimates were based on electrofishing, while spring estimates were based on both electrofishing and snorkeling. Mark-recapture experiments in fall and spring were used to characterize detection probability (the proportion of fish captured or detected). These values were used to expand counts at a large number of index sites sampled by a single pass of effort. A hierarchical Bayesian model (HBM) integrated these data to estimate abundance and uncertainty in abundance estimates.

Index sampling sites covered 21% and 7% of the total useable shoreline length in Brohm and Cheakamus Rivers in fall 2010, and 31% and 20% in spring 2011, respectively. Median abundance estimates of age 0 steelhead in the Cheakamus River in fall ranged from a high of 240,000 in fall 2008, to a low of 70,000 in 2010. Parr abundances in the Cheakamus River in fall are likely biased low due to overestimation of river-wide detection probability, and ranged from 5,000-26,000 for age 1 parr, and 2,000-9,000 for age 2 parr. Age 0, 1 and 2 year abundance estimates in spring, all of which are unbiased, ranged from 23,000-50,000, 3,000-18,000, and 2,000-4,000, respectively. Estimates of age 0, 1, and 2 year abundance in Brohm River in fall ranged from 22,000-24,000, 4,000-5,000, and 2,000-5,000, respectively. Estimates of age 0, 1, and 2 year abundance in Brohm River in spring (excluding 2009 when electrofishing was not done resulting in a negative bias in abundance) ranged from 4,600-5,300, 1,000-3,000, and 1,100-1,200. Abundance in Brohm for all age classes has been very stable through time. Most abundance estimates for the Cheakamus and Brohm Rivers had coefficients of variation of 0.2 or less, especially in recent years when sampling intensity has increased.

Survival rates for various life stages were computed from changes in abundance estimates through time. In the Cheakamus River, egg – fall fry (age 0) survival rates ranged from a high of 45% for the 2008 spawning cohort, to a low of 4% for the 2010 cohort. Survival from fall fry to the spring two winters later (when fish are age 1+) ranged from 4-8% in the Cheakamus River, and 5-12% in Brohm River. Coefficient of variation in these survival rates ranged from 0.22-0.30, which is relatively low considering the challenges of estimating survival rates in moderate-sized river systems.

Estimates of steelhead smolt production derived from juvenile surveys in spring 2009 through 2011 were within 30% of estimates from the Rotary Screw Trap (RST). This may indicate that our production estimates are relatively unbiased. However, the comparison is a relatively insensitive test because of uncertainty in both juvenile survey- and RST-based estimates, and uncertainty in assumptions required to convert abundance of parr into smolt production. The comparison at least establishes that the juvenile and RST-based estimates of juvenile production are in reasonably close agreement. However, there were significant discrepancies in length distributions of fish captured and aged during juvenile surveys compared to those from the RST program. In particular, it appears that age 1 and 2 year steelhead parr captured during the juvenile surveys are too small compared to the sizes of fish aged as 2 and 3 year smolts at the RST. We expected the length frequency distributions for these age classes to differ by no more than 20-30 mm owing to the growth between the time juvenile surveys are conducted (early April) and when most steelhead are captured at the RST (May). However, RST captured fish at a given age (e.g. 2 years) tended to be 50-60 mm larger than fish of the same age captured during juvenile surveys (age 1+ parr). As steelhead are unlikely to growth this much in less than two months, we conclude that fish captured from juvenile surveys are either over-aged, or fish from the RST program are under-aged. We suspect the latter is more likely, but further work is required to evaluate the discrepancy. Regardless, stock-recruit analysis and the comparison of juvenile survey- and RST-based abundance estimates should be considered highly preliminary until this uncertainty is resolved.

The most significant finding from the juvenile analysis conducted to date is the demonstration that reasonable precision in estimates of survival rates across various freshwater juvenile life stages can be achieved. This will likely allow evaluation of the effects of major changes in flow and other abiotic and biotic factors on juvenile survival rates. Given reasonably accurate escapement estimates, we have also shown it is possible to compute egg-fry and egg-parr survival rates, and all these rates can be compared over time and to literature values in unregulated streams to evaluate potential effects of the current and future flow regimes. As an example, the substantive decrease in egg-fall fry survival in 2010 may be due to the much greater egg deposition in that year, resulting in greater density dependent mortality. Alternatively, rapid stage reductions in summer of

2010, aimed at increasing the catch of Chinook broodstock for Tenderfoot Ck. Hatchery, may have increased the mortality rate on recently emerged steelhead using low angle cobble bars that are highly vulnerable to dewatering. We should be able to resolve this uncertainty based on data from 2011 where egg deposition was high and when these rapid stage changes did not occur. If egg-fall fry survival rates for the 2011 cohort are similar to those in 2008 and 2009, this would indicate that rapid stage changes can have a substantive effect on production of steelhead. Our assessment should also be able to resolve whether there is strong density dependence in survival rates for later stages (e.g. for age 0 fish over winter) which could reduce the impacts of flow-related mortality on freshwater production.

Glossary of Terms and Abbreviations

Adipose Fin: A soft, fleshy fin found on the back of a fish behind the dorsal fin and just forward of the caudal fin (tail).

AIC: The Akaikie Information Criteria is a model selection criterion based on parsimony where more complicated models, which may fit the data better, are penalized for the inclusion of additional parameters.

Anadromous: Fish that migrate from the sea to fresh water to spawn.

Beta Distribution: In probability theory and statistics, the beta distribution is a family of continuous probability distributions defined on the interval (0, 1).

Bias: How far the average statistic lies from the parameter it is estimating.

Binomial Distribution: A calculation that measures the likelihood of events taking place where the probability is measured between 0 (the event will certainly not occur) and 1 (the event is absolutely certain).

CV: The Coefficient of Variation is a measure of the ability to repeatedly obtain the same value for a single sample or method (i.e., duplicate or replicate analyses). It is computed by dividing the standard deviation by the mean.

Detection Probability: The fraction of a population in a specific area (e.g., a fish sampling site) that is detected by a unit of effort (e.g., a single pass of electrofishing).

Escapement: That portion of a migrating fish population that is not harvested and escapes to natural or artificial spawning areas.

Fry: A stage of development in young salmon or trout. During this stage the fry is usually less than one year old, has absorbed its yolk sac, is rearing in the stream, and is between the alevin and parr stage of development.

GIS: A Geographic Information System is used to store and display spatially-reference data.

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

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

HBM: A Hierarchical Bayesian Model is most useful for data that is composed of exchangeable groups, such as fish sampling sites, for which the possibility is required that the parameters that describe each group might or might not be the same.

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

Length-Frequency: An arrangement of recorded lengths, which indicates the number of times, each length or length interval occurs.

Maiden Spawner: A steelhead adult returning to freshwater that has not spawned before.

Mark-Recapture: A method to estimate the size of a population. It usually involves live-capturing salmon, marking or tagging them and releasing them back into the water at one location.

Maximum Likelihood: Maximum likelihood estimation (MLE) is a popular statistical method used for fitting a statistical model to data.

Orthophotograph: An orthophoto or orthophotograph is an aerial photograph geometrically corrected ("orthorectified") such that the scale is uniform.

Parr: life stage of salmonid fishes, usually in first or second year, when body is marked with parr marks

Poisson Distribution: A theoretical distribution that is a good approximation to the binomial distribution when the probability is small and the number of trials is large.

Posterior Distribution: The expected distribution of parameter values determined from a Bayesian analysis that is based on prior information about the parameter as well as data being directly used in the estimation.

Precision: The measure of the ability to repeatedly obtain the same value for a single sample or method (i.e., duplicate or replicate analyses). Precision can be quantified by calculated the coefficient of variation (CV).

Prior Distribution: In Bayesian statistics, a prior probability distribution, often called simply the prior, expresses prior knowledge about the uncertainty in a parameter.

Q: An abbreviation for discharge.

Radio Telemetry: Automatic measurement and transmission of data from remote sources via radio to a receiving station for recording and analysis. In this context, it refers to the deployment of radio tags to provide information on the movement and distribution of adult steelhead while in freshwater.

Redd: A egg nest formed in the gravel by salmon and other fish.

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

Smolt: A juvenile salmonid that is undergoing the physiological change to migrate from fresh to salt water

Stock-Recruitment: The relationship between the abundance of animals at one life stage (e.g., spawners) relative their abundance at a later stage (e.g., smolts).

Survey Life: The length of time a surveyed object (e.g., a fish or redd) is visible to an observer (e.g., how long a steelhead spends in the surveyed area).

Thalweg: The deepest part of a stream's channel.

TRIM: Electronic and hard copy maps of topography, streams, and other features in BC at a 1:20,000 scale.

WUP: The Water Use Planning process was used to define new flow regimes and monitoring programs for dams operated by BC Hydro.

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Acknowledgements

This project was supported through a contract from BC Hydro to Ecometric Research to provide data for the Cheakamus River Water Use Plan. Additional funding for the steelhead radio telemetry program was provided by the Canadian National Railway Company and the Habitat Conservation Trust Fund, respectively. Brent Mossop and Ian Dodd provided technical and administrative support, respectively. Robert Ahrens, David Bryan, Scott Decker, Caroline Melville, Brent Mossop, Mathew Rochetta, Jeff Sneep, Mike Stamford, Pier van Dischoeck, LJ Wilson, Heath Zander assisted with the fieldwork. Scott Decker and Don McCubbing provided estimates of age for juvenile and adult steelhead, respectively. Heath Zander conducted the creel survey, and Caroline Melville supervised the angler logbook, creel survey and telemetry programs. Brian Klassen, Clint Goyette, Ken Meehan, Roman LeHockey, Don Moore, Stu Reynolds, Daryl Ross, Tom Velisek, Nathan Webb, and Heath Zander captured adult steelhead and recorded sampling effort for the radio telemetry and angler log book programs. Tami Nicol and Darren Ham provided GIS data and expertise for habitat mapping. Andrew Gelman and Robert Dorazio provided helpful suggestions on the structure of the juvenile hierarchal Bayesian model. Stephen Vincent programmed the animation of radio tagged steelhead distribution.

1.0 General Introduction

The Cheakamus River is a productive tributary of the Squamish River that supports populations of steelhead, chinook, coho, pink, and chum salmon, as well as resident populations of rainbow trout, bull trout, and other species. The Cheakamus River has an unregulated mean annual discharge of 65 $m^3 \cdot sec^{-1}$ (at the Brackendale gauge location) and drains an area of 1032 km^2 of the Coastal Mountain range in southwestern B.C. (Fig. 1.1). It was impounded in 1957 by Daily Lake Dam 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. 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 much smaller today, it still attracts considerable angling effort and is likely one of the more productive wild steelhead population in southern BC (Van Dischoeck 2000). Steelhead juveniles rear for two to four years in the Cheakamus River before migrating to sea as smolts. Steelhead juveniles are potentially more sensitive than other juvenile salmonids in the Cheakamus River to changes in flow because they have a longer period of freshwater residency. All these factors contribute to a strong interest among resource users and fisheries managers in determining whether changes in the flow regime below Daisy Lake Dam are affecting steelhead in the Cheakamus River.

The timing and volume of diversion rates from the Cheakamus River, which effects flow downstream of the dam, have varied considerably since impoundment. From 1958-1994, diversions were largely driven by power generation within the constraints of the original water license. Historical operations did not always follow these constraints, so the Department of Fisheries and Oceans issued an instream flow order (IFO) to BC Hydro in 1997. This order was subsequently modified to become an instream flow agreement (IFA). The IFA specified that the greater of 5 $m^3 \cdot sec^{-1}$ or 45% of the previous seven days average inflow be released downstream (within a daily range of 37-52%). In February 2006, the operating constraints were modified based on a recommended flow regime from the Water Use Plan (WUP). The WUP flow regime was based on meeting minimum flows at the dam and further downstream at Brackendale. Operating rules no longer depend on releasing a fixed fraction of inflows to the reservoir. Under the WUP regime, flows from the dam must now exceed 3 $m^3 \cdot sec^{-1}$ (November 1-March 31st) or 7 $m^3 \cdot sec^{-1}$ (April 1st-Octber 31st), and additional water must be released to maintain minimum flows at Brackendale of 15 $m^3 \cdot sec^{-1}$ (November 1st-March 31st), 20 $m^3 \cdot sec^{-1}$ (April 1st-June 30th), or 38 $m^3 \cdot sec^{-1}$ (July 1st – August 15th or 31st). This history of operations has led to a number of changes in the flow regime in the Cheakamus River. As many of the operating rules focused on minimum flows, and the effect of operations on flow in the Cheakamus River is greatest during winter when inflows are lowest, there has been a noticeable change in minimum flows during winter (Fig. 1.2).

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. Much of the debate focused on steelhead, which is a highly valued species in the watershed and hypothesized to be more susceptible to flows than other salmonids because of its longer freshwater rearing period.

As part of the new water license agreement for the Cheakamus River, BC Hydro currently supports a number of monitoring programs to assess the effects of the WUP flow regime on fish populations downstream of the dam (BC Hydro 2007). This project, which tracks the abundance of returning steelhead spawners and juveniles, is one such program. Its central objectives are to determine if the number of adult returns and juvenile abundance are affected by the WUP flow regime, and more broadly, to determine how flow affects steelhead production in this system. The overall approach of this project is relatively straightforward: 1) quantify escapement and juvenile abundance in the fall and 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. 1.3).

Steelhead escapement to the Cheakamus River has been consistently assessed since 1996 (Korman et al. 2007). The historical time series of escapement in part reflects the rivers capacity to produce steelhead under pre IFA- and IFA-flow regimes. In the future, this time series can be used to evaluate the WUP regime as well. The simplest way to determine whether changes in flow have affected steelhead production is to compare escapement over these time periods (e.g., Fig. 1.3a). However, as escapement is also determined by parental abundance and marine survival, inferences from this comparison may be weak unless flow effects are very large relative to these other factors. To address this limitation, this project will estimate steelhead parr abundance in the spring as an index of freshwater productivity during the period of freshwater residency (e.g., Fig. 1.3b). Each annual estimate of escapement and parr abundance will contribute a single data point to estimate a freshwater stock-recruitment relationship between escapement and parr abundance. The relationship controls for the effects of escapement on juvenile production, and removes any effects associated with changes in marine survival (e.g., Fig. 1.3c). As data points accumulate (Fig. 1.4), it will be possible to relate outliers from the escapement-to-parr stock-recruitment relationship, 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 late fall, or the duration of minimum flow periods during the winter. If the flow regime from Daisy Lake Dam changes in the future, the escapement-to-parr stock-recruitment relationship developed under the current WUP flow regime can be compared to a relationship estimated under the new regime (e.g., Fig. 1.3c).

An escapement-to-parr stock-recruitment relationship is necessary for evaluating population-level effects of flow, but provides 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 late fall could increase mortality of recently emerged age 0 steelhead, but this mortality may not effect subsequent age 1 abundance and overall freshwater production because of compensatory survival responses over the winter due to lower densities. To account for such dynamics, it is necessary to quantify the stock-recruitment relationship for multiple juvenile life stages. This project will therefore develop relationships between escapement and age-0 steelhead in the fall, between age 0 fish in the fall and the following spring, and between age 0 and age 1 fish in the spring (Fig. 1.3). 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.

Uncertainties with regard to the stock structure of the Cheakamus River steelhead population complicate the interpretation of the adult and juvenile abundance data. Brohm River, a secondary tributary of the Cheakamus River (Fig. 1.1), is a potentially important component of the steelhead production in the system. Between 10-40% of radio tagged adult steelhead that entered the Cheakamus River survey area (upstream of the Cheekye confluence) eventually migrated into Brohm River and spawned (Korman et al. 2005). To determine the escapement in the Cheakamus River proper, escapement in Brohm River therefore needs to be estimated so it can be subtracted from the aggregate estimate that is currently obtained. In addition, an unknown proportion of juvenile steelhead that originated in the Brohm River may migrate into the Cheakamus River and contribute to the estimate of total abundance in the Cheakamus. Three working hypotheses can be used to describe the range of possible dynamics between Brohm and Cheakamus stocks: 1) Brohm and Cheakamus steelhead can be treated as a single stock. Returning adults have no fidelity to the river they were spawned in, and juveniles fertilized in Brohm River can migrate into and rear in the Cheakamus River; 2) Brohm and Cheakamus are completely independent stocks. Adults always return to the river they were spawned in and juveniles rear entirely in their natal systems; 3) An intermediate case where there is some site fidelity and some straying among returning adults and rearing juveniles. This program will attempt to evaluate the likelihood of these hypotheses through monitoring of escapement and juvenile abundance in Brohm River.

This report summarizes and interprets data from the fourth year of the Cheakamus River WUP steelhead monitoring project, covering the fall 2010 and spring 2011 surveys (Fig. 1.4). See Korman 2008 and Korman et al. 2010 and 2011 for year 1, 2, and 3 results, respectively. The year 4 report is divided into two main chapters. Chapter two summarizes the adult escapement methods and results, and includes a summary of creel and telemetry information collected in 2009-2011 to determine the proportion of hatchery- and wild-origin steelhead in the escapement. Chapter two also includes information on adult escapement to Brohm River. Chapter three summarizes the methods and results from the juvenile abundance program.

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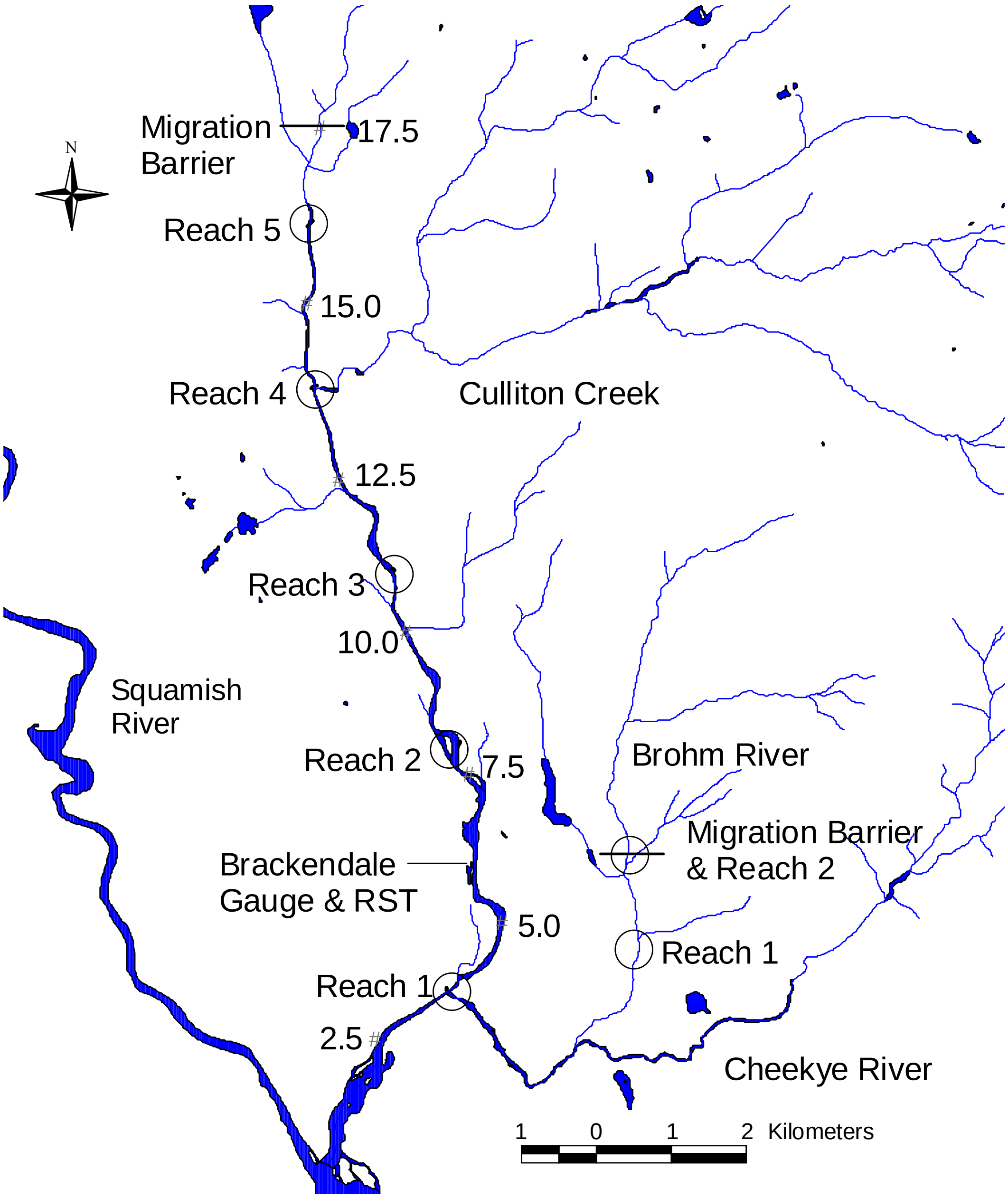

Figure 1.1. Map of the Cheakamus River study area showing the locations of the upstream limit of reach breaks used for habitat and juvenile surveys (open circles), distance (km) from the Squamish River confluence (gray points), migration barriers for anadromous fish in the Cheakamus and Brohm Rivers,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

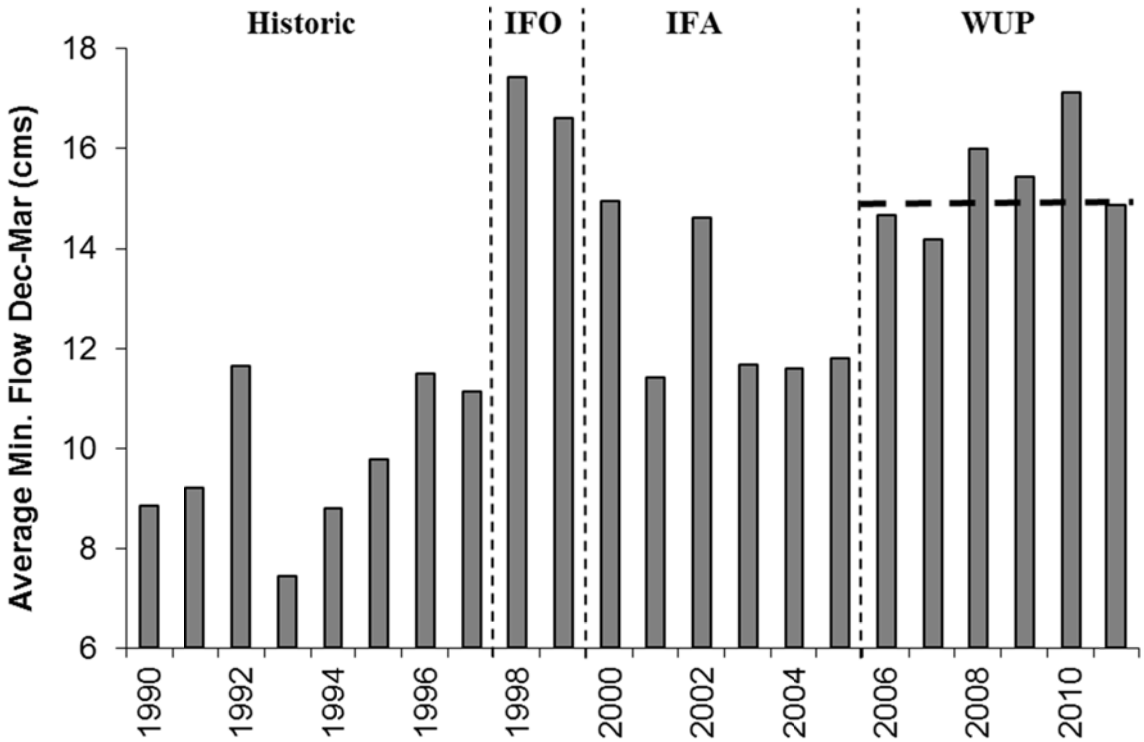

Figure 1.2. The average minimum flows during winter at the Brackendale gauge on the Cheakamus River, 1990-2011. The average minimum flow between December and March was computed as the average of the minimum flow in December from the previous year (based on average daily flows), and the minimum flows in January, February, and March for the current year (specified on x-axis). Labels at the top of the graph denote historic operations, and operations under the Instream Flow Order (IFO), Instream Flow Agreement (IFA), and the current Water Use Plan (WUP). The dashed horizontal thick line shows the 15 $m^3 \cdot sec^{-1}$ minimum flow target during winter at the Brackendale gauge.

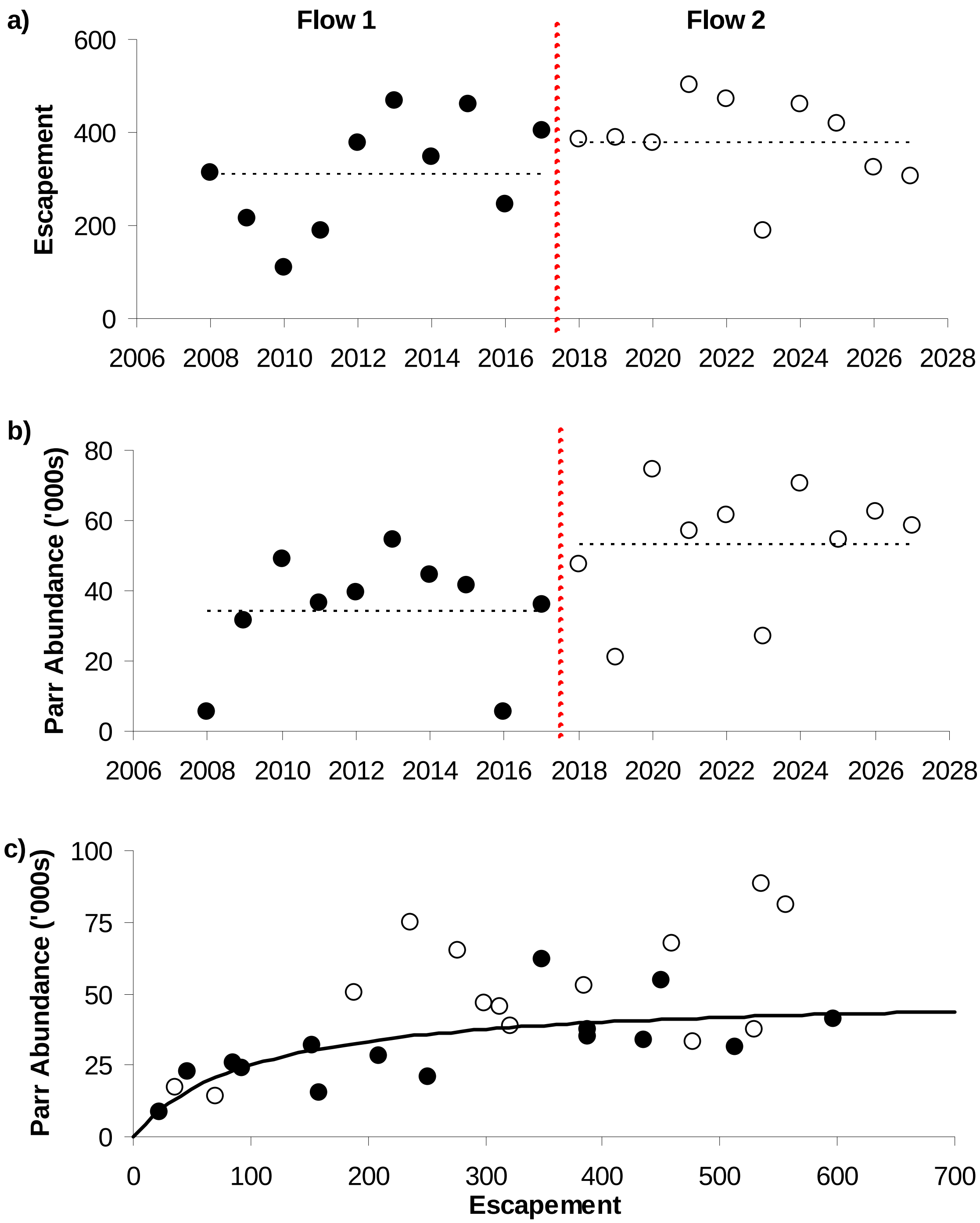

Figure 1.3. Theoretical responses of escapement (a) and parr abundance (b) under two flow regimes, with 10 years of data collected under each regime, and the stock-recruit relationship between these life stages over the two periods (c). Solid and open circles represent data collected under flow regimes 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).

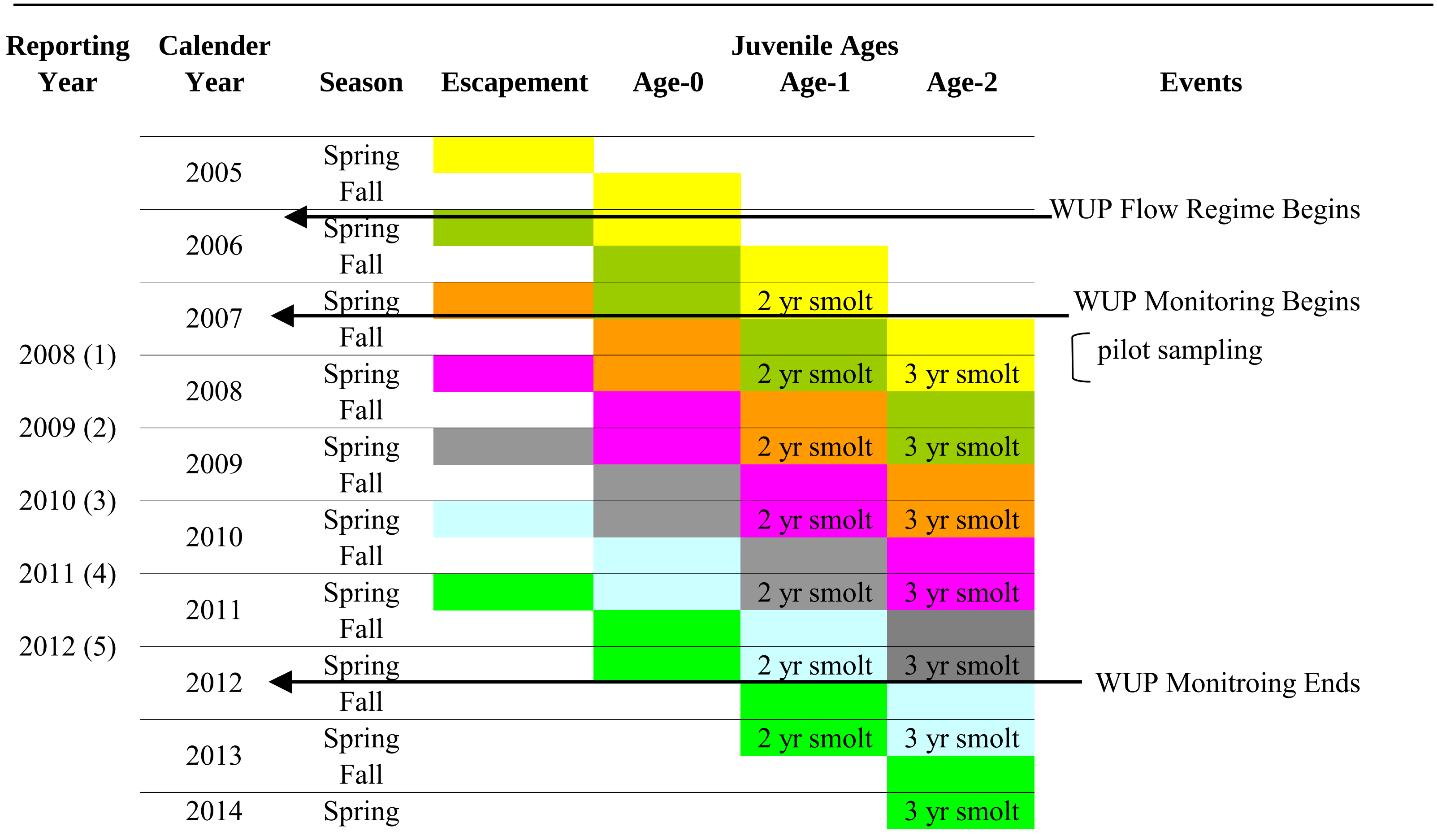

Figure 1.4. Life history table for the freshwater life stages of steelhead in the Cheakamus River in relation to annual-seasonal monitoring periods, the five-year WUP assessment and reporting periods, and implementation of the WUP flow regime. Each color tracks the cohort from individual broods (year of spawning). Note that an age-0 fish sampled in spring (mid-March to mid-April) is just less than one year old from the date of fertilization. An age-1 parr enumerated in early spring during the surveys (e.g., March) can potentially smolt in the same calendar year in late spring (e.g., May) as an age-2 smolt. Juvenile sampling began in fall 2007 and will end in spring 2012. Pilot juvenile sampling was conducted in year 1 (both fall 2007 and spring 2008) to evaluate alternate sampling approaches. Reliable juvenile abundance estimates are available beginning fall 2008. Reliable escapement estimates are available back to 1996.

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 an important measure of population status and can be used to evaluate changes in freshwater productivity affected by flow (Korman and Higgins 1997). However, as escapement may also be effected by other factors such as marine survival rate, it will likely only be useful for detecting very large flow-related effects (Bradford et al. 2005, Fig. 1.3a). To address this issue, a significant portion of the Cheakamus WUP steelhead monitoring project focuses on estimating juvenile abundance (section 4). Juvenile abundance will be more sensitive to flow effects but can also be influenced by marine survival via its effect on escapement (Fig. 1.3b). In particular, if marine survival rate is very low, escapement will be low and could limit juvenile abundance (i.e., the system will not be 'fully seeded'). By developing relationships between escapement and the abundance of various juvenile life stages, it is possible to evaluate whether this limitation is occurring and to correct for such density dependent effects on juvenile abundance (Fig. 1.3c).

Escapement is estimated by fitting parameters of a run-timing model to count data from repeat swim surveys conducted over the adult migration and spawning season (Korman et al. 2007). Estimates of diver detection probability, survey life and departure timing, determined from swim survey and radio telemetry data, are also incorporated in the model. This section of the report provides an estimate of steelhead escapement to the Cheakamus River in 2011. A synthesis of relevant physical data, other supporting information required to generate the 2011 escapement estimate, and counts of resident rainbow trout and char are also provided. Telemetry data collected in 2009-2011 resulted in a modest change in escapement estimates over the entire time series because the escapement model assumes that data on survey life and departure timing are exchangeable among all years that surveys have been conducted. The version of the model presented here stratifies telemetry-based data on detection probability into two groups of years to avoid bias resulting from a reduction in detection probability in recent years. We therefore present an updated time series of steelhead escapement estimates from 1996 to the present.

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

A sodium hydroxid 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. Assuming these smolts return to the Cheakamus River at the same ocean ages as wild steelhead (2-3 yrs), escapement in 2009 through 2011 will be composed of both wild- and hatchery-origin spawners. 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). Escapement estimates for both wild- and hatchery-origin returns must be determined to do this (Table 2.1). With respect to flow-related questions, we need to determine the extent to which the spill reduced wild adult returns to decide which years should be removed from the WUP analysis. The spill also provides 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. 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. An estimate of the combined escapement of wild- and hatchery-origin fish is needed to determine whether there were a sufficient number of returns to fully seed available habitat to interpret the juvenile data. In this regard, it is essential to estimate escapement for both stocks to develop an unbiased estimate of total escapement due to potential differences in run timing and spatial distribution (effecting detection probability) between stocks. Finally, marine survival rates can be accurately determined for hatchery-origin fish since a known number of smolts are released. These survival estimates, can be compared with those from other systems to guide future flow-related decisions. For example, if marine survival rates for Cheakamus River steelhead are similar to those in other systems, but escapement is much higher, this indicates that the freshwater rearing environment in the Cheakamus is relatively productive which in turn may temper our expectation about the extent to which productivity can be increased via flow manipulation. It may also be possible to estimate marine survival rates for wild-origin fish in the Cheakamus River using hatchery return rates and data comparing hatchery and marine survival rates determined from acoustic tagging (Melnychuck et al. 2009).

Thus, to address the critical flow-related questions effected by the sodium hydroxide spill, we modified the existing steelhead escapement model to estimate the escapement of both wild- and hatchery-origin steelhead returns and report on results of this new model. We use the estimated hatchery-origin escapement in 2009-2011 to calculate the return rate for smolts released in 2007 and 2008. We examine the stock-recruitment relationship between steelhead escapement and the adult returns produced in the next generation using the historical time series. This provides information on the escapement level required to attain the current adult carrying capacity for the system, which in turn is used to evaluate the efficacy of the hatchery program with respect to its objective of increasing the rate of recovery of the Cheakamus River steelhead population.

2.2 Methods

2.2.1 Swim Counts and Angler Surveys in the Cheakamus River

Swim Counts

The Cheakamus River, downstream of Daisy Lake Reservoir, extends 26 km to its confluence with the Squamish River. Only the lower 17.5 kilometers of this river are accessible to anadromous salmon and steelhead (Fig. 1.1). The area surveyed for returning steelhead was limited to the upper 14.5 km of the anadromous portion of the river, and begins approximately 500 m below a natural barrier, extending to the confluence with the Cheekye River. Higher turbidity and turbulence downstream of the Cheekye confluence severely limit opportunities to conduct informative swim surveys. In 2011, twelve surveys were conducted between March 1st and May 5th. Survey methods and timing were the same as previous assessments (Korman et al. 2010 and 2011, Korman and McCubbing 2010). On each survey, a team of three divers floated the entire survey area in four to six hours. The survey area is divided into 34 sections averaging 500 m in length. The number of steelhead (*Oncorhynchus mykiss* approximately >40 cm, purple-silver hue, few black spots, fusiform shape), resident rainbow trout (*Oncorhynchus mykiss* approximately 20-40 cm, darker coloration, black spots common and large, more ‘blocky’ shape), and bull trout (*Salvelinus confluentus*) observed in each section was recorded. Wild- and hatchery-origin steelhead captured by angling were given pink and green spaghetti tags beginning in 2009, respectively (see section 2.2.2). The number of tagged fish that were observed during swim surveys was also recorded. Horizontal visibility (HV) was estimated by measuring the maximum distance from which a diver could detect a dark object held underwater at 1 m depth. Horizontal visibility was measured at 14.25 (section 4) and 7.65 (section 21) river kilometers (rkm) upstream of the Squamish River confluence to index conditions upstream and downstream of Culliton Creek, respectively (Fig. 1.1). Mean daily discharge (Q) over the survey period was computed from the Water Survey of Canada (WSC) hourly discharge record at the Brackendale gauge (WSC 08GA043). Hourly water temperatures were recorded with an Onset Tidbit temperature logger placed at the North Vancouver Outdoor School just downstream of the WSC Brackendale gauge.

Creel Survey

A creel survey was conducted on the Cheakamus River from March 1st through May 30th in 2009-2011 to quantify catch and effort for a sample of individual anglers. The survey was not intended to quantify total angling effort or total catch. Each week a maximum of eight hours was dedicated to the survey. All interviews were conducted in the area between the Bailey Bridge (rkm 7.65) and Cheekye River confluence (rkm 3.65, the downstream boundary of the survey area). We often arranged to meet anglers at the end of the day to get a complete record of their day of fishing. During the interview, each angler was asked to provide information on the number of hours fished, the number of steelhead and other species that were captured, and whether the steelhead that were captured had an adipose fin. Anglers participating in the tagging program (Section 2.2.2), who have considerable fishing experience on the Cheakamus River, were given logbooks to record similar statistics.

2.2.2 Tagging and Radio Telemetry Surveys and Ageing

Steelhead were captured by skilled volunteer anglers fishing both within and downstream of the survey area (Fig. 1.1). Methods were the same ones used in previous telemetry efforts (Korman et al. 2007). Upon capture, a MCFT-3A radio tag (Lotek Engineering Inc.) was placed in the stomach of each fish and a 6-inch fluorescent spaghetti tag was attached through the dorsal muscle mass so that divers could visually identify fish that were radio tagged to determine detection probability. Green and pink colored tags were used to unambiguously distinguish wild- and hatchery-origin fish, respectively. Fork length and gender were recorded during tagging and scale samples were taken for ageing. Fish were held in a submersible holding tube for a minimum of one-half hour prior to release to provide the fish a recovery period post handling and to ensure that the radio tag was properly placed and that tag regurgitation had not occurred.

The movements of radio-tagged steelhead were determined using data from three fixed telemetry stations and mobile tracking during the swim surveys. Mobile tracking was conducted from a raft that followed 50-100 meters behind the divers on each survey to identify the presence of tagged steelhead by river section using a Lotek SRX 400 version 4.01/W5 mobile receiver outfitted with a 3-element Yagi antenna (model F-3FB). In addition, four mobile surveys of Brohm River, and two mobile surveys of the Squamish River (from the Elaho and river mile 40 to the Cheakamus confluence were completed in 2011. Fixed stations were located at the upstream and downstream boundaries of the lower survey area (Fig. 1.1) and at the Brohm-Cheekye confluence. Lotek SRX_400 receivers with CODE LOG W17 and W20 firmware were used at fixed telemetry stations to record upstream and downstream movements.

The fixed station at the downstream end of the lower survey area was configured so it could also record movement of fish up and down the Cheekye River. In 2010 and 2011, a fixed station was installed in Brohm River approximately approximately 75 m upstream from the confluence with the Cheekye River. Telemetry stations consisted of a 12-volt deep cycle battery, a watertight enclosure, three 4-element Yagi antennas, double insulated coaxial cable fitted with BNC connectors and an ASP-8 antenna-switching unit. The antennas were pointed in the upstream and downstream directions of the Cheakamus and Brohm Rivers. A third antenna was added to the lower station on the Cheakamus River to detect upstream and downstream movement in the Cheekye River. The direction of travel was determined based on the relative signal strength detected by each antenna (Koski et al. 1993). Receivers at fixed telemetry stations were set up to continuously scan all frequencies in use. When a steelhead outfitted with a digitally encoded tag moved into detection range, the date, time, channel, code, signal strength and the antenna number were recorded within the receiver's memory. Fixed stations were installed well before the deployment of the first radio tag (prior to February 25th) and were retrieved well after the end of spawning and kelting period in mid-July.

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

We analyzed a variety of models derived from radio telemetry to determine how to structure the escapement model. The escapement estimation model includes relationships that predict survey life, departure timing, and detection probability. We fit a linear model predicting survey life as a function of data of entry. We fit a beta distribution to the departure timing data to model the cumulative proportion of fish that have left the survey area by specific dates. We used a logistic relationship to model how detection probability varies with river conditions. For each of these models, the unstratified simplest form was compared to more complex models that included stratification by year, sex, and stock origin. We used the Akaikie Information Criteria corrected for small sample size (AIC_c) to compare models (Burnham and Anderson 2002). Models with AIC_c values that are similar to the model with the lowest AIC_c score were considered to have strong support (ΔAIC_c = 0-2), while those with larger AIC_c values were considered to have moderate (ΔAIC_c = 4-7) or essentially no (ΔAIC_c >10) support.

2.2.3 Steelhead Escapement Model

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

Process and observation model parameters are estimated by maximizing the value of a likelihood function that integrates data on the number of marked and unmarked fish observed on each survey, the number of marks present in the survey area, survey life, and departure timing. Data for the latter three elements were collected by marking fish with an external spaghetti tag that could be identified by divers, and through radio telemetry. This marking-telemetry program has been undertaken in eigth (2000, 2001, 2003-2005, 2009-2011) of 15 years that the swim surveys have been conducted (1996-2011, 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. 2011). 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 2.2 and 2.3). 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. 1b). We refer to this latter model as the 'deviate' arrival-timing model.

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

Observation and Statistical Models

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

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

The ratio of horizontal visibility to discharge is a good predictor of detection probability in the Cheakamus River (Korman et al. 2007). Physically-based detection probability estimates are required to estimate the number of fish present on surveys where there are no tagged fish in the survey area. In this analysis, we recognize that physically-based detection probability predictions can also be used on surveys where tags are present. Precision of a purely tag-based estimate of detection probability will be very poor when the total number of tags present or the true detection probability, is very low. In this situation, estimates of detection probability from the physically-based model, which incorporates information on detection probability from multiple surveys within and across years under similar environmental conditions, will make an important contribution to the estimate of the numbers present.

A logistic model is used to predict detection probability based on the ratio of horizontal visibility to discharge (eqn. 2.12). Two additional likelihoods for the observed number of marked (L_{pr}) and unmarked (L_{pu}) fish can now be computed by replacing the conditional detection probabilities (q_i) in eqn.'s 2.9 and 2.10 with detection probabilities by the physical model (p_i, eqn.'s 2.13 and 2.14). Parameters of the p-HV/Q relationship are jointly estimated with other model parameters using data from all surveys when tags were present (eqn. 2.15). Two sets of p-HV/Q parameters are estimated for data collected between 2000-2005 and 2009-2010. Escapement estimates prior to 2009 are based on the former set, while estimates after that are based on the latter. Note that L_{pr} is the sum of likelihoods across surveys in the year that escapement is being estimated for. L_p is the sum of likelihoods across all surveys when tags were present over all years when telemetry was conducted, excluding observations used in calculating L_{pr} to avoid double counting.

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

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

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

We used the year-independent model to estimate the historical time series of escapement for the Cheakamus River steelhead population. This model estimates all model parameters independently for each year. In years with only wild-origin steelhead returning, eight parameters are separately estimated for each year. An additional 3 parameters are estimated in years when hatchery-origin fish are returning. To derive estimates of the number of wild-origin fish from 1996-2010 and hatchery-origin fish in 2009 and 2010, a total of 118 parameters are estimated (1998 is excluded as no surveys were conducted). A penalty term, used to constrain arrival timing on hatchery-origin fish in the 2009 analysis (Korman and McCubbing 2010, Korman et al. 2010), was not required for the current analysis. The current analysis stratifies p-HV/Q models by year groups (< 2009, >=2009). This alters the trend in the expanded number present by survey, resulting in more realistic run-timing for both hatchery- and wild-origin fish.

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

2.2.4 Stock-Recruit Analysis

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

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

where ε_W is the wild-origin escapement in year $t+a$ and P is the proportion of maiden fish returning in year t at total age a. Age proportions were specific to years when ageing was conducted, which occurred in years when telemetry was done (2000, 2003-2005, 2009-2011). Age proportions in other years were held constant at the multi-year average (see Table 2.9). As no escapement estimate was available for 1998, we averaged escapements from 1997 and 1999 to calculate escapement for this year. This was necessary to compute the spawning stocks for the 2001-2003 return years. Stock-recruit analyses of adult data are traditionally only applied to semalparous species, or to immature stages of iteroparous species. In the case of steelhead, which are iteroparous, the number of repeat spawners must be removed from the number of recruits or they would be double-counted in the stock-recruit analysis. We used the average repeat spawner rate based the complete ageing dataset of 0.15 (see Table 2.9) to compute the number of maiden recruits (maiden recruits = total recruits * (1-repeat spawner fraction)). We then plotted the number of maiden adult recruits as a function of the spawning stock that produced it.

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

2.2.5 Hatchery Return Rates

Return rates for hatchery-origin steelhead smolts released into the Cheakamus River in 2007 and 2008 were computed by dividing estimates of the hatchery-origin escapement from these release groups by the number of smolts released. The former estimates were determined by multiplying the hatchery-origin escapement in each year by the proportion of fish originating from each release group, which was determined based on the total age from a sample of fish captured by angling in each return year. Our hatchery return rates apply to steelhead only and do not account for the fraction of hatchery smolts that residualized. An estimate of the marine survival rate for wild fish was determined by multiplying the hatchery return rate by the ratio of survival rates of acoustically-tagged wild- and hatchery-origin steelhead. We use the terms return rate and marine survival rate interchangeably in this analysis, even though freshwater mortality during outmigration is included in both estimates.

2.2.6 Redd and Resistivity Counter Data from Brohm River

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

In 2011, we conducted five surveys of the entire 2.4 km of Brohm River that is accessible to steelhead at roughly two-week intervals between May 4th – June 23rd. The two-week interval 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 and Schick 2010). 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 (see Table 3 of Korman and McCubbing 2005). Under these assumptions, the total number of redds can be converted to the total escapement by multiplying it by a redd-to-spawner conversion of 1.7 (i.e., 2 spawners/female / 1.2 redds/female = 1.7 spawners/redd).

A resistivity counter was installed in Brohm River approximately 75 m upstream from the confluence with the Cheekye River in spring 2010 and 2011. The objectives of this project were to derive an independent estimate of steelhead escapement (relative to redd counts) and to better understand the relationship between migratory timing of adult returns and flow in Brohm River[1]. In 2011, the counter operated between April 3rd and June 9th. The number of upstream counts from the resistivity counter was converted to an estimate of escapement in Brohm River. We first compared a histogram of peak signal size (PSS) for each upstream passage event from the Brohm River counter with those from a similar counters on the Chilcotin and Coldwater Rivers where video validation was conducted (McCubbing data on file) to determine the minimum PSS value that represented an upstream movement event for steelhead. The resulting total upstream steelhead counts over time were expanded based on an assumed counter efficiency for upstream movement events of 80%, a value determined from a similar counter on the Chilcotin River based on video validation (McCubbing data on file). We assumed that the corrected upstream count represents the total escapement. This approach assumes there are no repeated upstream and downstream movements of individual fish over the counter ('cycling' of fish). Data from the radio telemetry station at this location was used to partially support this assumption.

We compare estimates of the number of spawners in Brohm River and entry timing derived from redd counts with those determined by the resistivity counter. We compared these values with a tag-based estimate of escapement for Brohm River,

[1] The 2010 and 2011 resistivity counter was not funded or approved for funding by BC Hydro. This project was supported solely by Instream Fisheries Research and will be summarized in detail in a report prepared for Ministry of Environment.

calculated as the product of the proportion of steelhead radio tagged in the Cheakamus River that moved into Brohm River and the total escapement estimate for the Cheakams River.

2.3 Results

2.3.1 Swim Counts and Creel Survey

Discharge in the Cheakamus River was generally low and steady for the majority of the swim survey period in 2010, although, like in most other survey years, high flows limited survey opportunities in May (Fig. 2.1). Water temperature during winter and spring of 2011 increased from approximately 4 °C in February to almost 8 °C in May. We conducted a total of 12 swim surveys in 2011 (Table 2.4). Counts of steelhead, rainbow trout, and bull trout across surveys ranged from 52-157, 9-46, and 64-262 fish, respectively. The peak count for steelhead was the highest on record since surveys began in 1996.

Angling data provided useful information on steelhead origin. The creel survey and the logbook records from anglers who participated in the tagging program documented a total of 993, 1414, and 1458 hours of effort in 2009, 2010, and 2011, respectively (Table 2.5). A total of 167 and 46 wild- and hatchery-origin steelhead were landed in 2011, respectively. The catch of wild steelhead was very similar to that in 2010, but the catch of hatchery steelehead was reduced by almost 50% in 2011, owing to the fact that only ocean age 3 year returns from the 2008 smolt release were returning in 2011. Catch per effort in 2010 and 2011 was over 2.5-fold higher than in 2009. The proportion of wild-origin steelhead averaged 0.43 in 2009, 0.70 in 2010, and 0.78 in 2011. In 2009, based on variation in proportions of wild- and hatchery-origin steelhead captured in March, April, and May, hatchery-origin steelhead had a much later arrival timing than wild-origin fish, but this was not evident in 2010, and barely evident in 2011(Fig. 2.2).

2.3.2 Radio Telemetry and Age structure

A total of 126 resident rainbow trout and steelhead were captured by volunteer anglers and were sampled for age in 2011. Forty-six of these fish that were classified as steelhead in the field based on the criteria used for swim counts and were radio tagged and marked with a spaghetti tag so detection probability by divers could be estimated (Tables 2.6, 2.7). Tagging occurred downstream and within the survey area. In 2011, hatchery-origin fish were about 100 mm larger than wild fish due to the fact that wild fish consisted of ocean age 2 and 3 returns, while hatchery fish consisted only of ocean age 3 returns (as the last year of smolt release was 2008). Forty-four of the 46 radio tagged steelhead could be aged. An additional 47 fish that were not radio tagged were aged, of which 11 were resident and the remaining 38 were steelhead. All resident fish aged in 2010 were hatchery in origin (10) and 10 of 11 resident fish sampled in 2011 were hatchery in origin.

The majority of wild-origin steelhead returning in 2011 were ocean age 3 years, likely due to the high marine survival rates for outmigrating smolts in 2008 (Table 2.8). The average proportion of ocean age 3 year wild-origin steelhead across all years where ageing data is available was 0.32, compared to 0.63 in 2011. All hatchery-origin fish returned at ocean age 3 years as the last year of smolt release was in 2008. A total of 11 hatchery-origin or 'residuals' were confirmed based on angling captures and ageing between 2010 and 2011 (Table 2.9). Ten wild-origin resident rainbow trout were aged in 2011 and the dominant age was 5 years.

A summary of telemetry-based statistics relevant to estimation of steelhead escapement across all years is provided in table 2.10. This includes information to estimate detection probability (the cumulative number of tags available to be detected across swims each year), survey life, and departure timing. A total of 209 tag-swim days were accumulated in 2011, about 16% of the total available across the eight years of available data. Fourteen survey life estimates were obtained in 2011 bringing the total to 71(of which 9 were hatchery-origin fish). To obtain a survey life estimate for an individual fish, it must be tagged downstream of the survey area (i.e., below the Cheekye confluence), move upstream into the survey area (based on detections at the Cheekye fixed station and from mobile tracking), and eventually be detected leaving the survey area in a downstream direction (based on detections at the Cheekye fixed station). In 2011, departure date could be unambiguously determined (based on a downstream departure record at the Cheekye fixed station) for 30 steelhead, bringing the total departure record to 184 observations (of which 29 were hatchery-origin fish). Three steelhead that were radio tagged moved into and likely spawned in Brohm River, and one of these fish was hatchery in origin (Table 2.11). Averaged across all years, 15% of the 271 steelhead that have been radio tagged moved into Brohm River. Estimates of the proportion of fish spawning in Brohm River in 2010 (6%) and 2011 (7%) were about half of the average across the eight years of available data.

A spatial representation of the location of tagged steelhead in the Cheakamus and Cheekye/Brohm Rivers for all steelhead tagged since 2000 is presented in Appendix A. In 2011, one hatchery-origin steelhead was tracked in the Tenderfoot Creek pond. In addition, two wild-origin fish tagged in the Cheakamus River downstream of the Cheekye confluence (but a few km upstream from the mouth of the Squamish-Cheekye confluence), were tracked in the Squamish River at river mile 20 and 30, well above the confluence with the Cheakamus, on May 19-20th. One of these fish (radio code 55) held in the lowest pool in the survey area within the Cheakamus River until at least May 5th before departing downstream and eventually moving up the Squamish. The other fish (radio code 36) never moved into the survey area, so its residency in the Cheakamus River prior to moving into the Squamish could not be determined. 2011 was the only year where tracking in the Squamish River upstream of the Cheakamus confluence was done, so we cannot comment on whether similar movement patterns occurred in other years.

Using all available data, survey life declined with date of entry and was longer for males than for females (Fig. 2.3). There was strong support for a sex-stratified linear model predicting survey life as a function of date of entry relative to an unstratified model (Table 2.12). However, sex cannot be reliably determined during swim surveys, so a sex-stratified survey life model cannot be used in the assessment. Relative to the unstratified model, there was limited support for a year-stratified model (ΔAIC~4). Perhaps due to low sample size of hatchery-origin fish (n=9), the origin-stratified model has similar predictive ability (similar AIC) to the unstratified model.

Departure timing in 2011 was similar to the timing in 2009-2011, which is later than in earlier years (Fig. 2.4a). As in 2010, hatchery-origin steelhead in 2011 departed the survey area about one-week later than wild-origin fish (Fig. 2.4b). Assuming survey life of hatchery- and wild-origin steelhead is similar (as indicated by the AIC analysis in

Table 2.12), this implies that hatchery-origin fish arrive slightly later than wild-origin fish, which is consistent with the creel and logbook data in 2009 and to a much lesser extent in 2011 (Table 2.5). We fit beta distributions to the departure timing data using nonlinear estimation to compare the effects of origin, sex, year, and combinations of these factors on departure timing (Table 2.13). Of the five models that were examined, the most complex model that allowed departure timing to vary by year and origin had the strongest support and there was virtually no support for other models. The analysis indicated that year explains more variability in departure timing than does origin or sex. Unfortunately, escapement estimates are based on a model which stratifies departure timing by origin only. It is not possible to account for variation in departure timing by year in the modeling framework because departure timing is a derived parameter (see eqn. 2.6 in Table 2.2).

A maximum of 26 radio and spaghetti tagged fish were present in the survey area over 12 swim surveys in 2011 (Table 2.14) and over twenty tags were present on half of these swims. The additional 209 tag-swim observations in 2011 (the sum of tags present across all swims) brings the multi-year total to 1327 (Table 2.10). Across all 2011 surveys, detection probability averaged 0.21 (Table 2.14). Average detection probability for wild-(0.19) and hatchery-origin (0.26) fish in 2011 were similar considering the uncertainty in survey-specific estimates driven by relatively low sample sizes. Aggregating data across all 3 years when hatchery-origin fish were present and tagged, detection probabilities were very similar across these groups and there was no support for an origin-stratified detection probability model (Table 2.15). Discharge (Q) and horizontal visibility (HV) are important determinants of diver detection probability (Korman et al. 2007). Combining data across all years when detection probability estimates are available, the ratio of HV/Q explained 13% of the variation in detection probability (p, Fig. 2.5). There is considerable scatter around the p-HV/Q relationship because many values of p are highly uncertain when the number of tags present on that survey is low. For values of HV/Q less than 0.25, detection probability was lower in 2009-2011 compared to earlier years. There was strong support for the model where p-HV/Q parameters were uniquely estimated for periods 2000-2005 and 2009-2011 (model 2) compared to the unstratified model where only one group of parameters was estimated (model 1, Table 2.16). This supports the estimation of two p-HV/Q relationships in the escapement model for the 1996-2008 and >=2009 periods.

2.3.3 Escapement Estimates

We fit the two-stock escapement model (Korman et al. 2011) to all years of data. This was necessary since we assume that telemetry information is exchangeable among years. Hence data collected in 2011 contributes to estimates in that year as well as previous years. The expected value for wild- and hatchery-origin escapement in 2011 was 724 (CV=0.13) and 347 (CV=0.30), respectively. The expected value for the total escapement was 1071 (CV=0.15). This estimate is similar to the 2010 estimate (1144) and four-fold higher than the average escapement between 1996 and 2009. There was some evidence in the creel data that the fraction of hatchery-origin fish was lower early in the run (before April 1st) in 2011, so the model delayed arrival timing of hatchery-origin fish (Fig. 2.6a) to predict the decline in the proportion of wild fish in the catch (Fig. 2.6f) As a result of later run timing, the hatchery-origin escapement estimate in 2011 was more uncertain than the wild-origin estimate. Later run timing results in the model predicting that a larger proportion of the run is present later in the swim season when detection probability is lower (late April, early May) and when swims are not possible (after early May), leading to greater uncertainty. The model provided good fits to the expanded count (Fig. 2.6b), departure timing data (Fig. 2.6c), survey life (Fig. 2.6e), angling-based stock composition (Fig. 2.6f), and p-HV/Q data (Fig. 2.6h). In general, there was reasonable agreement in the numbers present estimated by expanding counts based on the ratio of tags detected to tags present (r/R points in Fig. 2.6b) and those based on the p-HV/Q expansion (open points).

The historical escapement trend for the Cheakamus River can be segregated into 3 periods (Fig. 2.7). Returns were low (average 181) in years when the juveniles that produced these returns reared in freshwater prior to the imposition of the Instream Flow Agreement (IFA, escapement from 1996-2001), and the average was twice as high after this but prior to the sodium hydroxide spill (362, escapement from 2002-2007). This difference was statistically significant (p=0.008). Wild-origin escapement declined over two consecutive years for returns produced from juveniles that were present in the river during the spill (escapement in 2008, 2009). However, because of the exceptional escapement in 2010 and 2011, the post-spill average of wild-origin steelhead (447) was higher than the IFA/pre-spill average. A post-spill average that includes hatchery-origin returns (668) is 1.8-fold greater than the IFA/pre-spill average.

2.3.4 Stock-Recruit Analysis

We did not attempt to fit a stock-recruitment model to the data as the initial slope of that relationship is poorly defined due to the absence of very low escapement values (Fig. 2.8). There is no indication that recruitment declines with escapement over the range of estimates that are available. The estimates suggest that escapements as low as 100-200 fish are sufficient to fully seed the river, and that the replacement level (intersection of 1:1 and stock-recruit lines) is approximately 300 spawners. The 2006 positive outlier highlights the exceptional survival for this brood. This was the first brood that spawned following the sodium hydroxide spill. Above average smolt production in 2008 (Melville and McCubbing 2010) indicate that the freshwater survival of this brood was approximately 40% higher than normal, perhaps due to lack of intra- and inter-specific competition and predation due to spill-related mortality. However, the exceptional total survival rate for this brood was mostly driven by an increase in marine survival inferred from the hatchery return rate for the 2008 release (see analysis below). The 2004 negative outlier was likely caused by the sodium hydroxide spill which severely limited freshwater production from this brood year.

There was substantive variation in the number of eggs deposited per spawner across years due to differences in sex ratios and the average size of female spawners (Table 2.17). Average fecundity varied from a low of 3,206 (2010) to a high of 4,885 (2011). The proportion of the escapement that were females varied from a low of 0.41 (2001) to a high of 0.61 (2011). Egg deposition varied from a low of 171,000 (2000) to a high of 3,178,000 (2011). The ratio of egg deposition (in ‘000s) to total escapement varied from a low of 1.4 (2010) to a high of 3.0 (2011) with an average of 2.1. Sex- and size-structure information is only available for about ½ of years where escapement estimates are available. In other years, an average multiplier of 2.1 would need to be applied to translate spawning stock to egg deposition on the x-axis of the stock-recruit curve. As most of the points on that curve do not have year-specific estimates, this results in an equal shift along the x-axis for most points, resulting in a very similar stock-recruit relationship. However, year-specific estimates of egg deposition will be useful in the computation of egg-fry survival rates from the more recent juvenile data collected in years when sex- and size-structure data for the escapement is available (see Section 3).

2.3.5 Hatchery Return Rate and Estimation of Wild Marine Survival

Estimates of hatchery-origin steelhead escapement and age structure from 2009 through 2011 were used to evaluate the extent to which the hatchery program mitigated spill impacts on adult returns (Table 2.18). Hatchery-origin steelhead escapement in 2009, 2010, and 2011 was 101, 436, and 347, respectively. These escapements were assigned to the 2007 and 2008 release year based on the age-structure of hatchery-origin fish in these years determined from scales (Table 2.8 and 2.18). The estimated total return rate (i.e., the sum of ocean age 2 and 3 year returns for each smolt release) for the 2007 and 2008 smolt releases was 0.75% and 4.11%.

The return of wild steelhead from the 2006 brood year was much higher than expected given the spawning stock that produced these fish (Fig. 2.8), especially when one considers that few 3 yr smolts were expected to outmigrate in 2008 due to effects of the sodium hydroxide spill. Differences in ocean age 2 yr return rates for the 2007 and 2008 release years indicate that marine survival for the 2008 release was 5.5-fold greater than the marine survival for the 2007 release (Table 2.18). Estimated smolt production in 2008 from the RST program was 1.4-fold greater than other years when estimates were available, and this estimate is likely biased low relative to other years due to the inability to operate the traps over a larger proportion of the steelhead outmigration period (Melville and McCubbing 2010). However, there is considerable overlap in confidence intervals for the 2008 smolt production estimate relative to earlier years with lower estimates. Assuming the 2008 increase is real and not due to sampling error, the higher value in 2008 is surprising as it should have been approximately 30% lower than the historical average due to the loss of 3 yr smolts resulting from the spill. In summary, high adult returns in 2010 and 2011 were the result of greater than expected smolt production and high marine survival, although the latter effect was very likely much more significant.

We estimated marine survival rates for wild-origin steelhead smolts outmigrating in 2008 based on hatchery return rates (Table 2.19) and an acoustic tagging study that compared survival of wild- and hatchery-origin smolts (Melnychuck et al. 2009). Average survival rate for tagged steelhead smolts released in the Cheakamus River to the southern end of Howe sound in 2008 was 67% for wild-origin smolts and 27% from hatchery-origin smolts. The wild-to-hatchery survival ratio based on these estimates was 2.5. The majority of survival differences occurred in freshwater, and likely reflects mortality of fish not well adapted to escape predation in the wild. Estimated marine survival rate for wild-origin smolts outmigrating in 2008 was computed as the product of the wild-to-hatchery smolt survival ratio and the 2008 hatchery return rate, which was 10.3% (=2.5*4.1%). This estimate can be used to backcalculate 2008 wild smolt production to determine if escapement and smolt production estimates are consistent (Table 2.19). Total returns from smolts outmigrating in 2008, determined by ocean age 2 year returns in 2010 and ocean age 3 returns in 2011 was 1,121. Given a 10.3% wild survival rate estimate, this implies that almost 11,000 smolts left the Cheakamus System, 1.6-fold higher than the estimate of 6,810 smolts (Melville and McCubbing 2009). This discrepancy could be due to an underestimate of smolt production, or an overestimate of escapement or marine survival rate. It is more likely that escapement is underestimated because the late run component is difficult to assess due to poor counting conditions at that time. We see no reason for a major bias in the marine survival rate, thus the most likely cause for the discrepancy between estimated and back-calculated smolt production is an underestimate of the former. In part this could be due to an inability to run the RSTs during the latter part of the smolt run. It is also likely that there is substantive smolt production below the RST (Melville and McCubbing 2009). Assuming the RST estimate is unbiased, the comparison suggests that approximately 37% of the smolt production from the Cheakamus River occurs downstream of the RST. In our comparison of mainstem parr production based on juvenile surveys in the Cheakamus River, we calculated 42.7 km of useable shoreline for the entire river, and 27.3 km upstream of the RST. This indicates that 36% of the shoreline length is located below the RST, which is very close to the discrepancy between estimated and back-calculated smolt production estimates in 2008.

2.3.6 Redd and Resistivity Counter Data from Brohm River

A total of 42 unique redds were enumerated over five surveys in 2011, which translated to 70 spawners based on the 1.7 spawner-per-redd conversion (Table 2.20). The 2011 estimate is exactly the same as the estimate from 2010. Spawn timing in Brohm River, based on the temporal pattern in the cumulative number of redds (Fig. 2.9), was approximately 3 weeks later in 2011 compared to 2010, likely due to the unusually cool spring in 2011.

The total upstream arrivals for steelhead from the resistivity counter in 2011, under an assumed 80% upstream counting efficiency, was 54 spawners (Table 2.20, Fig. 2.9). Down counts were not subtracted from the upstream counts to estimate escapement because: 1) recycling of radio tagged fish around the counter was not observed (i.e. only one upstream event followed by one downstream event was recorded for the tagged fish); 2) entry dates were highly varied as were residence periods for tagged fish (range 9 to 26 days) indicating both up and down counts were likely from "new" fish rather than from fish recycling over the counter over short time periods; and 3) all tagged fish exhibited a single kelting event, that is, were detected on the Cheekye receiver shortly after a downstream detection on the Bohm receiver (McCubbing and Melville 2010). Timing of steelhead spawning in Brohm River in 2010 and 2011 based on redd counts was virtually identical to spawn-timing inferred based on the net upstream arrivals of fish past the resistivity counter. Brohm escapement based on redd counts in 2011was 25% higher than the counter-based estimate, but estimates were very similar in 2010. The discrepancy in 2011 could be due to an overestimate of the number of true redds, a change in the number of redds/spawner, or an overestimation of the efficiency of the counter. We do not have any data to distinguish among these hypotheses.

Assuming the 2011 counter-based escapement estimate is unbiased, the spawner-per-redd conversion for Brohm River in 2011 was 1.26, compared to 1.55 based on 2010 data. A total of three of radio tagged steelhead migrated into Brohm River in 2011. All three of these fish were males, and two were wild-origin. The estimated number of spawners in Brohm River in 2011, based on the product of the total escapement to the Cheakamus River (1071, which can include fish destined to spawn in Brohm River) and this 7% Brohm migration rate (3 of 46 tags), was 67 fish, close to the estimate of 70 fish based on redd counts (Table 2.20).

2.4 Discussion

The estimated steelhead escapement to the Cheakamus River in 2011 was 1071 fish (724 wild-origin, 347 hatchery-origin). The total return rate of hatchery-origin fish from the 2008 release was 4.11% which was over 5-fold higher than the rate for the 2007 release (0.75%). These results indicate that the marine survival rate for 2008 outmigrants was much higher than in 2007. The number of wild steelhead smolts in 2008 was 1.4-fold greater than the historical average (Melville and McCubbing 2010), a surprising result given the expected loss of age 3 yr smolts in 2008 due to the 2005 sodium hydroxide spill. The unusually high wild adult return in 2010 and 2011 was therefore caused by both higher than expected smolt production and marine survival for the 2008 outmigrating cohort, although, as discussed above, the change in marine survival was very likely the bigger factor. In contrast, returns of wild-origin fish in 2009 were the lowest on record, likely due to the reduction in freshwater survival rates due to the spill coupled with lower marine survival. Surviving hatchery-origin smolts released in 2007 combined with wild-origin escapement produced a total return of 204 fish in 2009. The most recent stock-recruit analysis indicates that this is a sufficient escapement to fully seed available habitat under the assumption that hatchery-origin fish are as successful as wild-origin fish in terms of reproducing in the wild. In 2010 and 2011, escapement of wild-origin fish alone was well above the estimate of the full seeding requirement.

The angling data in 2011 indicated that hatchery-origin steelhead had a later arrival timing, with few hatchery fish present prior to April 15th. This result contrasts with the similar run timing of both stocks in 2010. In 2009, hatchery-origin fish arrived considerably later than wild-origin fish (Korman and McCubbing 2010), and the difference was greater than what was estimated in 2011. The 2009 difference is consistent with the hypothesis that the return of hatchery fish in 2009 would be late given that the brood stock from which they were produced were collected late in the run in 2006, and that arrival-timing is a heritable trait (Groot and Margolis 1991). However, this pattern of brood collection cannot explain the across-stock difference in run timing in 2011, although the difference is much less than in 2009.

There was relatively good agreement between estimates of steelhead escapement to Brohm River based on redd counts (70 in 2010 and 2011) estimates from the resistivity counter (65 and 54), and those derived based on total Cheakamus escapement and immigration rates of tagged fish into Brohm (67-70 fish). Assuming the counter-based estimate is unbiased, the spawner-to-redd conversion for Brohm River ranges from 1.25-1.5, slightly lower than the value derived from the literature of 1.7. The amount of spawning gravel in Brohm River is quite limited, and it may be that the lower spawner-to-redd conversion ratio in this system is caused by females having to dig more redds to deposit their eggs because of limited gravel availability. Ideally, redd counts and resistivity counter estimates would be obtained in additional years to determine how stable the conversion ratio is through time. That said, the resistivity counter estimate is subject to unknown error as is the redd count data, so it may be that differences reflect these errors rather than variation in spawners per redd in Brohm. In 2010 and 2011, the contribution of Brohm River spawners to the total escapement to the Cheakamus system was low. However in years of low returns, this proportion may be higher and in these circumstances, obtaining accurate estimates of Brohm River escapement increases in importance.

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Table 2.1. Indicators estimated by the current Cheakamus River steelhead escapement program in relation to key questions related to assessing the effects of flow regime and the effects of the CN sodium hydroxide spill.

Indicator	Flow Regime Assessment	Spill Assessment
Wild Escapement	1. What years of WUP escapement time series are potentially effected by spill? 2. Can escapement detect major changes in freshwater survival rate?	Did spill effect wild returns as predicted?
Hatchery Escapement	What fraction of adult returns was derived from fish not produced in Cheakamus River, and therefore not influenced by flow regime?	Was hatchery program effective at mitigating impacts of spill on adult returns?
Total Escapement	1. Was total escapement sufficient to fully seed river and therefore not limit juvenile abundance or future adult returns (assuming equal productivity among wild and hatchery components)? 2. Can we reliably estimate total escapement in years with wild and hatchery returns if there are differences in return timing and distribution among stocks?	
Hatchery Return Rate	How does marine survival for Cheakamus Steelhead compare to other systems (Keogh)? What is the marine survival rate for wild-origin steelhead from the Cheakamus River?	Was hatchery program effective?

Table 2.2. Equations used in the model to estimate steelhead escapement from swim survey, radio telemetry, and angler catch data. See Table 2.3 for definition of model variables.

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

Table 2.2. Con't.

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

Table 2.3. Definition of variables used in the steelhead escapement model.

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

Table 2.4 Physical conditions and counts of adult steelhead (SH), resident rainbow trout (RB), and bull trout (BT) during adult surveys in 2011.

Survey Date	Discharge (Q in m3/sec)	Horizontal Visibility (HV in m)	HV/Q	Count SH	Count RB	Count BT
01-Mar	16.0	7.7	0.48	56	17	262
21-Mar	22.0	5.9	0.27	52	9	127
03-Apr	22.5	4.6	0.20	50	17	70
07-Apr	20.6	5.5	0.27	100	26	130
08-Apr	21.1	5.6	0.27	87	20	188
13-Apr	26.2	5.6	0.21	65	19	84
18-Apr	22.2	5.95	0.27	79	21	142
21-Apr	21.0	5.1	0.24	85	22	93
28-Apr	23.0	5.5	0.24	96	46	82
29-Apr	23.2	6.2	0.27	154	41	193
04-May	23.0	5.7	0.25	157	29	64
05-May	23.8	5.8	0.24	140	53	136

Table 2.5. Catch of steelhead by year and origin based on creel survey and angler logbook data, 2009-2011.

Year	Date	Angling Hours Surveyed	Wild Steelhead Landed	Hatchery Steelhead Landed	Proportion Wild	Catch/Hr (CPE)
2009	< March 1	14	0	0		0.00
	March 1-10	44	0	0		0.00
	March 11-20	101	3	0	1.00	0.03
	March 21-31	284	3	1	0.75	0.01
	April 1-10	213	8	3	0.73	0.05
	April 11-20	111	4	2	0.67	0.05
	April 21-30	95	3	7	0.30	0.11
	May 1-10	60	1	9	0.10	0.17
	May 11-20	55	1	8	0.11	0.16
	May 21-30	17	1	2	0.33	0.18
	Total	**993**	**24**	**32**	**0.43**	**0.06**
2010	< March 1	106	5	3	0.63	0.08
	March 1-10	249	19	9	0.68	0.11
	March 11-20	104	12	10	0.55	0.21
	March 21-31	310	32	18	0.64	0.16
	April 1-10	120	25	3	0.89	0.23
	April 11-20	232	34	13	0.72	0.20
	April 21-30	171	23	12	0.66	0.20
	May 1-10	112	18	5	0.78	0.21
	May 11-20	8	1	0	1.00	0.13
	May 21-30	4	0	0		0.00
	Total	**1414**	**169**	**73**	**0.70**	**0.17**
2011	< March 1	28	2	0	1.00	0.07
	March 1-10	143	11	1	0.92	0.08
	March 11-20	222	19	4	0.83	0.10
	March 21-31	273	21	3	0.88	0.09
	April 1-10	226	25	15	0.63	0.18
	April 11-20	273	43	13	0.77	0.21
	April 21-30	187	20	5	0.80	0.13
	May 1-10	82	22	3	0.88	0.31
	May 11-20	19	3	2	0.60	0.26
	May 21-30	7	1	0	1.00	0.14
	Total	**1458**	**167**	**46**	**0.78**	**0.15**

Table 2.6. Summary of information on Cheakamus River captured in 2011 as part of the tagging program. Origin of fish is specified as wild (W) or hatchery (H). Average holding location and maximum upstream (U/S) location refers to the number of river kilometers upstream of the Squamish-Cheakamus River confluence. Age is specified as freshwater. ocean years (r denotes a replacement scale where freshwater age cannot be determined, 1s1 denotes a repeat spawner that returned after two years in the ocean, spawned and returned to spawn a second time).

Radio Code	Capture Date	Capture Location	Origin	Sex	Age	Fork Length (mm)	Date of Entry	Date of Departure	Survey Life (days)	Average Holding Loc.	Most Upstream Loc.	Fate
77	25-Feb-11	5.5	W	F	r.3	885		31-Mar		5.75	6.1	Kelt
81	3-Mar-11	3.3	W	F	r	865	07-Mar	28-May	82	6.4	11.2	Kelt
73	4-Mar-11	3.3	W	M	r.1s1	980	04-Mar			11.5	12.5	Dead
78	6-Mar-11	3.3	H	M	1.3	870	12-Mar	21-May	70	3.75	3.75	Kelt/Brohm
88	8-Mar-11	3.3	W	M	3.3	980						Harvested
83	9-Mar-11	3.3	W	M	r.2	820	19-Mar	12-May	54	3.75	3.75	Brohm
30	10-Mar-11	3.3	W	M	2.2	670	11-Mar	13-May	63	4.25	4.25	Kelt
31	10-Mar-11	3.3	W	M	3.2	715	08-Apr	04-May	26	3.75	4.7	Kelt/Brohm
34	10-Mar-11	4.3	W	F	3.2	710				11.5	15.1	Dead
51	10-Mar-11	6.1	W	M	r.3	920		04-Jun		13.7	15.1	Kelt
53	10-Mar-11	6.1	W	F	r.2	715		24-May		7.8	13.25	Kelt
72	10-Mar-11	6.1	W	M	r.3	870		01-Jun		7.4	10.75	Kelt
89	10-Mar-11	6.1	W	F	2.2	620				17.25	17.25	Dead
33	19-Mar-11	4.3	H	F	1.1s1	830		02-Jun		5.5	5.75	Kelt
36	19-Mar-11	3.3	W	F	2.3	790						Squamish
52	19-Mar-11	8.8	H	F	r.3	755		28-Apr		9.75	13.8	Kelt
35	20-Mar-11	3.3	W	F	3.3	790						No records
54	20-Mar-11	6.1	H	F	1.3	830		09-May		6.1	9.75	Kelt
55	23-Mar-11	3.3	W	F	3.1s1	665	03-Apr			3.75	3.75	Squamish
32	25-Mar-11	3.3	W	F	3.2	680						No records
37	25-Mar-11	3.3	W	M	r.3	945	26-Mar	10-Jun	76	6.75	11.5	Kelt
57	25-Mar-11	3.3	H	M	1.1s1	895	05-May				6.75	Tenderfoot/Dead
56	28-Mar-11	3.8	H	F	1.3	830		25-Apr		4.7	5.5	Kelt
26	8-Apr-11	3.3	W	M	3.3	965	21-Apr	28-Jun	68		7.65	Kelt
28	8-Apr-11	5.5	H	F	r.3	810		01-Jun		4.1	4.25	Kelt
29	8-Apr-11	6.1	H	F	1.1s1	825		18-May		5.5	6.4	Kelt
44	8-Apr-11	6.4	H	F	r.3	820				6.1	6.4	Dead
46	8-Apr-11	3.3	W	M	3.1s1	870	18-Apr			7.4	7.65	Dead
45	9-Apr-11	3.3	H	F	1.3	820	21-Apr	08-Jun	48	4.1	6.4	Kelt
24	10-Apr-11	7.1	H	F	1.3	820		01-Jun		7.8	12.5	Kelt
25	10-Apr-11	5.8	W	F	2.3	860		09-Jun		6.4	6.4	Kelt
27	12-Apr-11	3.3	H	F	1.1s1	720	13-Apr	11-Jun	59	5.75	11.5	Kelt
64	16-Apr-11	3.3	W	F		810	17-Apr	11-May		3.75	3.75	?
69	19-Apr-11	3.3	W	M	r.ss1	830	22-Apr	06-Jun	45	4.7	6.4	Kelt
65	20-Apr-11	3.3	W	F	2.3	810	03-May			3.75	3.75	?
66	20-Apr-11	5.5	W	F	2.3	735				6.4	6.4	Dead
67	20-Apr-11	5.5	H	F	1.1s1	870		24-May		6.4	6.4	Kelt
47	22-Apr-11	3.3	W	F	r.3	875						?
59	22-Apr-11	3.3	W	F	r.3	840	23-Apr	30-May	37	4.25	5.5	Kelt
48	23-Apr-11	3.3	H	F	1.3	840	24-Apr	04-Jun	41	5.75	6.4	Kelt
60	23-Apr-11	5.5	W	F	2.ss1	800		02-May		4.1	4.25	Kelt
63	4-May-11	3.3	W	F		795	12-May				15.75	Dead
68	6-May-11	3.3	W	F	2.3	880	07-May	10-Jun	34		15.1	Kelt
61	7-May-11	3.3	W	F	2.3	870	08-May	21-May	13		7.1	Kelt
62	7-May-11	3.3	W	M	2.3	990	11-May				15.75	Dead
58	10-May-11	7.1	H	F	1.3	835		05-Jun			7.65	Kelt

Table 2.7. Number of rainbow trout (steelhead and resident trout) that were sampled (age and genetics), the number of steelhead that were radio tagged, and the average and minimum fork length across all samples by sex and origin in 2011.

Origin	Female	Male	Unknown	Total
# Sampled				
Hatchery	18	6	1	25
Wild	49	30	4	83
Total	67	36	5	108
# Radio Tagged				
Hatchery	13	2	0	15
Wild	19	12	0	31
Total	32	14	0	46
Average Fork Length (mm)				
Hatchery	824	896	380	824
Wild	757	786	300	746
Total	775	805	316	764
Minimum Fork Length (mm)				
Hatchery	720	870	380	380
Wild	320	350	150	150
Total	825	950	199	199

Table 2.8. Proportions of freshwater, ocean, and total ages for Cheakamus River wild (W) and hatchery (H)-origin adult steelhead from scale samples collected over all years when telemetry was conducted. Note that ocean age and total age proportions are based on maiden spawners only. The proportion of repeat spawners is also shown. A total of 251 and 279 freshwater and ocean (maiden fish only) ages were estimated, respectively. These sample sizes differ because freshwater and ocean ages cannot be determined for all scales. '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
Avg	H	0.98	0.02	0.00	0.00	56
	W	0.00	0.68	0.32	0.01	195

			Ocean Age		Repeat	
Year	**Origin**	**1**	**2**	**3**	**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
Avg	H	0.11	0.50	0.39	0.10	55
	W	0.03	0.64	0.34	0.15	224

Table 2.8. 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
Avg	H	0.11	0.49	0.39	0.00	0.00	50
	W	0.00	0.01	0.51	0.35	0.13	163

Table 2.9. Number of resident rainbow trout aged by year and origin in the Cheakamus River and their average fork lengths. 'H' and 'W' denote hatchery- and wild-origin fish and the former groups represents hatchery smolts that residualized in freshwater.

		Total Freshwater Age					
Year	**Origin**	**3**	**4**	**5**	**6**	**7**	**Total**
Number of Fish							
2010	H	3	7	0	0	0	10
2011	H	0	0	1	0	0	1
	W	0	1	5	3	1	10
Average Fork length (mm)							
2010	H	393	414				408
2011	H			380			380
	W		305	374	390	370	372

Table 2.10. Summary of information obtained from radio telemetry of steelhead from the Cheakamus River since 2000. The number of fish tagged in each year, the total number of tags in the survey area across all swims, the number of survey life estimates, and the number of estimates of the final exit date from the survey area (departure timing) are summarized.

Year	# Tagged	Detection Probability (tag-swims)[1]	Survey Life	Departure Timing
2000	17	22		
2001	31	113	8	25
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
Total	271	1327	71	183

[1] Each annual value is the sum of the number of tags present in the survey area over all swims in that year.

Table 2.11. Summary of number of radio tagged steelhead that were tracked in Brohm River, 2000-2011.

Year	# Tagged	# in Brohm	% in Brohm
2000	17	7	41
2001	31	3	10
2003	33	7	21
2004	36	4	11
2005	37	4	11
2009	20	2	10
2010	51	3	6
2011	46	3	7
Total	271	33	15

Table 2.12. Comparison of four linear models predicting survey life as a function of date of entry into the survey area based on alternate stratification schemes (unstratified, sex-stratified, year-stratified, and origin-stratified). b0 and b1 represent the constant and slope of the relationship, while n and K represents the sample size and number of parameters in the mode, respectively. LL, AIC, and ΔAIC are the log-likelihood, Akaikie Information Criteria statistic, and the difference in AIC relative to the model with the lowest AIC score, respectively. ‘M’, ‘F’, “W”, and “H”denote males, females, wild-origin, and hatchery-origin steelhead, respectively. Note the model with the lowest AIC score is considered to be the most reliable. There is little support for models with AIC scores > 7 relative to the model with the lowest score.

Model	**Sex**	**Year**	**Origin**	**b0**	**b1**	**n**	**K**	**LL**	**AIC**	**ΔAIC**
1	No	No	No	100.58	-0.58	71	2	-295	593	6
2	M	No	No	113.29	-0.65	34	4	-289	587	0
	F			93.41	-0.56	37				
3	No	2001	No	111.68	-0.64	8	14	-284	597	10
		2003		117.15	-0.83	14				
		2004		80.14	-0.34	7				
		2005		109.87	-0.76	4				
		2009		38.53	0.06	4				
		2010		56.92	-0.19	20				
		2011		120.21	-0.70	14				
4	No	No	W	104.23	-0.63	9	4	-293	594	7
			H	90.03	-0.41	62				

Table 2.13. Comparison of models predicting departure date. The median exit date represents the date when 50% of the tagged fish have migrated downstream out of the survey area (downstream of the Cheekye confluence). n, K, LL, AIC, and ΔAIC are the sample size, number of parameters in the model, log-likelihood, Akaikie Information Criteria statistic, and the difference in AIC relative to the model with the lowest AIC score, respectively. 'M', 'F', 'W', and 'H' denote males, females, wild-origin, and hatchery-origin fish, respectively. Note the model with the lowest AIC score is considered to be the most reliable. There is little support for models with AIC scores > 7 relative to the model with the lowest score.

Model	Sex	Origin	Year	Median Exit Date	n	LL	K	AIC	ΔAIC
1	No	No	No	18-May	183	-778	2	1559	392
2	M	No	No	22-May	80	-326	4	1481	314
	F			15-May	103	-411			
3	No	W		17-May	154	-652	4	1505	338
		H		26-May	29	-97			
4	No	No	2001	11-May	25	-79	14	1232	65
			2003	05-May	22	-76			
			2004	19-May	30	-100			
			2005	13-May	26	-78			
			2009	23-May	17	-47			
			2010	25-May	33	-119			
			2011	21-May	30	-104			
5	No	W	2001	11-May	25	-79	20	1167	0
			2003	05-May	22	-76			
			2004	19-May	30	-100			
			2005	13-May	26	-78			
			2009	21-May	14	-37			
			2010	22-May	20	-65			
			2011	19-May	17	-55			
		H	2009	28-May	3	-3			
			2010	26-May	13	-34			
			2011	21-May	13	-36			

Table 2.14. Summary of number of steelhead counted by survey date in the Cheakamus River stratified by presence of a tag (radio + spaghetti) and origin (wild or hatchery) in 2011. Detection probability is the proportion of the tagged fish present based on telemetry to the number that were counted during swim surveys.

	Counted				Present (telemetry)			Detection Probability		
Survey Date	**No Tag**	**Wild Tags**	**Hatchery Tags**	**Total Tags**	**Wild Tags**	**Hatchery Tags**	**Total Tags**	**Wild**	**Hatchery**	**Total**
01-Mar	56	0	0	0	1	0	1	0.00		0.00
21-Mar	48	1	3	4	10	4	14	0.10	0.75	0.29
03-Apr	48	1	1	2	9	4	13	0.11	0.25	0.15
07-Apr	98	1	1	2	8	3	11	0.13	0.33	0.18
08-Apr	84	3	0	3	7	3	10	0.43	0.00	0.30
13-Apr	62	1	2	3	10	9	19	0.10	0.22	0.16
18-Apr	77	1	1	2	12	9	21	0.08	0.11	0.10
21-Apr	81	2	2	4	12	11	23	0.17	0.18	0.17
28-Apr	91	4	1	5	16	10	26	0.25	0.10	0.19
29-Apr	146	4	4	8	15	9	24	0.27	0.44	0.33
04-May	149	4	4	8	14	10	24	0.29	0.40	0.33
05-May	134	5	1	6	12	11	23	0.42	0.09	0.26
Total/Average								0.19	0.26	0.21

Table 2.15. Comparison of detection probability models for steelhead in the Cheakamus River without (model 1) and with (model 2) stratification by fish origin ("H" = hatchery, "W"= wild) based on data from 2009, 2010, and 2011. b0 represents detection probability, while # of tag-swims represents the cumulative number of tags present across swims. LL, AIC, and ΔAIC are the log-likelihood, Akaikie Information Criteria statistic, and the difference in AIC relative to the model with the lowest AIC score, respectively. The model with the lowest AIC score is considered to be the most reliable.

Model	Origin	b0	# of tag -swims	K	LL	AIC	ΔAIC
1	No	0.19	617	1	-104	209	0
2	H	0.20	209	2	-104	211	2
	W	0.19	408				

Table 2.16. Comparison of two logistic models predicting detection probability as a function of the ratio of horizontal visibility to discharge. b0 and b1 represent the constant and slope of the relationship, while n and K represents the sample size and number of parameters in the model (twice as many for model 2 where 2 sets of b0 and b1 values are estimated). LL, AIC, and ΔAIC are the log-likelihood, Akaikie Information Criteria statistic, and the difference in AIC relative to the model with the lowest AIC score, respectively. The model with the lowest AIC score is considered to be the most reliable. There is little support for models with AIC scores > 7 relative to the model with the lowest score**.**

Model	Year	b0	b1	n	K	LL	AIC	ΔAIC
1	2000-2011	0.53	1.38	90	2	-171	345	24
2	2000-2005	0.35	1.80	52	4	-157	322	0
	2009-2011	0.37	3.66	38				

Table 2.17. Calculations used to estimate annual egg deposition for steelhead in the Cheakamus River in years when information on sex ratio and size is available from angling surveys. Egg deposition is computed as the product of escapement, the proportion females, and fecundity. The latter estimates are computed based on mean female fork length and a fecundity-fork length relationship from the Keogh River (Ward and Slaney 1993).

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

Table 2.18. Return rate for the hatchery-origin steelhead smolts released into the Cheakamus River in 2007 and 2008. Return rate is computed by dividing the total hatchery origin escapement from each release year by the number of smolts released. Hatchery escapement estimates by return year are assigned to release year based on the proportion of ocean age 1, 2, and 3 yr fish in the hatchery-origin escapement determined by ageing.

Number of Hatchery Smolts Released				
Release Year				Total
2007				21,505
2008				17,618
Hatchery Returns		Return Year		
	2009	2010	2011	
Escapement (return yr only)	101	436	347	
Hatchery age composition				
Ocean age 1	0.23	0.00	0.00	
Ocean age 2	0.77	0.74	0.00	
Ocean age 3	0.00	0.17	1.00	
Escapement (release x return yr)				Total
2007	78	83	0	161
2008	23	353	347	723
Hatchery Return Rate				
Release Year				Total
2007				0.75%
2008				4.11%

Table 2.19. Calculations used to compare estimated smolt production at the Rotary Screw Trap (RST) on the Cheakamus River in 2008 with a back-calculated estimate of smolt production based on adult returns by ocean age and an estimated marine survival rate for wild fish.

Marine survival from relase to southern Howe Sounds (POST)1	
Wild	68%
Hatchery	27%
Wild-to-hatchery survival rate	2.5
estimated return rate of 2008 hatchery-origin smolts	4.1%
Calculated marine survival for 2008 wild-origin smolts	10.3%
Estimated wild-origin escapement from 2008 outmigrants	
2010 returns (ocean age 2)	626
2011 returns (ocean age 3)	495
Total	1,121
Back-calculated wild-origin smolts in 2008	10,843
Estimated wild-origin smolts at RST in 2008[2]	6,617
Upper Paradise smolt production in 2008[2]	193
Total smolt production above the RST	6,810

[1]Melnychuck et al. 2009.
[2]Melville and McCubbing 2009.

Table 2.20. Summary of steelhead escapement estimates to Brohm River in 2010 and 2011 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**
Brohm Escapement		
Resistivity Counter	65	54
Redd Counts	70	70
Derived Brohm Escapement		
Cheakamus Escapement		
Wild	708	724
Total	1144	1071
Brohm Immigration Rate	5.9%	6.5%
Escapement to Brohm River		
based on Wild	42	47
based on Total	67	70

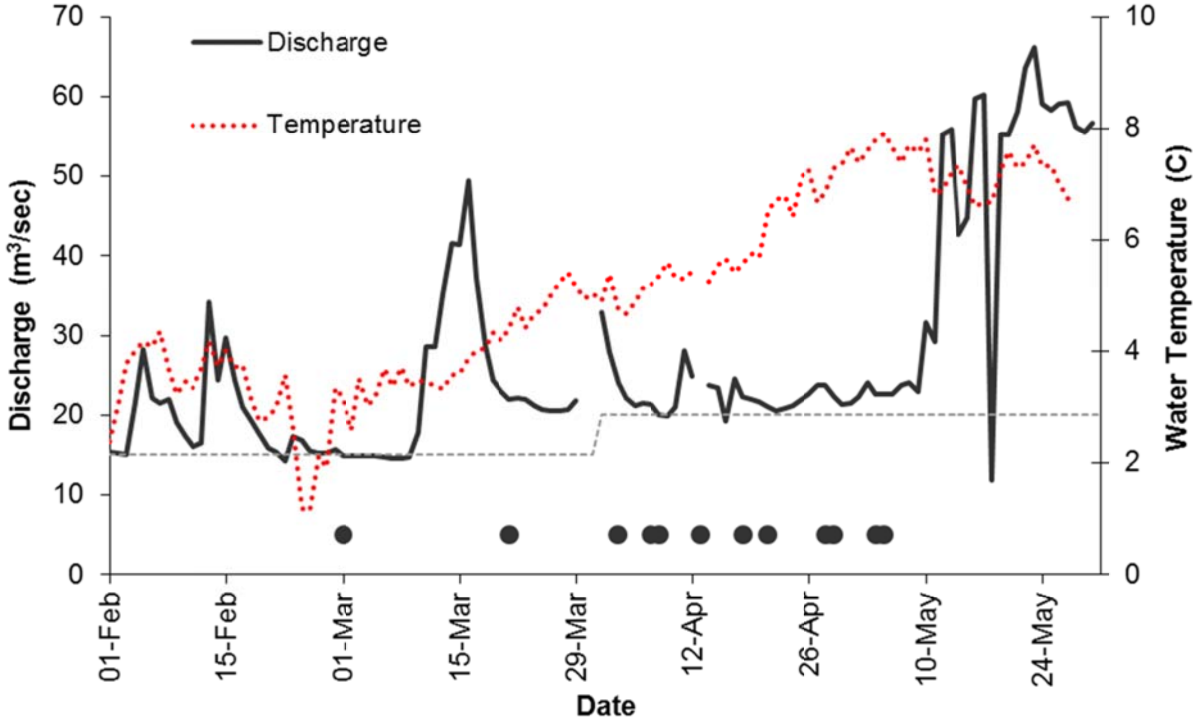


Figure 2.1. Discharge (black solid line) and water temperature (red dashed line) at the Brackendale gauge locations on the Cheakamus River in winter and spring of 2011. The gray dashed line shows minimum discharge requirements at the Brackendale gauge before and after March 31st. The points denote the dates that adult swim surveys were conducted.

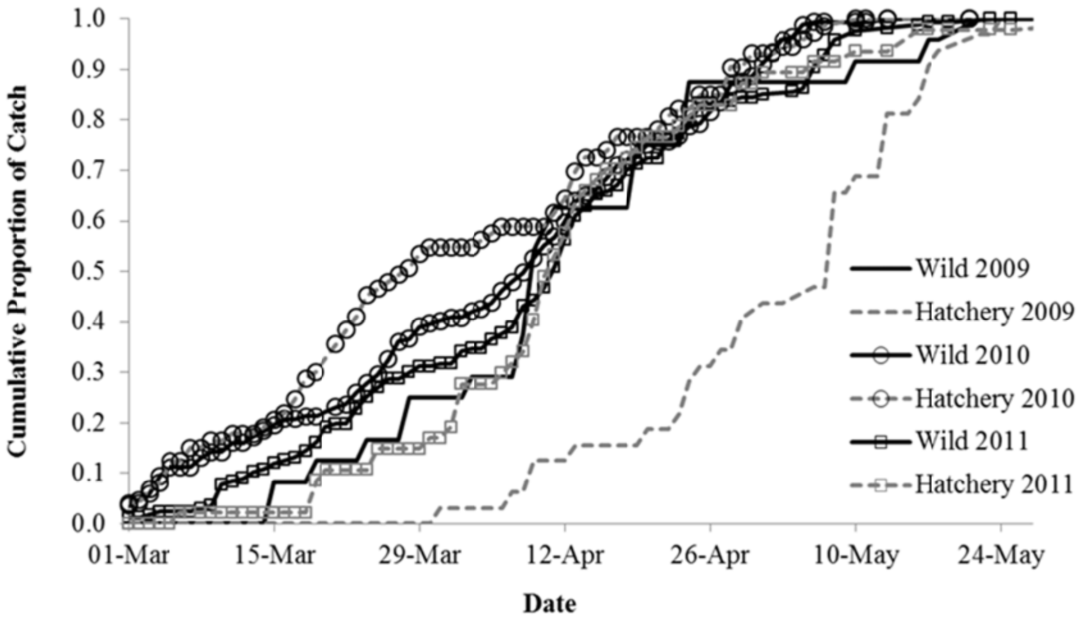
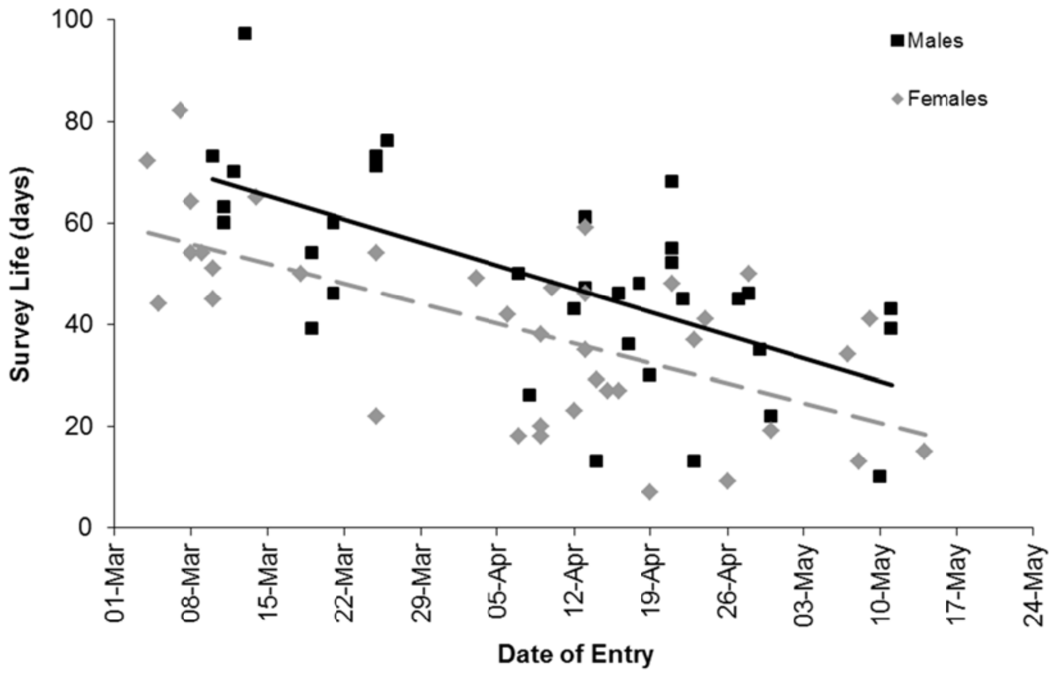


Figure 2.2. Cumulative proportion of steelhead caught by date by stock origin and year in the Cheakamus River. Proportions are based on catch determined by the creel survey and angler logbook program.



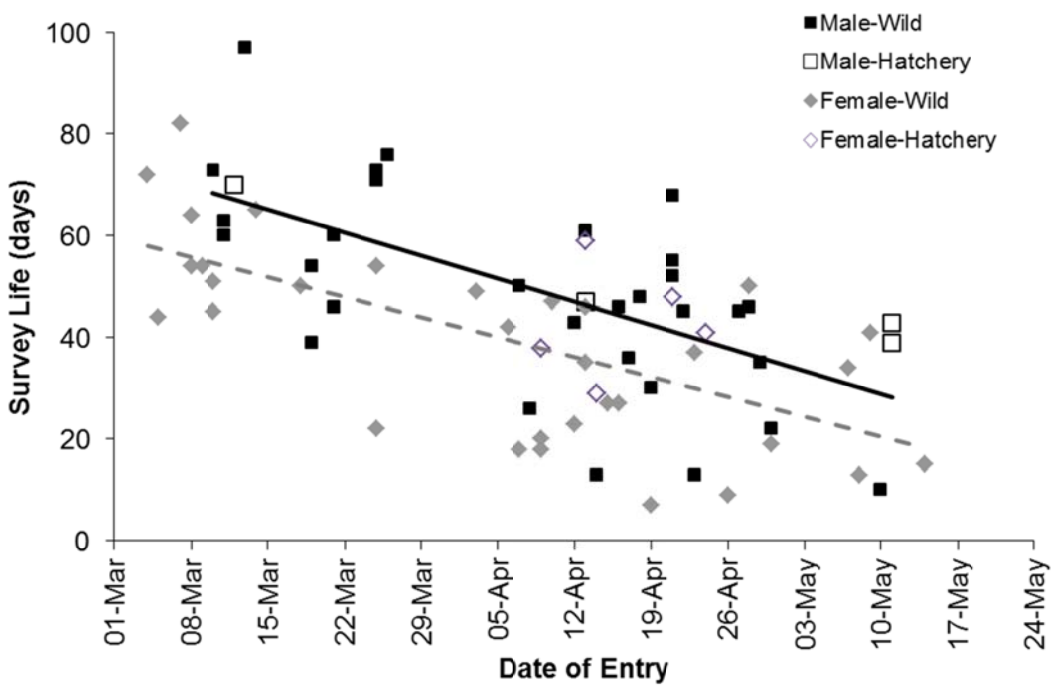


Figure 2.3. Relationship between date of entry into the survey area and the number of days spent in the survey area (survey life) for steelhead in the Cheakamus River stratified by sex and stock origin using data from all years when telemetry was conducted. Lines are the best-fit linear relationships fit to data by sex using data from both stocks.

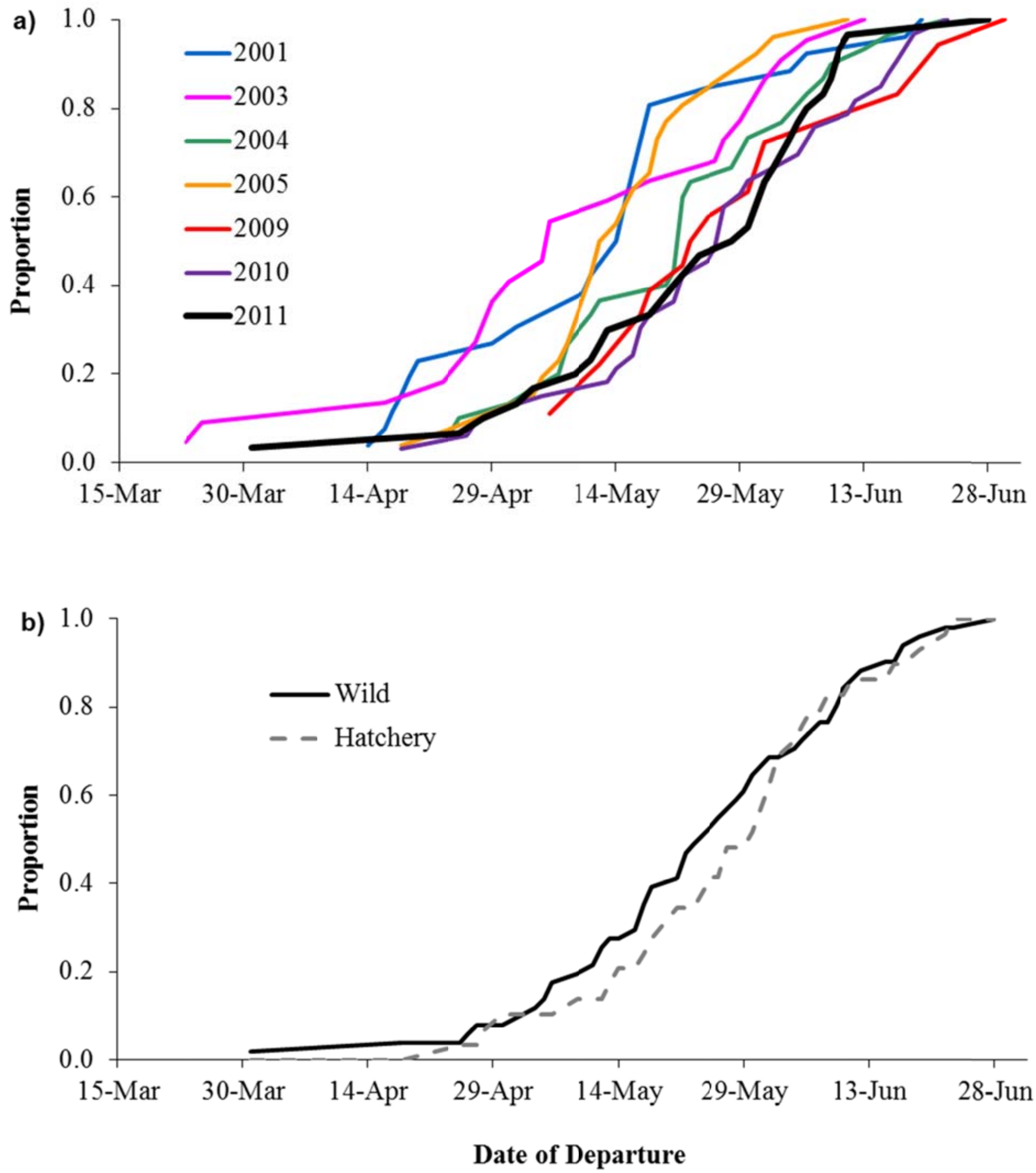


Figure 2.4. Cumulative proportion of radio tagged steelhead departing the survey area by date from 2001 through 2011 (a) and the departure schedule for wild- and hatchery-origin fish in 2011 (b).

F

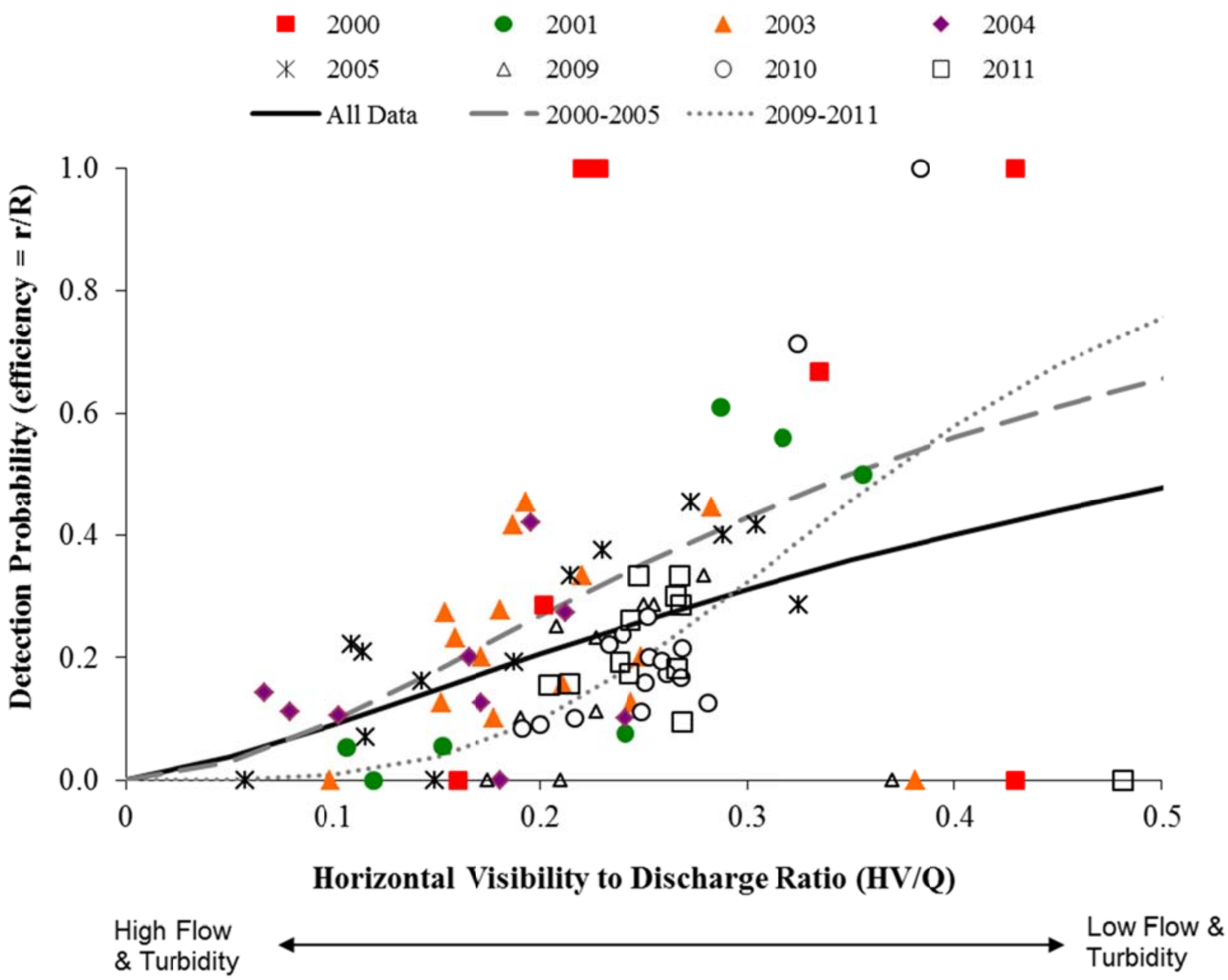


Figure 2.5. The relationship between detection probability for adult steelhead during snorkel surveys and the ratio of horizontal visibility (HV) to discharge (Q) in the Cheakamus River. Lines are best-fit logistic relationships to all the data (black solid line) or to 2000-2005 (gray dashed line) and 2009-2011(gray dotted line). The latter models are used to estimate escapement.

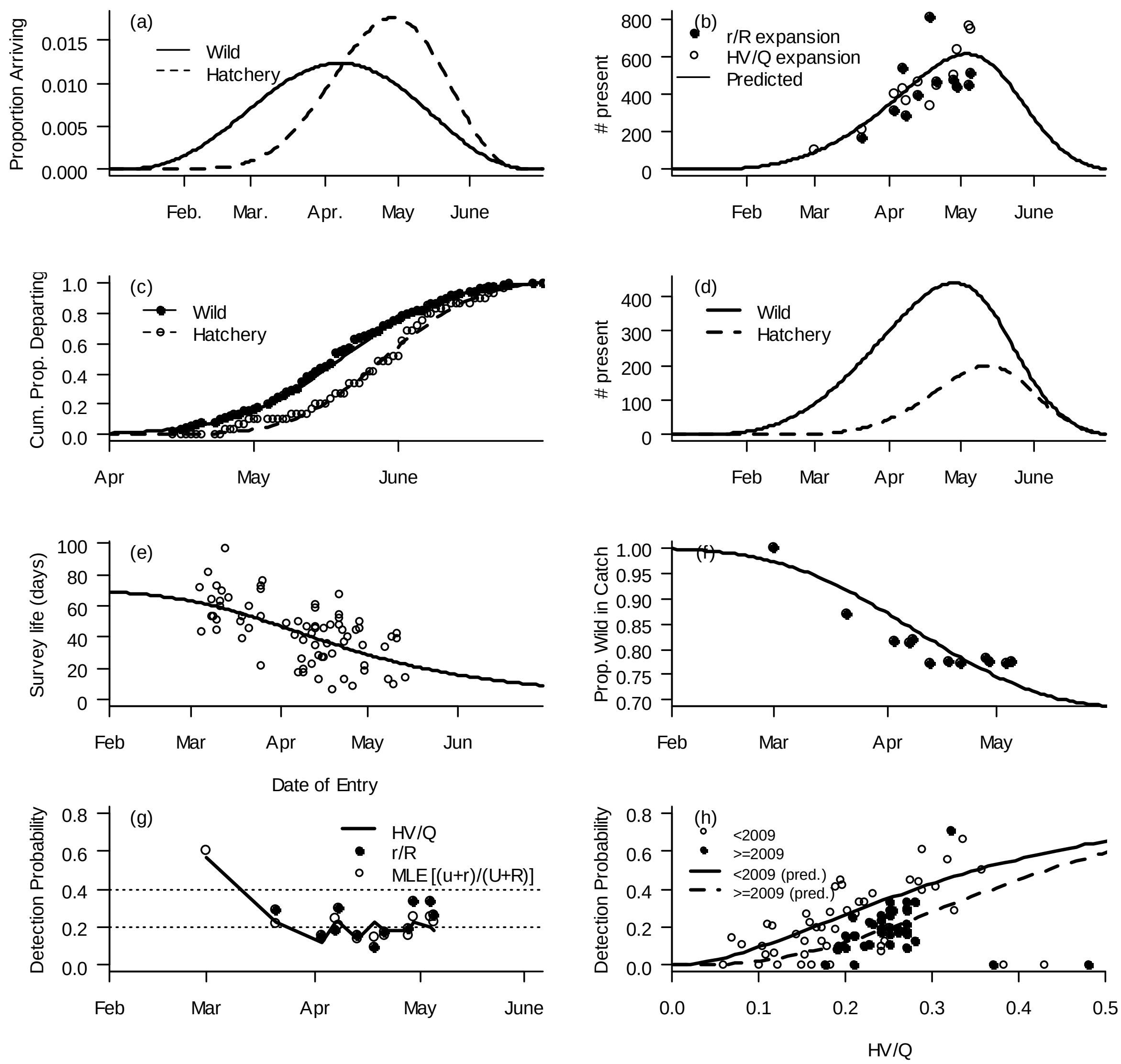


Figure 2.6. Fit of the two-stock steelhead escapement model to the 2011 data. a) shows the predicted proportion of the composite run arriving by day. b) shows the predicted number present (line) through the run, and the expected numbers present on individual surveys based on expanding counts by the ratio of tags observed to tags present (r/R) and based on detection probability predicted from the ratio of horizontal visibility to discharge (HV/Q). c) shows the predicted (line) and observed (points) departure schedule (data from 2001-2011). d) shows the number present by stock group. e) shows the predicted and observed survey life – date of entry relationship (data from 2001-2011). f) shows the predicted and observed (from angling) proportion of wild fish present. g) shows the predicted detection probability by survey date based on the p-HV/Q model (lines), and estimates of detection probability based on tagging data (r/R) or the conditional estimate (MLE). h) shows the predicted detection probability – HV/Q relationships (lines) and estimates of detection probability from tagging data only based on data from 2000-2011 (r/R, points).

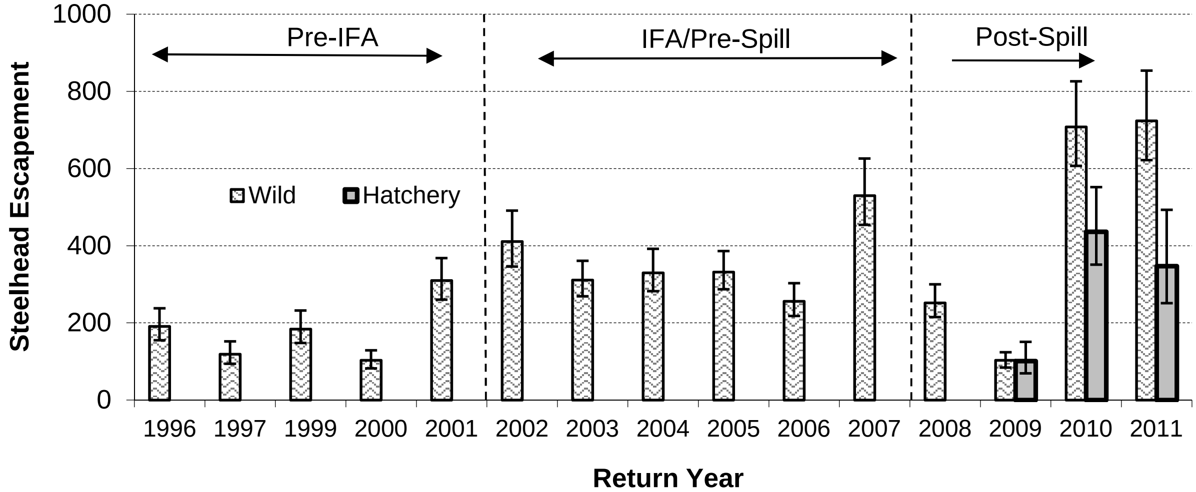


Figure 2.7. The steelhead escapement trend in the Cheakamus River, 1996-2011 showing abundance of returns that reared as juveniles in the river before and after the Instream Flow Agreement (IFA) was implemented and the year that the sodium hydroxide spill occurred (Post-Spill). The height of the bars and error bars show the average and 90% credible intervals from the posterior distribution of escapement estimates for each year, respectively.

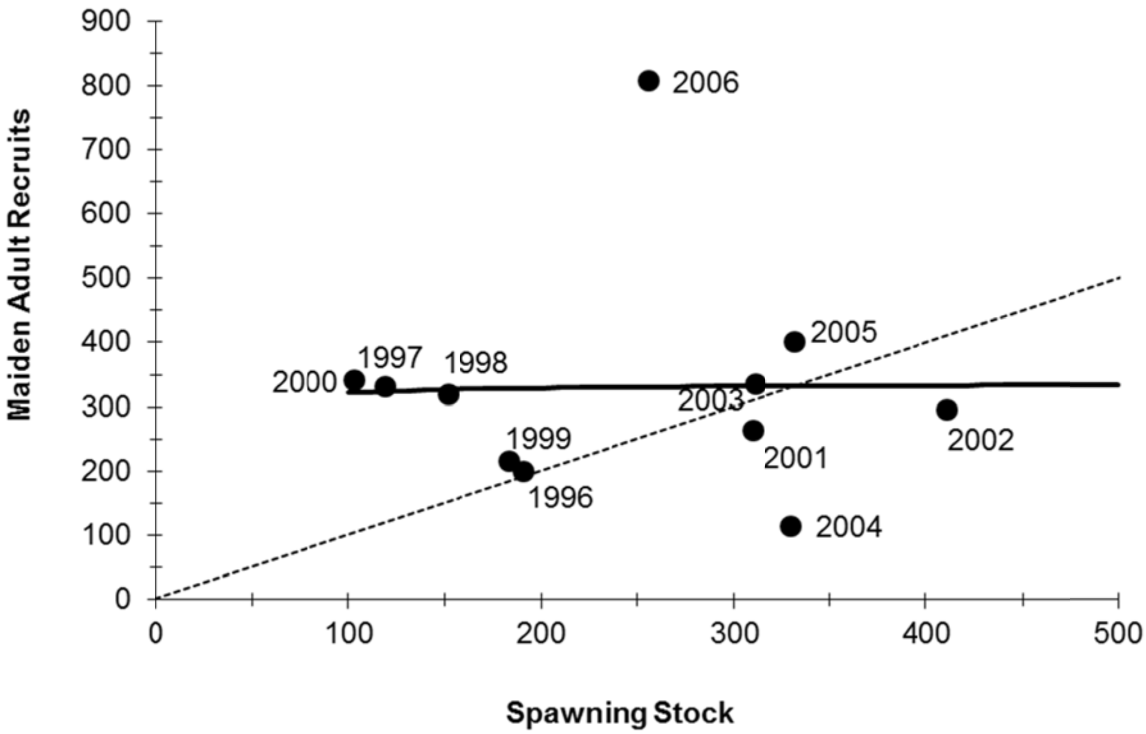


Figure 2.8. The relationship between the number of steelhead spawners in the Cheakamus River and the resulting maiden adult returns (total returns less repeat spawners). The year beside each point represents the brood year. The solid line represents the average recruitment over the period of record and the dashed line represents the 1:1 relationship. Note that the recruitment estimate for the 2006 brood year is incomplete as it does not yet include 6 year old fish that will return in 2012.

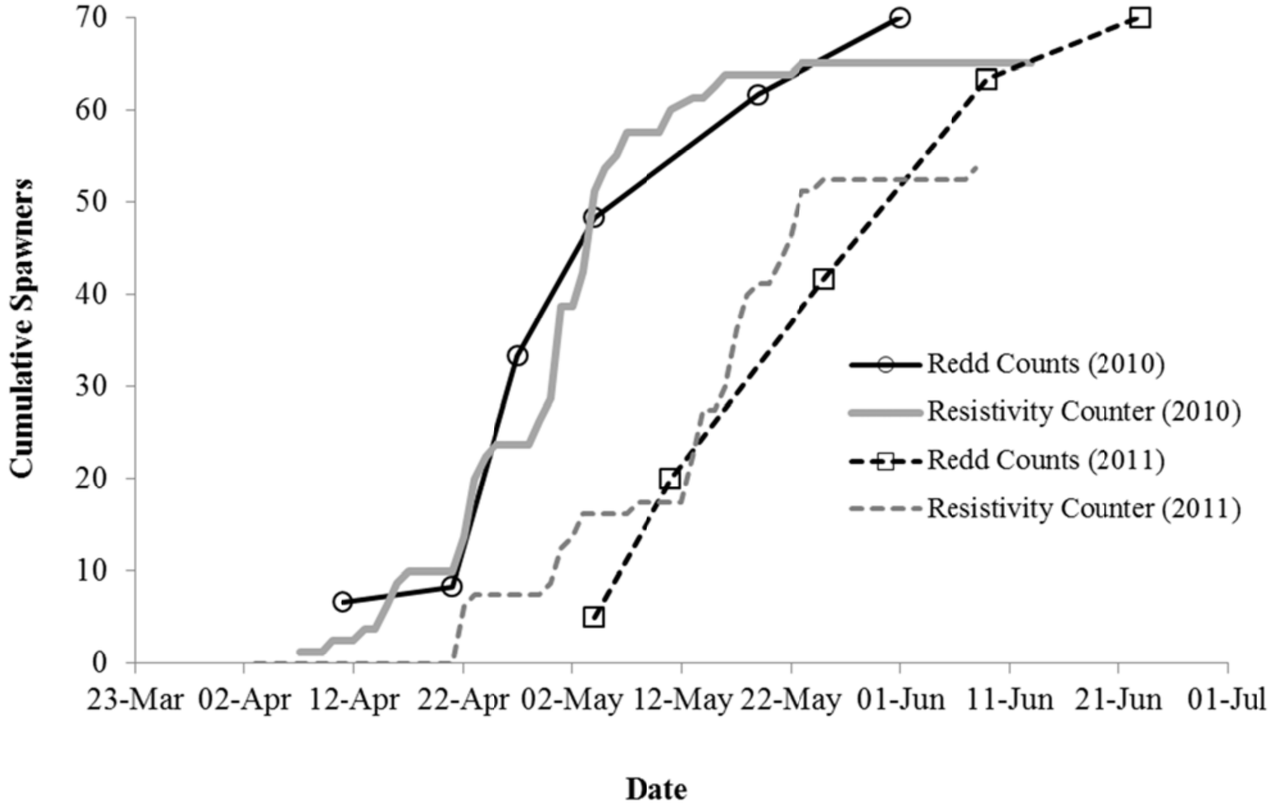
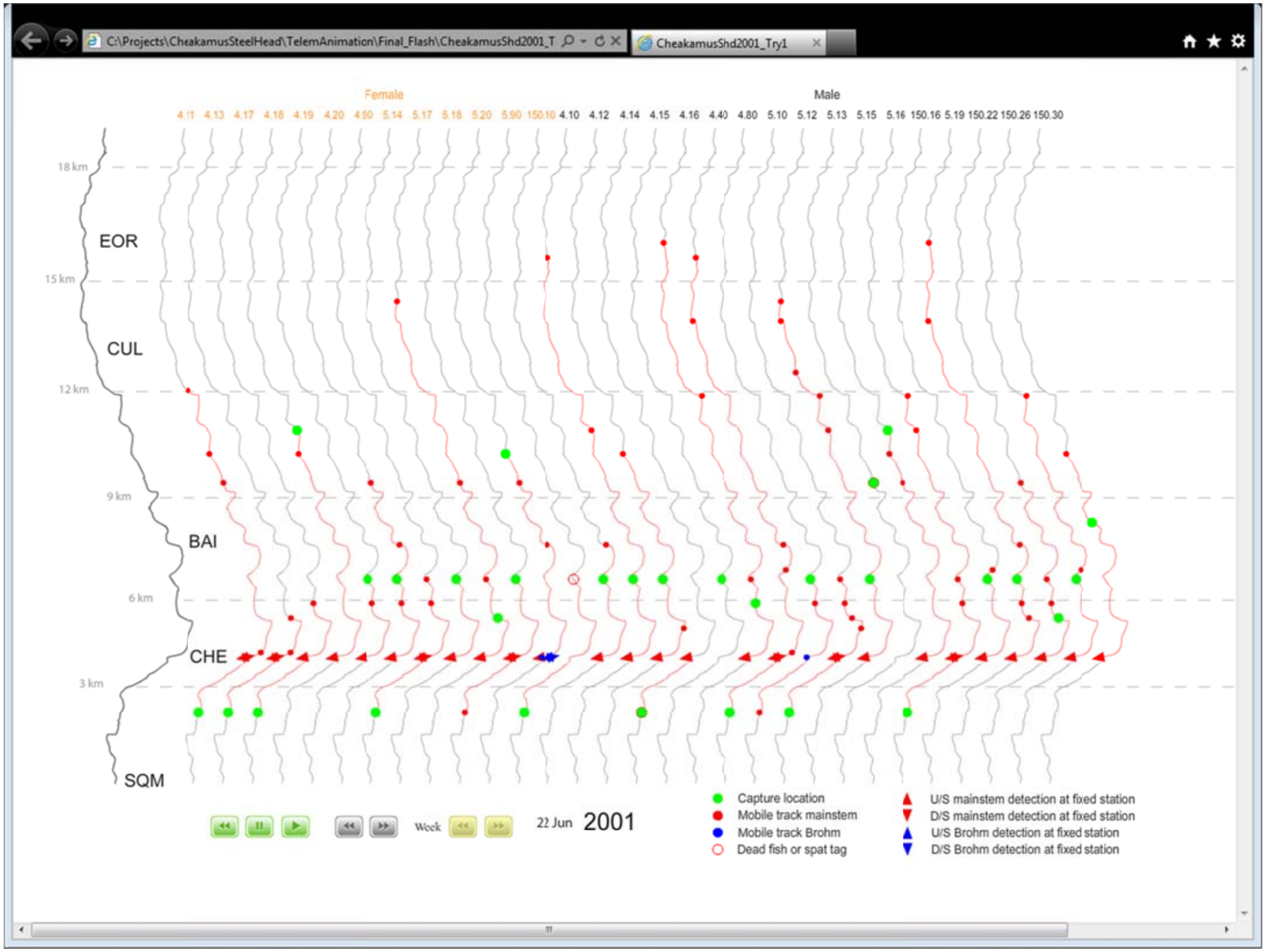


Figure 2.9. Comparison of steelhead run-timing in Brohm River in 2010 and 2011 based on redd counts (expanded to spawners) and net cumulative arrivals based on a resistivity counter near the mouth.

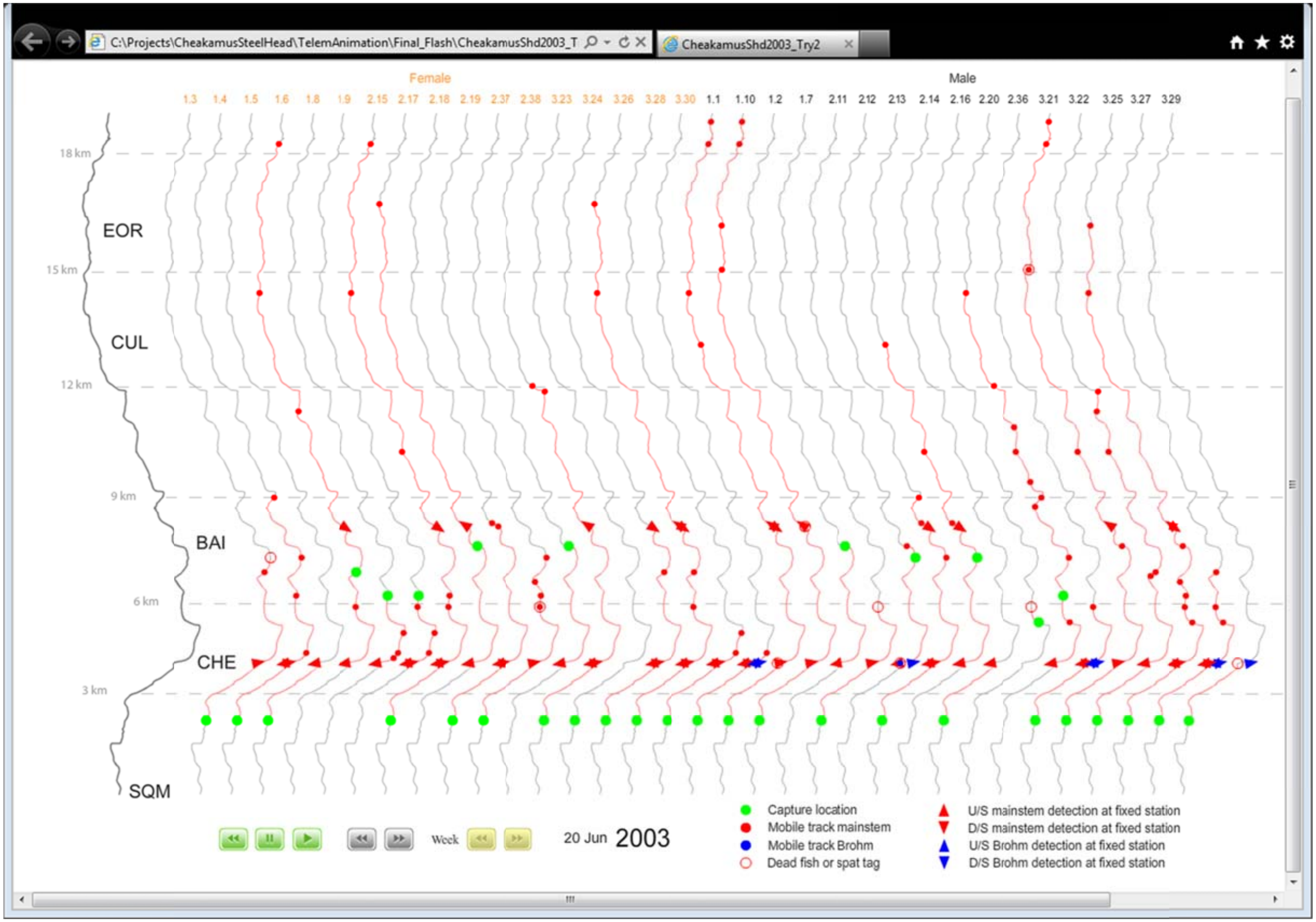
Appendix A.2. Distribution of Radio Tagged Steelhead, 2001-2011.

This appendix presents graphical representations of the distribution of radio tagged steelhead in the Cheakamus River based on tagging in 2001, 2003-2005, and 2009-2011. The graphics are based on an integration of data collected from fixed telemetry stations and mobile tracking in these years. The programs Adobe Flash Player CS3 and Adobe Illustrator CS3 with custom plug-ins were used to animate the position of each fish in a web browser based on these data. The plots below show the positions of each fish between tagging and when they left the system or died. The abbreviations "SQM", "CHE", "BAI", "CUL", and "EOR" denote the location of the Squamish-Cheakamus confluence, the Cheakamus-Cheekye confluence, the Bailey Bridge, the Cheakamus-Culliton confluence, and the end-of-road, respectively. Each fish is identified by its radio tag code. The red line for each fish represents its maximum range as inferred from the fixed station and mobile survey data. Arrows denote whether a fish was tracked moving upstream or downstream at a fixed station location.

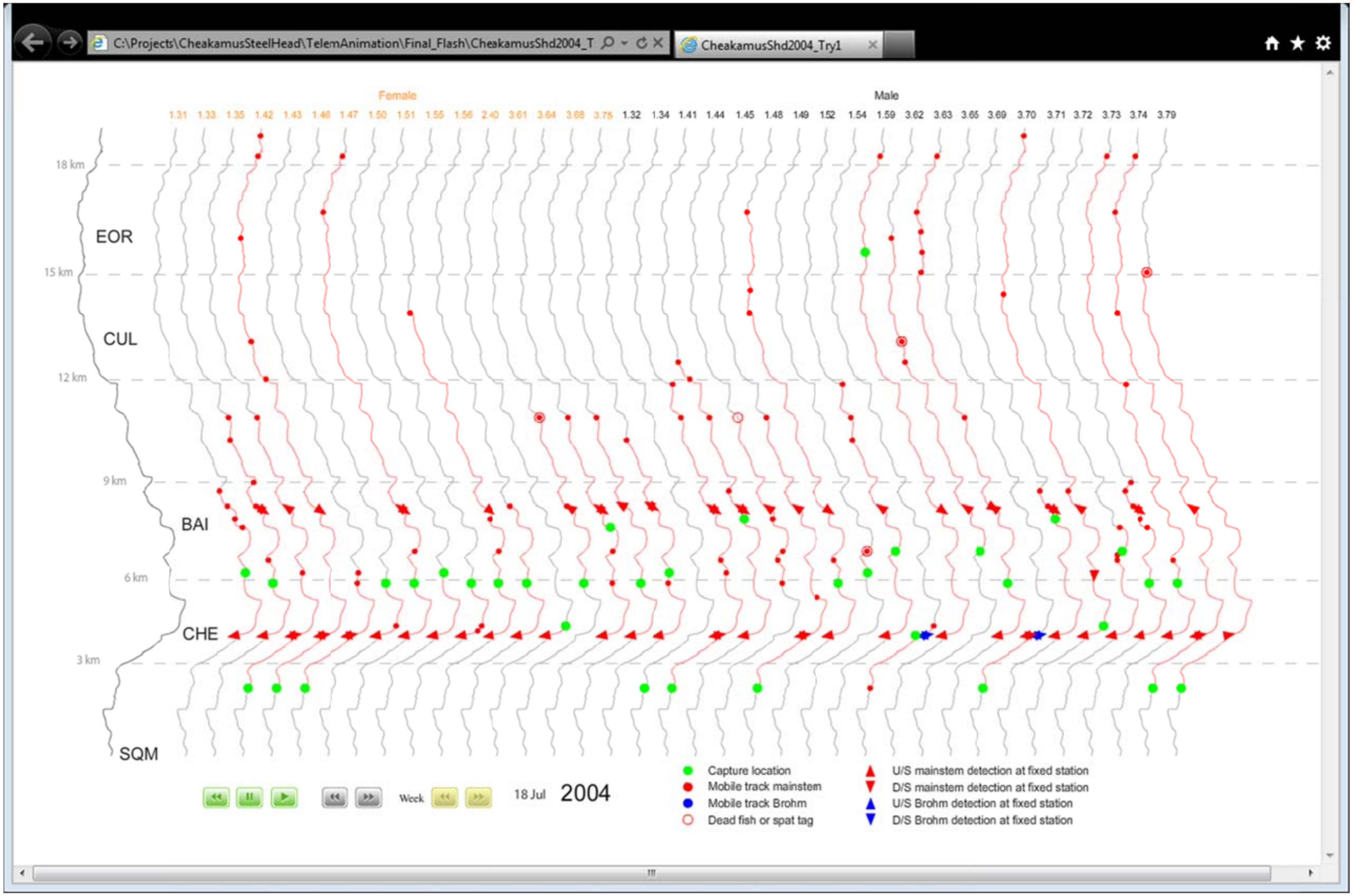
2001


C:\Projects\CheakamusSteelHead\TelemAnimation\Final_Flash\CheakamusShd2001_T
CheakamusShd2001_Try1
Female
Male
4.11 4.13 4.17 4.18 4.19 4.20 4.90 5.14 5.17 5.18 5.20 5.90 150.10 4.10 4.12 4.14 4.15 4.16 4.40 4.80 5.10 5.12 5.13 5.15 5.16 150.16 5.19 150.22 150.26 150.30
18 km
15 km
12 km
9 km
6 km
3 km
EOR
CUL
BAI
CHE
SQM
Week
22 Jun 2001
Capture location
Mobile track mainstem
Mobile track Brohm
Dead fish or spat tag
U/S mainstem detection at fixed station
D/S mainstem detection at fixed station
U/S Brohm detection at fixed station
D/S Brohm detection at fixed station

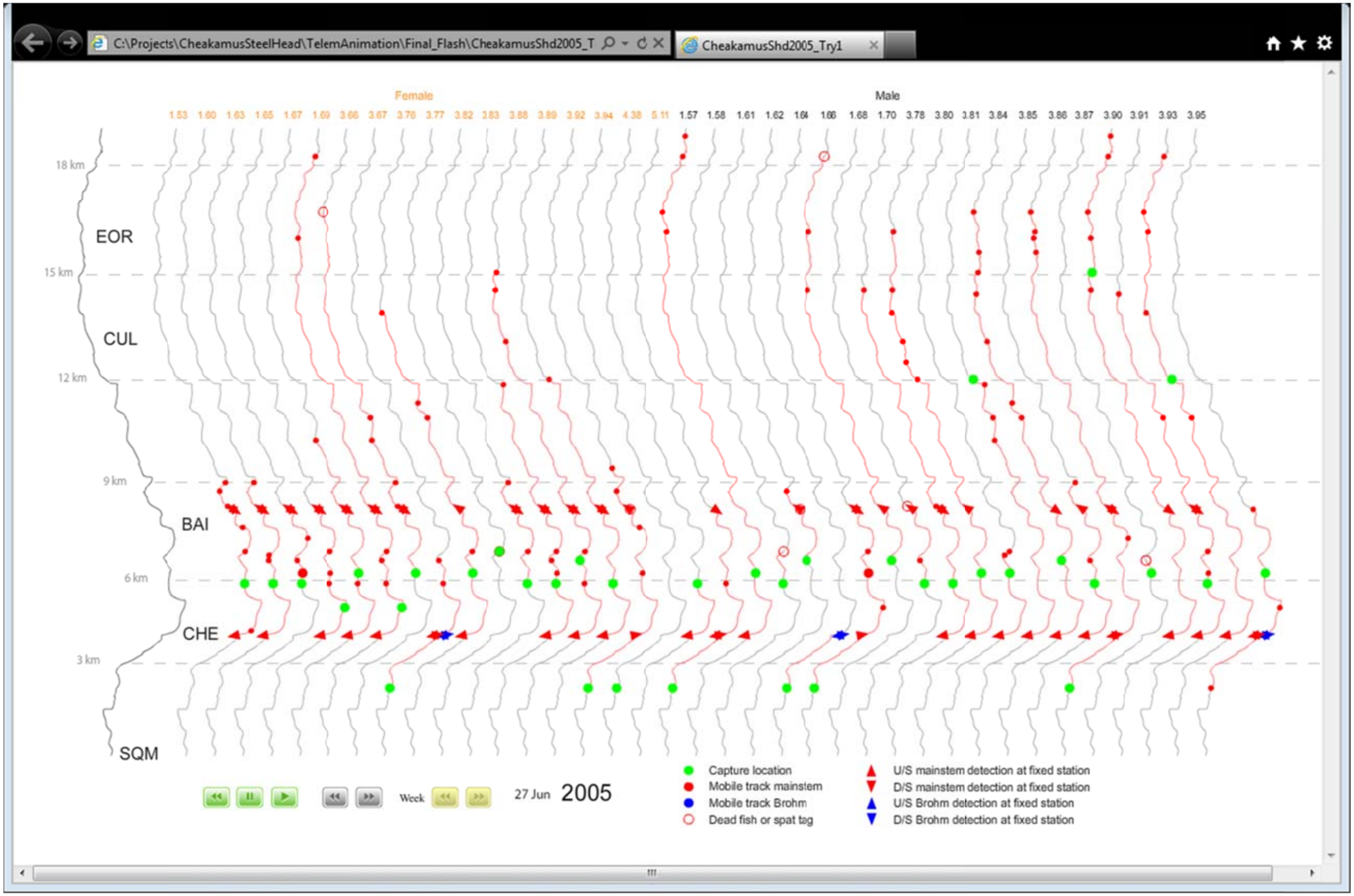
2003


C:\Projects\CheakamusSteelHead\TelemAnimation\Final_Flash\CheakamusShd2003_T
CheakamusShd2003_Try2
Female
Male
1.3 1.4 1.5 1.6 1.8 1.9 2.15 2.17 2.18 2.19 2.37 2.38 3.23 3.24 3.26 3.28 3.30 1.1 1.10 1.2 1.7 2.11 2.12 2.13 2.14 2.16 2.20 2.36 3.21 3.22 3.25 3.27 3.29
18 km
EOR
15 km
CUL
12 km
9 km
BAI
6 km
CHE
3 km
SQM
Week
20 Jun 2003
Capture location
Mobile track mainstem
Mobile track Brohm
Dead fish or spat tag
U/S mainstem detection at fixed station
D/S mainstem detection at fixed station
U/S Brohm detection at fixed station
D/S Brohm detection at fixed station

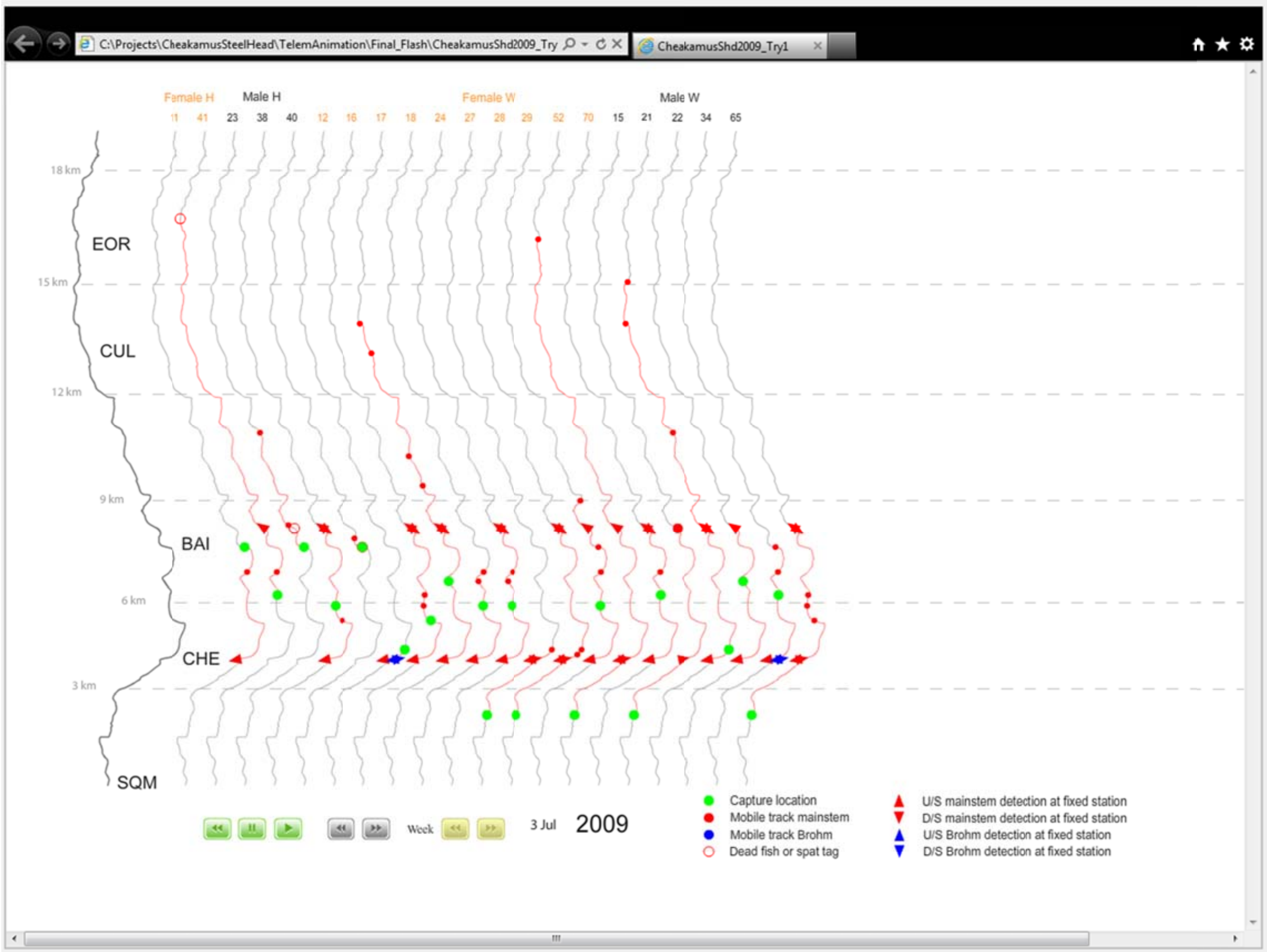
2004


C:\Projects\CheakamusSteelHead\TelemAnimation\Final_Flash\CheakamusShd2004_T
CheakamusShd2004_Try1
Female
Male
1.31 1.33 1.35 1.42 1.43 1.46 1.47 1.50 1.51 1.55 1.56 2.40 3.61 3.64 3.68 3.76 1.32 1.34 1.41 1.44 1.45 1.48 1.49 1.52 1.54 1.59 3.62 3.63 3.65 3.69 3.70 3.71 3.72 3.73 3.74 3.79
18 km
EOR
15 km
CUL
12 km
9 km
BAI
6 km
CHE
3 km
SQM
Week
18 Jul
2004
Capture location
Mobile track mainstem
Mobile track Brohm
Dead fish or spat tag
U/S mainstem detection at fixed station
D/S mainstem detection at fixed station
U/S Brohm detection at fixed station
D/S Brohm detection at fixed station

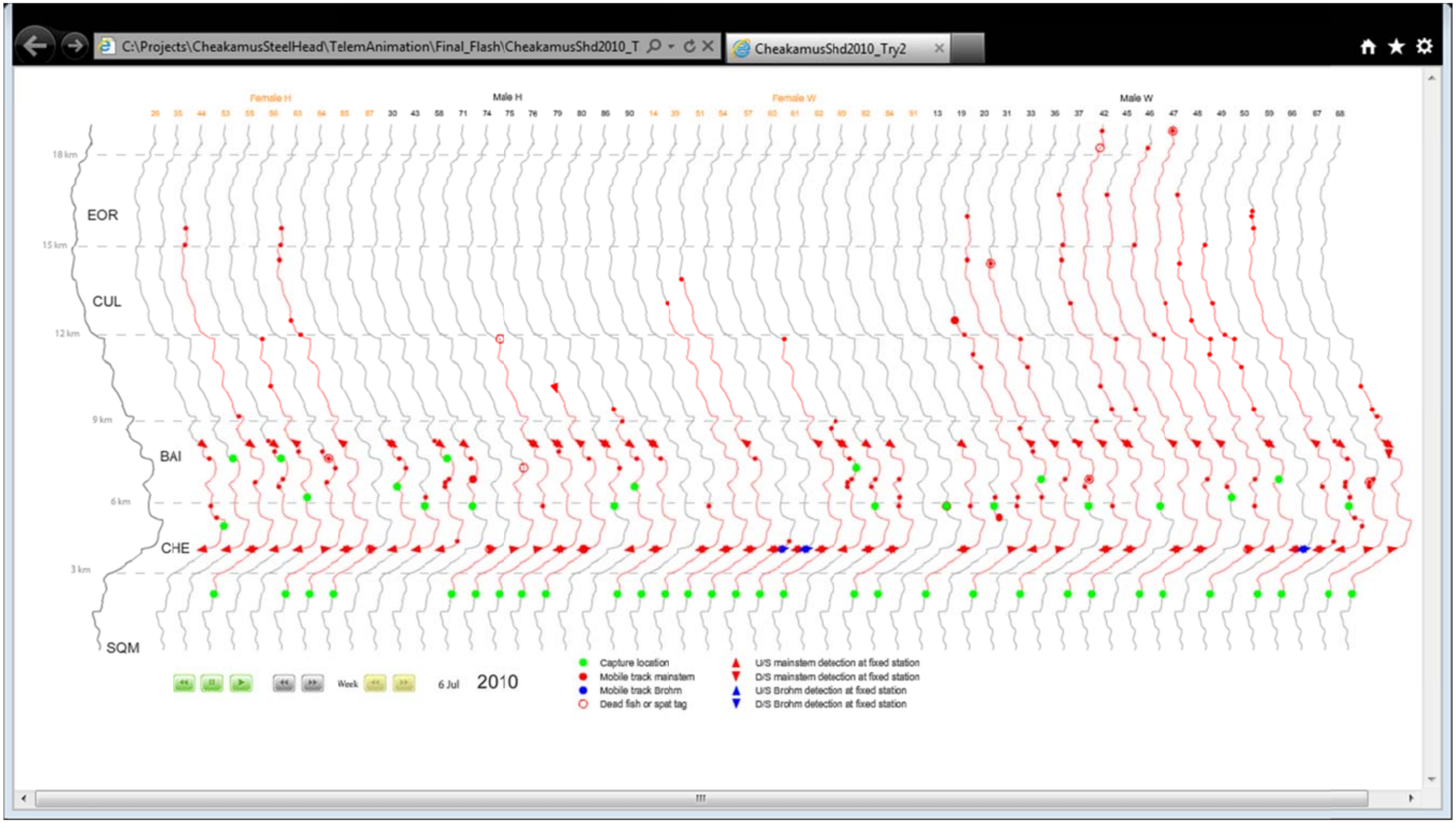
2005


C:\Projects\CheakamusSteelHead\TelemAnimation\Final_Flash\CheakamusShd2005_T
CheakamusShd2005_Try1
Female
1.53 1.60 1.63 1.65 1.67 1.69 3.66 3.67 3.76 3.77 3.82 3.83 3.88 3.89 3.92 3.94 4.38 5.11
Male
1.57 1.58 1.61 1.62 1.64 1.66 1.68 1.70 3.78 3.80 3.81 3.84 3.85 3.86 3.87 3.90 3.91 3.93 3.95
18 km
EOR
15 km
CUL
12 km
9 km
BAI
6 km
CHE
3 km
SQM
Week
27 Jun
2005
Capture location
Mobile track mainstem
Mobile track Brohm
Dead fish or spat tag
U/S mainstem detection at fixed station
D/S mainstem detection at fixed station
U/S Brohm detection at fixed station
D/S Brohm detection at fixed station

2009

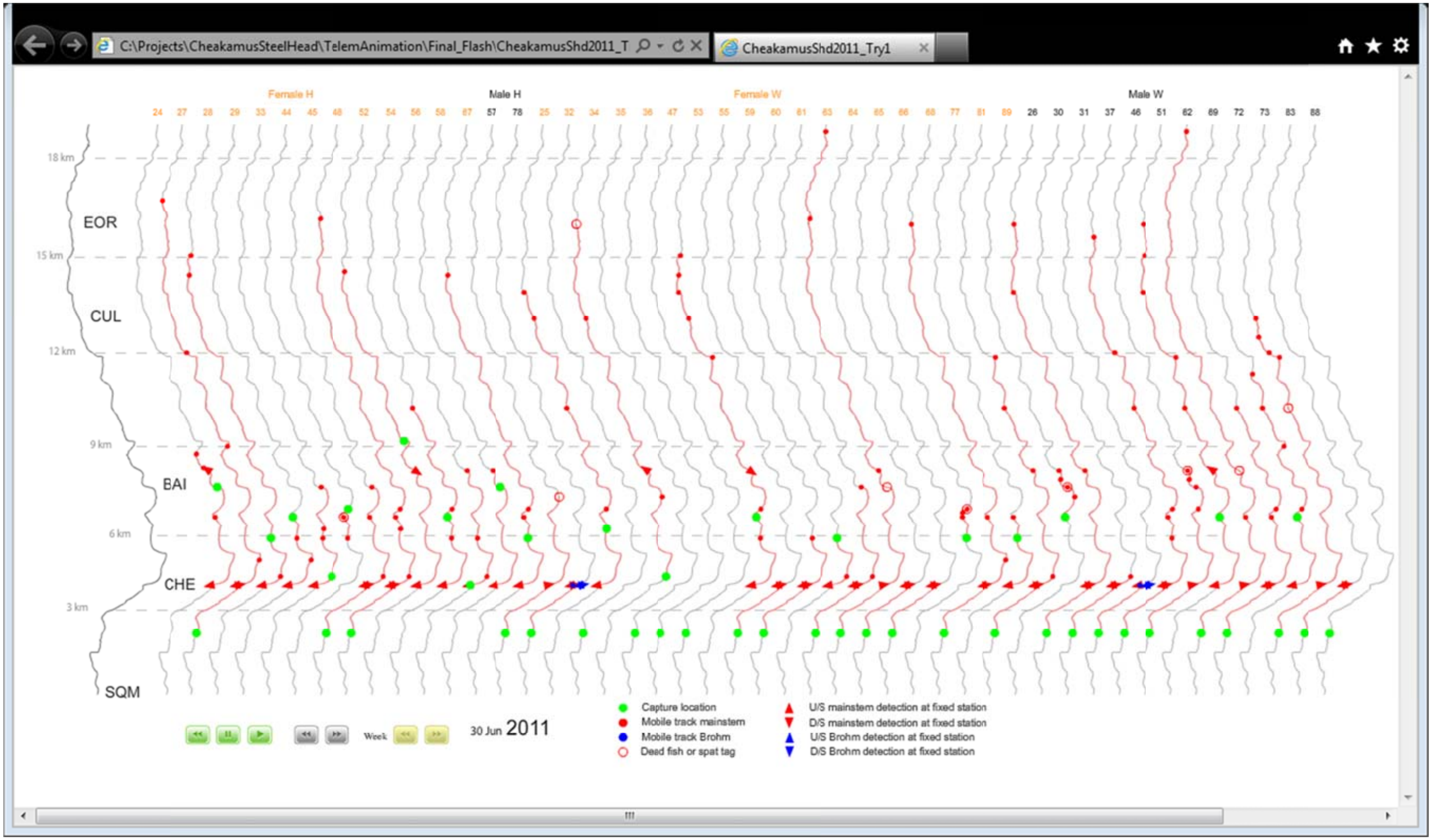

C:\Projects\CheakamusSteelHead\TelemAnimation\Final_Flash\CheakamusShd2009_Try
CheakamusShd2009_Try1
Female H
Male H
Female W
Male W
11 41 23 38 40 12 16 17 18 24 27 28 29 52 70 15 21 22 34 65
18 km
15 km
12 km
9 km
6 km
3 km
EOR
CUL
BAI
CHE
SQM
Week
3 Jul
2009
Capture location
Mobile track mainstem
Mobile track Brohm
Dead fish or spat tag
U/S mainstem detection at fixed station
D/S mainstem detection at fixed station
U/S Brohm detection at fixed station
D/S Brohm detection at fixed station

2010



C:\Projects\CheakamusSteelHead\TelemAnimation\Final_Flash\CheakamusShd2010_T
CheakamusShd2010_Try2
Female H
Male H
Female W
Male W
18 km
EOR
15 km
CUL
12 km
9 km
BAI
6 km
CHE
3 km
SQM
Week
6 Jul
2010
Capture location
Mobile track mainstem
Mobile track Brohm
Dead fish or spat tag
U/S mainstem detection at fixed station
D/S mainstem detection at fixed station
U/S Brohm detection at fixed station
D/S Brohm detection at fixed station

2011



C:\Projects\CheakamusSteelHead\TelemAnimation\Final_Flash\CheakamusShd2011_T
CheakamusShd2011_Try1
Female H
Male H
Female W
Male W
24 27 28 29 33 44 45 48 52 54 56 58 67 57 78 25 32 34 35 36 47 53 55 59 60 61 63 64 65 66 68 77 81 89 26 30 31 37 46 51 62 69 72 73 83 88
18 km
EOR
15 km
CUL
12 km
9 km
BAI
6 km
CHE
3 km
SQM
Week
30 Jun 2011
Capture location
Mobile track mainstem
Mobile track Brohm
Dead fish or spat tag
U/S mainstem detection at fixed station
D/S mainstem detection at fixed station
U/S Brohm detection at fixed station
D/S Brohm detection at fixed station

3.0 Juvenile Steelhead Abundance

3.1 Introduction

This section summarizes the methods and results from steelhead juvenile abundance surveys conducted in Cheakamus and Brohm Rivers in fall 2010 and spring 2011. It also provides revised estimates of abundance from previous surveys. Changes in juvenile abundance over multiple years can be related to changes in flow regime or other habitat changes to make inferences about how freshwater habitat quantity and quality effects juvenile steelhead production (Fig. 1.3b). The evaluation of habitat effects includes assessing potential benefits and impacts of the new WUP flow regime. Differences in the abundance within age classes between fall and spring surveys can be used to estimate apparent survival rates between these periods. The over-winter period (fall to spring surveys) is important to assess since flows in the Cheakamus River are most affected by regulation from Daisy dam during periods of low inflows, which are common during winter, and winter flow regimes have been shown to be important determinants of juvenile salmonid production and/or mortality in some systems (Hvidseten 1993, Bradford et al. 1995, Jensen and Johnsen 1999, Saltveit et al. 2001, Mitro et al. 2003). The summer period (spring to fall surveys) is important because habitat availability shortly after emergence (Elliot 1994, Nislow et al. 2004) or during low flow periods in late summer (Berger and Gresswell 2009, Harvey at al. 2005) have been shown to be important determinants of juvenile production as well, and most of the hypotheses during the Cheakamus WUP for steelhead focused on effects of low flow periods in the fall (Marmorek and Parnell 2002). Juvenile abundance can be related to escapement via estimation of life-stage specific stock-recruitment relationships so density-dependent effects can be accounted for when interpreting changes in juvenile abundance and survival through time (Fig. 1.3c). Estimates of juvenile abundance in Brohm and Cheakamus River can be compared to determine what fraction of the aggregated population rears in Brohm River, which is not effected by flow regulation from Daisy Dam.

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

The juvenile component of this project began in fall 2007 (Korman 2008) and only four years of juvenile abundance data are available (Fig. 1.4). Sampling for juvenile steelhead prior to 2007 has been limited and based on the non-random selection of sites thought to contain high quality parr habitat (see review in Van Dishoeck 2000). Changes in abundance estimates from such studies are unlikely to reflect river-wide changes in abundance because many factors, including variation in juvenile density, will affect patterns of habitat use (Bohlin 1978, Rosenfeld and Boss 2001, Girard et al. 2004, Rosenfeld et al. 2005, Gibson et al. 2008). The outmigrant trapping program has enumerated steelhead smolts since 2000, but estimates of steelhead smolt outmigration abundance are available for only a subset of these years, and uncertainty in these estimates may be significantly underestimated due to logistical and analytical challenges (Melville and McCubbing 2011). Given these historical difficulties and limitations, the emphasis of our analysis of the juvenile data collected in the early phases of this project focuses on evaluating potential bias and the precision of abundance estimates. In year 1, we investigated a variety of sampling techniques (Korman 2008), which guided the sampling design of the intensive program initiated in year 2. In this chapter, we report on the results from surveys conducted in year 4. A key assumption in our methodology is that data on detection probability of juvenile steelhead based on mark-recapture experiments is exchangeable among years. We combine data from mark-recapture experiments across years using a hierarchical Bayesian model (HBM) to compute year-specific abundance estimates. Thus, previously published juvenile abundance estimates for the Cheakamus and Brohm Rivers (fall 2008, 2009 and spring 2009, 2010 estimates from Korman et al. 2011) must be updated to reflect the addition of fall 2010 and spring 2011 mark-recapture data. Given the additional mark-recapture data, this chapter includes revised values for previously published estimates (Korman et al. 2011).

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 (see section 3) 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. 2011) which showed that electrofishing provides the most unbiased and precise estimates of age 0 abundance in habitat types where the gear can be applied, while snorkeling provides the most unbiased and precise estimates of abundance for age 1 and older juvenile steelhead (hereafter referred to as parr or age 1+ fish). In addition, the top priority of the juvenile program is to estimate the abundance of steelhead parr in the spring prior to outmigration, given the need to provide a reliable index of freshwater juvenile production. Given these various constraints, statistical considerations and priorities, fall estimates of abundance were based exclusively on electrofishing (Table 3.1). Spring abundance estimates were based on data from both electrofishing and snorkel surveys. For estimates of age 0 abundance, we used data from riffle and shallow sites sampled by electrofishing, and deep sites sampled by snorkeling. For estimates of age 1+ juvenile steelhead, we used data from riffle and shallow sites sampled by electrofishing, and shallow and deep sites sampled by snorkeling.

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

3.2.1 Sample Site Selection and Field Methods

A total of 18 and 99 index sites were electrofished (EF) for the fall 2010 abundance estimates in the Brohm and Cheakamus Rivers, respectively (Table 3.1). A total of 2 and 5 mark-recapture experiments were completed in fall 2010 in the Brohm and Cheakamus Rivers, respectively. A total of 20 and 203 index sites were sampled in spring 2011 using either electrofishing and snorkeling in Brohm and Cheakamus Rivers, respectively. In addition, we conducted 6 electrofishing and one snorkel-based mark-recapture experiment in Brohm River in spring 2011.

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

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

We continued to test our ability to predict whether a given index site would have high or low juvenile steelhead densities. If such a classification was reliable and could be done with limited effort, it would be possible to classify the entire shoreline length in greater detail than the current approach (which determines whether a shoreline can potentially support juvenile steelhead or not). The more detailed classification of shorelines potentially included in the fish sample (i.e, can support juvenile fish habitat) could in turn be used to stratify our sampling effort, allowing us to use more effort at high density sites, ultimately leading to an improvement in the precision of total population estimates. We assumed that the variation in density of juvenile steelhead across sites would largely be determined by the variation in habitat quality. Our classification used to segregate poor and good quality habitat for age 0 (fry) and age 1+ (parr) steelhead was based on a visual assessment of depth, velocity, and cover. For age 0 steelhead, sites were classified as 'good' fry habitat if over 50% of the site area was comprised of shallow depth (< 0.5 m), low velocity (<0.2 m/s) and where cover was present in the form of interstitial spaces between cobbles. For age 1+ steelhead, sites were classified as 'good' parr habitat if over 50% of the site was comprised of low velocity area and where cover in the form of interstitial spaces, boulders, or large woody debris was present. We compared the number of fish detected at index sites across sites classified as 'poor' or 'good' habitat for both age 0 and 1+ steelhead.

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

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

We used methods developed by Korman et al. (2009) for electrofishing-based mark-recapture experiments. A two-person crew, using a Smith-Root 12b electrofisher (settings: 300V, frequency and pulse I4-J5), traversed the site in an upstream direction. Electrofishing was very methodical, requiring 0.75-1.5 hrs of effort to sample each site. After electrofishing, fish were anesthetized using clove oil and fork lengths were measured to the nearest mm. Fish were marked using red biological dye (fall) or a small caudal fin clip (spring). Dying is a more efficient method for marking many small fish that are commonly captured in the fall, but the dye can result in behavioral changes or mortality at very low water temperatures in the spring. For dying, fish were placed in an aerated bucket with neutral red biological stain (2 g per 15 L, Sigma-Aldrich Ltd.) for 20 minutes and then transferred to aerated buckets of clear water to recover. The fork lengths of the very small proportion of dead fish and those that were not actively swimming after processing were recorded so they could be excluded from the count of marked fish released into the site. The remaining fish were released throughout the sample site, avoiding areas with high water velocity and areas within 5 m from the upstream and downstream boundaries of the site. We felt this release strategy provided a more suitable environment for recovery and would minimize emigration from the site if fish were disoriented or unable to maintain their position immediately following release. We assumed that marked fish would resume an undisturbed distribution within the site before the second sampling event 24-hours later.

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

A fish length-stratified random sampling approach was use to collect scales for freshwater age determination. Age determinations were made for 65 and 71 juvenile steelhead from the Brohm and Cheakamus Rivers in fall 2010, respectively, and from 92 and 123 fish from the Brohm and Cheakamus Rivers in spring 2011, 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+ and 1+ in the spring sample would be one- and two-years old (one and two winters), respectively.

3.2.2 Analytical Methods

We developed a hierarchical Bayesian model (HBM) similar to model I of Wyatt (2003 and 2002) to estimate juvenile steelhead abundance. The model consists of two levels or hierarchies (Fig. 3.1). Site-specific estimates of detection probability and fish density at the lowest level of the hierarchy are considered random variables that come from hyper-distributions of detection probability and density at the higher level. The HBM jointly estimates both site- and hyper-parameters. The process component of the model assumes that variation in juvenile abundance across sample sites follows a Poisson/log-normal mixture. That is, abundance at-a-site is Poisson-distributed based on a mean density drawn from a lognormal distribution. The observation component of the model assumes that variation in the number of fish observed at index sites, and number of tagged fish observed at mark-recapture sites, follow binomial distributions, and that variation in detection probabilities across sites follows a beta distribution. Estimates of the total abundance across sampled sites within a reach are added to an estimate of the abundance in the unsampled shoreline in the reach to determine the total abundance in the reach. Reach-specific estimates are summed to determine the total abundance in Brohm River and Cheakamus River. Reach stratification is specified in section 3.0. Hyper-parameters for detection probability estimates are gear-specific. Only a single set of hyper-parameters are estimated for density, thus we assume that mean density does not vary across reaches or habitat types sampled by different gears.

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

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

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

We compared estimates of age 1 and 2 steelhead abundance in the Cheakamus River in spring 2009-2011 determined from the HBM with the estimated number of smolts passing the Rotary Screw Trap (RST) at ages 2 and 3 years, respectively. Recall that an age 1 parr sampled in early April would be considered a 2-year old fish by the time the winter is complete by May when most of the steelhead at the RST are caught. Similarly, age 2 parr sampled in early April would be 3 year smolts in May. A number of manipulations and assumptions were required for this comparison of the abundance of parr and smolt estimates. It is important to note that not all age 1 parr (which have essentially spent two winters in freshwater at the time of juvenile surveys) will leave as two years smolts, as some will reside in the river an additional year, and if they survive, will depart as 3 year smolts. As we can assume that the vast majority of smolts depart no later than age 3 (see results below), the easiest comparison to make is between the number of age 2 parr and the number of age 3 smolts because it is very likely that very few age 2 parr will remain in the river an additional year (owing to the virtual absence of 4 year smolts at the RST). We therefore focus our assessment on this age 2 parr – 3 year smolt comparison. Given the estimated proportion of 2 and 3 year smolts at the RST, we also compared our estimate of age 1 parr abundance with the required number to smolt at two years to maintain 2:3 year smolt ratio at the RST. Finally, to provide insight into the parr-smolt comparision, we compared the length frequency distributions from fish captured during our juvenile surveys (dominantly early April) that were aged with those from the RST (dominantly May). 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 21% (551 m) and 7% (3003 m) of the useable shoreline length of the Brohm and Cheakamus Rivers during the fall 2010 surveys, respectively (Table 3.1a). We sampled 31% (825 m) and 20% (8489 m) of the useablelshoreline length during the 2011 spring surveys in the Brohm and Cheakamus Rivers, respectively. Discharge and water temperature in the Cheakamus River spanning the period when juvenile surveys were conducted are shown in Fig. 3.2. Flows were generally near winter base flow levels of 15-20 m^3/sec during both surveys except for the initial effort in the Cheakamus in fall 2010. Water temperature during the fall survey ranged from 9-12 ^{o}C in the Cheakamus River and 10-11 ^{o}C in Brohm River. Water temperatures in the Cheakamus and Brohm Rivers during the spring surveys ranged from 5- 6 ^{o}C.

Results from scale ageing (Table 3.4) were used to assign maximum lengths for age 0, and 1 year old steelhead in Brohm River of 75 and 110 mm in fall 2010, and 75 and 120 mm in spring 2011, respectively. In the Cheakamus River, maximum lengths for age 0 and 1 year old steelhead in fall 2010 were 80 and 135 mm, and 100 and 130 mm in spring 2011. 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). However, there appears to be larger variation in size-at-age for age 0 fish in the Cheakamus River in the spring sample.

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

A total of 1226 and 1535 juvenile steelhead were enumerated at index sites in Brohm and Cheakamus Rivers in fall 2010, and 449 and 2310 in spring 2011, respectively (Table 3.5). Catch per effort (CPE) of steelhead was highly variable across index sites in the Cheakamus River, but sites classified as having “good” habitat quality for fry and parr had average CPEs that were 2-4 fold higher than sites classified as having “poor” habitat (Fig. 3.4).

Mark-recapture experiments conducted in fall 2010 and spring 2011 provided additional data to estimate hyper distributions of detection probability in the HBM (Table 3.6). Aggregating data from all years, detection probability for age-0 steelhead based on electrofishing was relatively consistent among experiments and was almost twice as high in the Cheakamus River compared to Brohm River (Table 3.7), likely due to the more porous nature of the substrate in Brohm. For 1+ steelhead, detection probability for electrofishing was higher in Brohm River than in the Cheakamus River, likely due to reduced channel width and shallower depths in Brohm. Electrofishing-based detection probability estimates for age 1+ steelhead in the Cheakamus River were highly uncertain because few fish are marked due to low capture probability. High variability among sites for this stratum likely 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.

Catch per effort (CPE) in Brohm River in fall was remarkably similar between 2008 and 2010 for all age classes (Table 3.8). Abundance of age 0 steelhead in the spring sample in 2009 was much lower, likely because electrofishing was not conducted in this first year. In the Cheakamus River, CPE for age 0 steelhead was approximately two- and three- fold higher in fall 2008 compared to fall 2009 and 2010, respectively. Catch per effort for age 1 steelhead in spring 2009 was 4-fold lower than in spring 2010 but similar to the CPE in 2011.

3.3.3 Estimates of Juvenile Steelhead Abundance from the Hierarchical Bayesian Model

An intense and successful sampling effort was implemented in fall 2010 and spring 2011 in both the Brohm and Cheakamus Rivers, resulting in catch data from a large number of index sites (Table 3.9). In addition, the multi-year mark-recapture datasets expanded based on experiments conducted in fall 2010 and spring 2011. These characteristics led to large improvement in precision (Coefficient of Variation (CV)) of estimates of juvenile steelhead abundance for the majority of strata, especially for Brohm River where the number of electrofishing-based mark-recapture experiments doubled based on fall 2010 and spring 2011 sampling (Table 3.6). An example of output from the HBM for one strata (Cheakamus River age 1 steelhead in spring 2011) 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). Higher densities of age 1 parr were occasionally seen at sites upstream of Culliton Creek and between the Cheekye confluence and the Bailey Bridge (3.5e). 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), which depends on uncertainty in the hyper-distribution of fish density (Fig. 3.5f).

Total abundance estimates in fall 2010 and spring 2011 were generally precise (average CV across 12 strata = 0.16, Table 3.10). Estimates for Brohm River were slightly more precise than for the Cheakamus owing to sampling a greater proportion of the river (Table 3.1) and lower variation in densities across sites. Estimates for the Cheakamus River were generally precise except for age 2 fish in fall 2010, which resulted from low and variable detection probability coupled with low catch. Note that abundance estimates for age 1 parr in the Cheakamus River in spring, perhaps the most important metric we measure as a surrogate for smolt production, had CVs of 0.28, 0.12, and 0.09 in 2009, 2010, and 2011, respectively. The improving precision is the result of increasing the number of index sites through time. Note that in spring 2009, the Brohm age 0 estimate was greater than the age 1 estimate, which was not the case in spring 2010 and 2011. This occurred because both electrofishing and snorkeling were used in the latter years, but not in 2009. It is very likely that the abundance of age 0 steelhead in spring 2009 was underestimated due to a positive bias in detection probability for small fish when snorkeling (Korman et al. 2011). Abundance estimates for Brohm River in fall 2008 were very imprecise, owing to the very limited number of index sites that were sampled (making it difficult to estimate variation in fish density across sites). Note that the revised estimates for fall 2008 presented here were based on uninformative priors, which was not the case when the original estimates were developed (Korman and Schick 2010). As this project continues, we will obtain multiple estimates of the variation in fish density across sites and in a final report, can use this information to develop informative priors to use for situations like 2008 when sampling effort is too low.

We tracked the change in the abundance of the 2008-2010 steelhead cohorts (fish from the spawn in 2008-2010) by combining estimates across strata (Table 3.11, Fig. 3.6). As an example, the 2008 cohort from the Cheakamus River declined from an estimated egg deposition of 532 thousand to 237 thousand age 0 fish in fall 2008 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 1, and from egg deposition to spring age 1, was 45%, 8%, and 4%, respectively. We use the term apparent survival because the estimate is potentially affected by immigrants from Brohm River as well as emigration out of the sampled area. Survival from fall age 0 to spring age 1 ranged from 4-12% for 2008 and 2009 cohorts from Cheakamus and Brohm Rivers, and estimates were reasonably precise considering the challenges of estimating survival rates, with CVs ranging from 22-30%. Although data to track the fate of all life stages from the 2010 cohort is not yet available, we note the substantially reduced egg-fall fry survival rate of 4%, compared to 21% for the 2009 cohort and 45% for the 2008 cohort. This lower survival rate could be caused by the 3-fold increase in egg deposition in 2010 resulting in greater density dependent mortality, or by unusual aspects of the hydrograph during the summer of 2010 which increased mortality of recently emerged fry. Both hypotheses are feasible and there is evidence for strong density dependent mortality in the adult-based stock-recruit analysis (Fig. 2.8). We plan on exploring this issue in more detail in next year's report when estimates of abundance and survival from the large 2011 spawning cohort are available.

Some life-stage specific survival estimates are likely inaccurate due to biases in population estimates (Table 3.11, Fig. 3.6). The estimate of age 1 abundance in fall in the Cheakamus for the 2008 cohort is likely biased low because the estimates for the same cohort the following spring are larger. This results in a nonsensical survival rate between sample periods of greater than one. The bias in estimates of abundance for age 1 steelhead in fall is not surprising, and is likely caused by an overestimation of river-wide detection probability for this age class. This occurs because few informative mark-recapture experiments for parr in deeper habitats are achieved due to low detection probability, so the ones from shallow habitats, where detection probability is higher (Fig. 3.7), dominate the estimated hyper distribution and population estimates. For Brohm River, the age 0 estimate in spring 2009 is very likely biased low (due to snorkeling only), resulting in a nonsensical survival estimate between spring 2009 and fall 2009. The survival estimate between fall 2008 and spring 2009 is also likely biased low. Such biases in Brohm River did not occur after spring 2009 because electrofishing was introduced as an additional sampling method. The overall fall age-0 to spring age-1 survival rate in Brohm River is likely unbiased because these two abundance samples are likely unbiased (electrofishing adequate to sample age 0 fish in fall, and snorkeling and electrofishing used for age 1 in spring 2010 sample).

Estimates of age 2 parr abundance above the RST in the spring of 2009, 2010, and 2011 were compared to estimates of 3 year smolt abundance at the RST. Juvenile survey-based estimates were 30% and 19% higher than RST-based ones in 2009 and 2010, respectively, but 30% lower in 2011 (Table 3.12). However, due to the uncertainty in both types of estimates, these differences could be solely due to sampling error (Fig. 3.8). The required number of age 1 parr to smolt at two years to maintain the 2:3 year smolt ratio at the RST was well below the estimated age 1 parr abundance in 2010 and 2011. However in 2009, virtually all of the age 1 parr would need to have smolted at two years, which is unlikely given that 53% of the smolts in 2010 were 3 year olds (i.e., some age 1 parr must have remained in the Cheakamus in 2009 to eventually smolt as 3 year olds in 2010). Assuming the 2:3 year smolt ratio and abundance at the RST is correct, this indicates that age 1 parr abundance in 2009 was likely biased low.

The comparison of juvenile survey- and RST-based abundance estimates depends entirely on correct and consistent aging of steelhead juveniles from both surveys. Examination of length frequency distributions for steelhead that were aged indicates there may be significant discrepancies in the age designations from these two surveys (Table 3.13). These length frequency distributions indicate the age 1 and 2 parr sampled in early April would need to grow approximately 50-60 mm to match the size distributions of 2 and 3 year smolts at the RST in May. This amount of growth in 1.5-2 months seems unrealistic and may indicate that fish from the juvenile surveys are over-aged, or fish from the RST survey are under-aged. A reexamination of scales by an independent biologist will be required to resolve this issue, but our initial suspicion is that smolts at the RST are under-aged. Ageing of fish from the juvenile survey may be more accurate because small fish of known age (age 0) are included in the sample and help calibrate age estimates for older fish. The age 0 fish provide a reference for verifying the presence of the first winter growth check on fish that can only have one check (i.e. fish < 60 mm in spring). This check can be difficult to observe owing to the very limited growth from emergence to the beginning of winter in the first year of life. Observing the first winter check on fish of known age in spring (age 0) makes it easier to assign correct age classes to older fish. At the RST, age 0 fish are not aged, so the first winter check may be missed, resulting in under-aging by one year. The same problem would occur for freshwater ages assigned from reading of adult scales. It is critical to resolve this ageing discrepancy as it effects stock-recruit and production analysis for most aspects of the work presented here. Further, until it is resolved, the comparison of juvenile survey- and RST-based abundance estimates should be considered highly preliminary. If the ageing discrepancy is substantive, the current evaluation (Table 3.12 and Fig. 3.8) is an apples-to-oranges comparison.

3.4 Conclusions

Juvenile steelhead population estimates in the Cheakamus and Brohm Rivers are generally quite precise due to increases in the number of index sites and the accumulation of mark-recapture data across years. The former provided better information on mean fish densities and variation in fish densities across sites, while the latter provided additional data on detection probability. In the Cheakamus River, most population estimates had CVs that were less than 0.2. At the currently level of effort, estimates for age 1 parr in the spring, which may be our best proxy of potential smolt production, are very precise (CV ~0.1). Estimates of steelhead smolt production derived from juvenile surveys in spring 2008-2011 were within 30% of estimates from the Rotary Screw Trap. This indicates that production estimates from the juvenile survey are likely relatively unbiased. However, this evaluation is a relatively insensitive test when one considers the uncertainty in both juvenile survey- and RST-based estimates. Further, this comparison should be considered highly preliminary until ageing discrepancies between fish collected during juvenile and RST surveys are resolved.

The most significant finding from the analysis is the demonstration that it is possible to estimate survival rates of juvenile steelhead after 2 winters in freshwater. Survival from age 0 in the fall to age 1 in the spring (i.e., 2 winters in freshwater) was 4-8% and 5-12% in the Cheakamus and Brohm Rivers, respectively with CVs between 0.22 and 0.3. This precision will likely allow evaluation of the effects of major changes in flow and other abiotic and biotic factors on juvenile survival rates. Given reasonably accurate escapement estimates and information on the size of returning spawners, it is also be possible to compute egg-fry and egg-parr survival rates. Estimates of egg-fall fry survival in the Cheakamus River were 45%, 21%, and 4% for 2008, 2009, and 2010 spawning cohorts. Such estimates can be compared over time and to literature values in unregulated streams to evaluate potential effects of the current and future flow regimes. The substantive decrease in egg-fall fry survival in 2010 may be due to the much greater egg deposition in that year, resulting in greater density dependent mortality. Alternatively, rapid stage reductions in summer of 2010 when fry were utilizing vulnerable low angle cobble bars may have increased the overall summer mortality rate. We should be able to resolve this uncertainty based on data from 2011 where egg deposition was high and when these rapid drawdowns did not occur. If egg-fall fry survival rates for the 2011 cohort are similar to 2008 and 2009, this would indicate that rapid drawdowns are having a substantive effect on production.

In spring 2010, fall 2010, and spring 2011 samples, catch per effort was two- to four-fold higher in sites classified as having good rather than poor quality habitat for age 0 and 1+ steelhead. However, there was considerable variation in catch per effort across sites classified as either poor or good quality habitat. Clearly, other habitat attributes and non-habitat effects (proximity to spawning locations, predator concentrations, food availability, water quality) are having an important effect on local juvenile steelhead abundance in this system. In a future analysis, we will use simulation techniques to evaluate the potential gains in precision that can be achieved through a habitat quality-stratified sampling design. The effectiveness of such a stratified depends on both the differences in mean density across habitat quality classes as well as the variation in density within classes.

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Table 3.1. Summary of juvenile steelhead sampling effort in Fall 2010 and Spring 2011 in Brohm and Cheakamus Rivers. 'EF' and 'SN' denote electrofishing and snorkelling sampling gear types, respectively. Index sites were sampled using one pass, while Mark Recapture (MR) sites were sampled using two passes.

a) Index Sites

		# Index Sites			Sampled	Useable	Proportion
		EF	SN	Total	Length (m)	Length (m)	Sampled
Fall	Brohm	18		18	551	2,675	0.21
2010	Cheakamus	99		99	3,003	42,752	0.07
Spring	Brohm	10	10	20	825	2,675	0.31
2011	Cheakamus	78	125	203	8,489	42,752	0.20

b) Mark-Recapture

		# Mark Recapture Sites		
		EF	SN	Total
Fall	Brohm	2		2
2010	Cheakamus	5		5
Spring	Brohm	6	1	7
2011	Cheakamus	0	0	0

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

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

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

Detection Model

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

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

Population Model

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

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

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

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

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

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

(3.9) $Nt_r = Ns_r + Nus_r$

(3.10) $Nt = \sum_r Nt_r$

Table 3.3. Con't.

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 fall (a) and spring (b). Yellow-shaded cells indicate the maximum size cut-offs used to assign ages based on fork length for fish that were not aged.

a) Fall

Fork	Brohm									Cheakamus								
Length	2008			2009			2010			2008			2009			2010		
(mm)	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2	0	1	2
<45							2											
45-49							6						1					
50-54							8						1			4		
55-59							3						6			8		
60-64							1						6			10		
65-69							2	1		1			11			3		
70-74					1		1	3		1	1		6	1		3		
75-79	2				2		1	3					3	2		6	1	
80-84		1			3			4			1		4	2		1	2	
85-89		2			6			2						1				
90-94		4			4			5			3			5				
95-99		3			4			3			5			2				
100-104		1			4			3			3			3			3	
105-109					4			3	1		7			4			2	
110-114						2		1						6	1		4	
115-119									1		2			4	1		2	
120-124						1			1		2			6	1		3	2
125-129			1			2			2		4			5	1		2	1
130-134			1			3			6		2	2		3				3
135-139											1	2		1	1			1
140-144									1		1	3			2			4
145-149			1									2			2			
150-154						1												1
155-159						1												2
160-164												3						1
170-174									1			2						
175-179												2						1
185-190			1															
>190																		1
Total	2	11	4		28	10	24	28	13	2	32	16	38	45	9	35	19	17

Table 3.4. Con't.

b) Spring

Fork	Brohm									Cheakamus											
Length	2009			2010			2011			2008			2009			2010			2011		
(mm)	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							5						1						1		
50-54				2			4						5			2			3		
55-59	1			1			4						3			6			4		
60-64				9			4						6			3	1		7		
65-69				4			2						2			6	1		6		
70-74	1			3				1					6			6	2		6		
75-79		1		1									3			6	4		7	1	
80-84					2		1	1			1		6	1		1	5		6	1	
85-89		3			1		1	6		1			3			2	11		5	1	
90-94		2			2			6			7		7	2			10		6	1	
95-99		4			2			4			3		1	2		1	11		5	3	
100-104					3			3	1		1			1			7		1	4	
105-109		1			4			6			1			3			12		2	6	
110-114		1			1				1					2			5			6	
115-119					1			5	1					6			5			4	1
120-124		2						2	8					1			4	1		5	3
125-129					3	1			1					7	1		1	1		2	1
130-134									4		3			4			1			2	2
135-139		1							7		3	1		7	2			1		3	2
140-144									6		4			1	2		1	2			2
145-149			2						3		3	4		1	1			4			1
150-154			1						1		1	2			1			2			4
155-159		1	1						2			4			3			4			
160-164			1						2		1	1			1						1
165-169			1								1	1			1			1			5
170-174																					1
175-179															1			1			1
180-184												2			1						
185-190															1						
Total	2	16	6	20	19	1	21	34	37	1	29	15	43	38	15	33	81	17	60	39	24

Table 3.5. Total number of juvenile steelhead captured by electrofishing (EF) or observed by snorkelling (SN) summed across all index sites in Brohm and Cheakamus Rivers by age class.

Season Year	**Gear**	**River**	**Age**			
			0+	**1+**	**2+**	**0+ - 2+**
Fall	EF	Brohm	827	212	187	1,226
2010	EF	Cheakamus	1,451	59	25	1,535
Spring	EF	Brohm	103	58	28	189
2011	SN		25	91	144	260
	EF	Cheakamus	696	27	16	739
	SN		1,063	304	204	1,571

Table 3.6. Summary of data from individual mark-recapture experiments for juvenile steelhead in Brohm and Cheakamus Rivers since the project was initiated in fall 2007. Detection probability (θ) is the ratio of recaptured (electrofishing) or resighted (snorkeling) fish to the total that were marked (Marked).

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

Table 3.6. Con't.

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

Cheakamus Age-1+ Electrofishing				
Year	Season	Marks	Recaps	θ
2007	Fall	11	1	0.09
2007	Fall	13	0	0.00
2007	Fall	4	0	0.00
2007	Fall	52	6	0.12
2007	Fall	20	2	0.10
2007	Fall	17	3	0.18
2008	Fall	2	0	0.00
2008	Fall	4	0	0.00
2008	Spring	19	5	0.26
2008	Spring	13	1	0.08
2008	Spring	18	3	0.17
2008	Spring	1	0	0.00
2008	Spring	34	10	0.29
2008	Spring	9	1	0.11
2008	Spring	12	1	0.08
2008	Spring	15	0	0.00
2009	Fall	2	2	1.00
2009	Fall	3	0	0.00
2009	Fall	1	0	0.00
2009	Fall	3	1	0.33
2009	Fall	1	0	0.00
2009	Fall	5	0	0.00
2009	Fall	2	2	1.00
2009	Fall	9	2	0.22
2009	Fall	10	4	0.40
2009	Fall	7	0	0.00
2009	Spring	2	1	0.50
2010	Spring	40	6	0.15
2010	Spring	39	4	0.10
2010	Spring	15	4	0.27
2010	Spring	19	3	0.16
2010	Fall	11	1	0.09
2010	Fall	5	0	0.00
2010	Fall	16	7	0.44
2010	Fall	16	1	0.06

Table 3.6. 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 3.7. Summary statistics of detection probability from mark-recapture experiemtns in Brohm and Cheakamus Rivers since the project was initiated in fall 2007 based on electrofishing (EF) and snorkeling (SN). 'N', 'Mean', and 'CV' denote the sample size (# of experiments), mean detection probability, and coefficient of variation in detection probability across experiments within each strata.

Strata	N	Mean	CV
Brohm Age-0 EF	14	0.18	0.30
Brohm Age-1+ EF	14	0.26	0.46
Cheakamus Age-0 EF	43	0.31	0.38
Cheakamus Age-1+ EF	35	0.18	1.39
Both Rivers, Age-0 SN	20	0.39	0.64
Both Rivers, Age-1+ SN	20	0.61	0.28

Table 3.8. Comparison of juvenile steelhead catch per effort (fish per km sampled) across years and seasons where random sampling has been implemented.

				Age	
River	**Season**	**Year**	**0**	**1**	**2**
Brohm	Fall	2008	1,488	512	291
		2009	1,646	510	249
		2010	1,501	385	339
	Spring	2009	73	590	125
		2010	283	595	203
		2011	155	181	208
Cheakamus	Fall	2008	1,550	85	32
		2009	606	36	9
		2010	483	20	8
	Spring	2009	225	42	16
		2010	124	183	41
		2011	207	39	26

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

				Index Sites			Mark Recapture		
River	**Year**	**Season**	**Age**	**EF**	**SN**	**Total**	**EF**	**SN**	**Total**
Brohm	2010	Fall	0	17		17	14		14
			1-2	17		17	14		14
Cheakamus			0	99		99	43		43
			1-2	99		99	35		35
Brohm	2011	Spring	0	10	0	10	14	20	34
			1-2	10	10	20	14	20	34
Cheakamus			0	78	72	150	43	20	63
			1-2	78	123	201	35	20	55

Table 3.10. Statistics of total population estimates (in thousands) for juvenile steelhead in the Brohm and Cheakamus 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	246.2	237.5	0.21	169.5	369.2
			1	26.7	24.7	0.36	15.1	49.8
			2	13.2	9.4	1.4	4.2	45.9
	2009	Spring	0	50.9	48.8	0.23	33.7	79.8
			1	6.5	6.2	0.28	4.2	10.8
			2	2.4	2.2	0.32	1.4	4.2
Brohm	2008	Fall	0	26.0	22.9	0.68	14.5	53.5
			1	8.3	5.5	9.5	3.4	13.8
			2	Did not converge due to low density/sample size				
	2009	Spring	0	0.5	0.5	0.9	0.3	0.9
			1	2.8	2.7	0.2	2.0	3.9
			2	0.6	0.6	0.23	0.4	0.9
Cheakamus	2009	Fall	0	101.1	97.4	0.22	68.9	157.3
			1	12.1	10.8	0.45	6.6	25.3
			2	2.7	2.4	0.51	1.2	6.2
	2010	Spring	0	24.3	23.3	0.22	16.5	37.5
			1	18.7	18.4	0.12	15.1	23.7
			2	3.8	3.7	0.23	2.6	6.0
Brohm	2009	Fall	0	25.0	24.1	0.21	17.9	37.3
			1	5.4	5.3	0.15	4.1	7.2
			2	2.6	2.5	0.2	1.8	3.9
	2010	Spring	0	5.2	5.0	0.31	3.4	8.7
			1	2.8	2.8	0.1	2.3	3.3
			2	1.1	1.0	0.17	0.8	1.4

Table 3.10. Con't.

River	Year	Season	Age	Mean	Median	CV	LCL	UCL
Cheakamus	2010	Fall	0	71.4	70.2	0.15	55.1	95.4
			1	5.4	5.2	0.22	3.5	8.0
			2	2.5	2.2	0.44	1.2	5.3
	2011	Spring	0	32.3	32.1	0.1	27.0	39.3
			1	3.6	3.5	0.09	3.0	4.3
			2	2.4	2.4	0.14	1.9	3.2
Brohm	2010	Fall	0	22.2	22.1	0.09	18.7	26.6
			1	4.0	3.9	0.13	3.1	5.1
			2	3.6	3.6	0.13	2.8	4.6
	2011	Spring	0	4.6	4.6	0.14	3.5	5.9
			1	1.2	1.2	0.15	0.9	1.6
			2	1.2	1.2	0.12	1.0	1.5

Table 3.11. Juvenile survival statistics for Cheakamus and Brohm River steelhead cohorts (year of spawning). Abundance for each age calss and sampling period is the median of the posterior distribution of the total abundance estimates from the HBM. See Table 2.17 for estimated annual egg deposition. Survival between periods is the ratio of abundances across adjacent rows. Values in parentheses denote the coefficient of variation of the survival estimates.

River	Cohort	Age	Sampling Period	Abundance ('000s)	Survival between Periods	Survival Fall Age-0 Spring Age-1	Survival Egg - Age 1 Spring
Cheakamus	2008	Eggs	Summer-08	531.6			
		0	Fall-08	237.5	0.45		
		0	Spring-09	48.8	0.21		
		1	Fall-09	10.8	0.22		
		1	Spring-10	18.4	1.70	0.08	0.03
	2009	Eggs	Summer-09	467.1			
		0	Fall-09	97.4	0.21		
		0	Spring-10	23.3	0.24		
		1	Fall-10	5.2	0.22		
		1	Spring-11	3.5	0.68	0.04	0.01
	2010	Eggs	Summer-10	1,608.5			
		0	Fall-10	70.2	0.04		
		0	Spring-11	32.1	0.46	NA	NA
Brohm	2008	0	Fall-08	22.9			
		0	Spring-09	0.5	0.02		
		1	Fall-09	5.3	11.69		
		1	Spring-10	2.8	0.53	0.12	NA
	2009	0	Fall-09	24.1			
		0	Spring-10	5.0	0.21		
		1	Fall-10	3.9	0.79		
		1	Spring-11	1.2	0.30	0.05	NA

Table 3.12. Comparison of steelhead smolt production estimates for the Cheakamus River from 2009-2011 based on the Rotary Screw Trap program (Melville and McCubbing, 2011) with those derived from juvenile surveys. Juvenile parr abundance estimates are the medians of the posterior distributions from the HBM. The age 1 parr – 2 yr smolt proportion are estimates of the proportion of age 1 parr (2 winters in freshwater) that will outmigrate as 2 yr smolts. Estimates of smolt numbers from the RST exclude side channel production and are based on a Pooled Peterson estimate. Shaded cells show the key comparison (age 2 parr vs. 3 Yr smolts).

	2009	2010	2011
Juvenile Survey Parr Abundance			
Age 1 Parr (--> 2 Yr Smolt)	5,130	13,990	2400
Age 2 Parr (--> 3 Yr Smolt)	1,580	2,810	1580
RST Estimates of Smolts	5,314	4,494	3812
% 2 Yr Smolts	77%	47%	38%
2:3 Yr Smolt Ratio	3.36	0.90	0.62
2 Yr Smolts	4,096	2,129	1,458
3 Yr Smolts	1,218	2,365	2,354
RST 3 Yr Smolt / Juvenile Survey Age 2 Parr	0.77	0.84	1.49
Age 1 Parr to maintain 2:3 Yr smolt ratio	5,315	2,529	978
Proportion Age 1 Parr Smolting at 2 Yr	1.04	0.18	0.41

Table 3.13. Comparison of length-at-age distributions from scale readings (# of fish by 10 mm length class) for steelhead collected from juvenile surveys reported here (Juv. Surv.), and those from the Rotary Screw Trap (RST) program, 2009-2011. Fish aged as 1 and 2 year parr from the juvenile surveys would be aged as 2 and 3 year smolts when captured at the RST approximately two months later.

Fork	2009				2010				2011			
Length	Juv. Surv.		RST		Juv. Surv.		RST		Juv. Surv.		RST	
Class (mm)	1	2	2	3	1	2	2	3	1	2	2	3
55-64					1							
65-74					3							
75-84	1				9				2			
85-94	2				21				2			
95-104	3				18				7			
105-114	5				17				12			
115-124	7				9	1			9	4		
125-134	11	1			2	1			4	3		
135-144	8	4	2		1	3	4		3	4	1	
145-154	1	2	3			6	5			5	2	
155-164		4	8			4	4	1		1	2	
165-174		1	9	1		1	1	2		6	4	2
175-184		2	6	1		1	2	3		1	2	6
185-194		1	3				1	6			1	6
195-204			1	3			1	4				4
205-214				2				3			1	2
215-224			1	1				1				1
225-234			1									
235-244				2								
245-254			1									
255-264			1									
295-304			1									
305-314				1								
Total	38	15	37	11	81	17	18	20	39	24	13	21

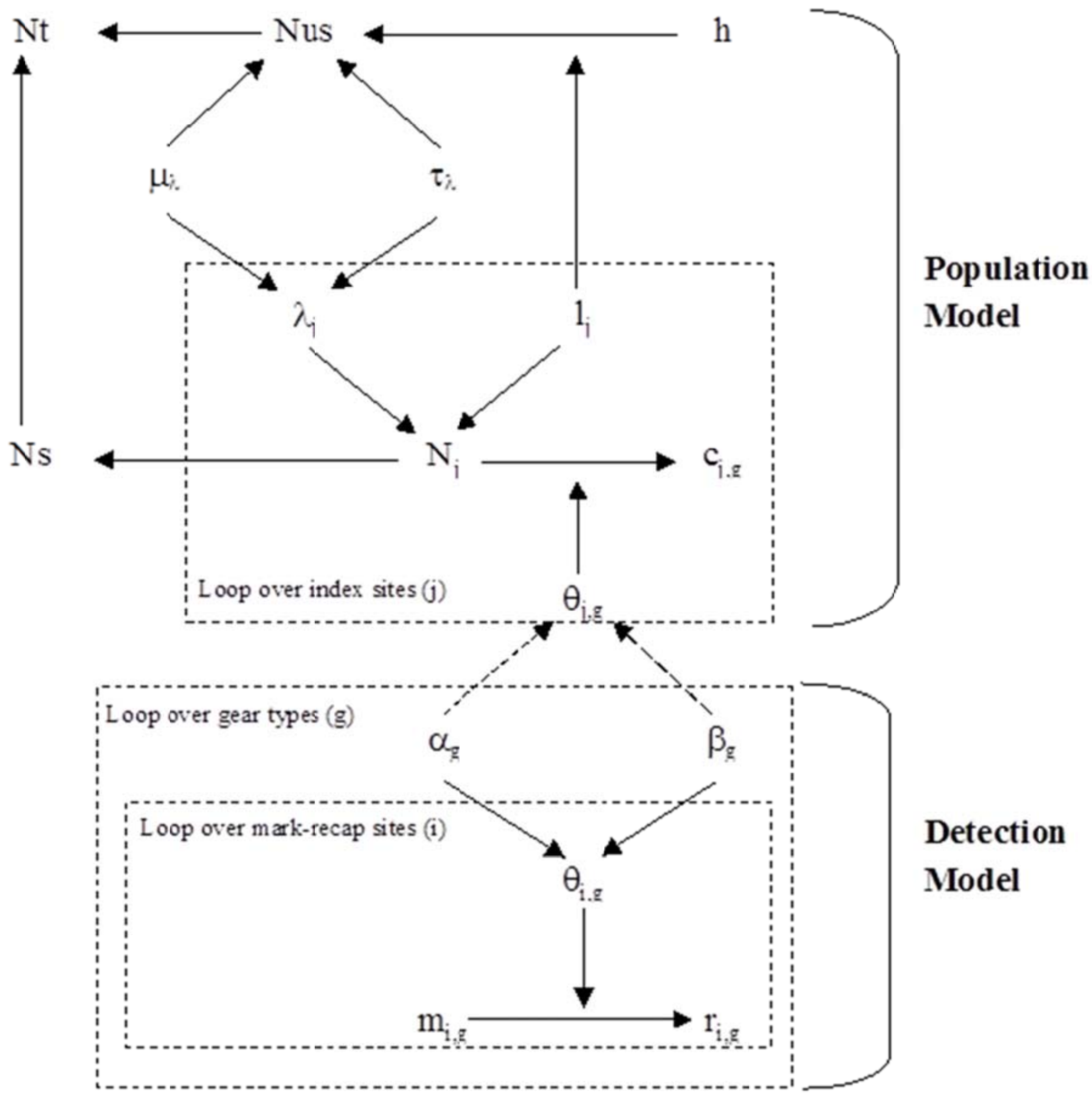

Figure 3.1. Graphical representation of the two-phase hierarchical Bayesian model to estimate juvenile steelhead abundance in the Cheakamus River. See Table 3.2 for definition of model variables. Arrows indicate conditional dependencies between the variables. The dashed arrows indicate that the hyper-parameters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

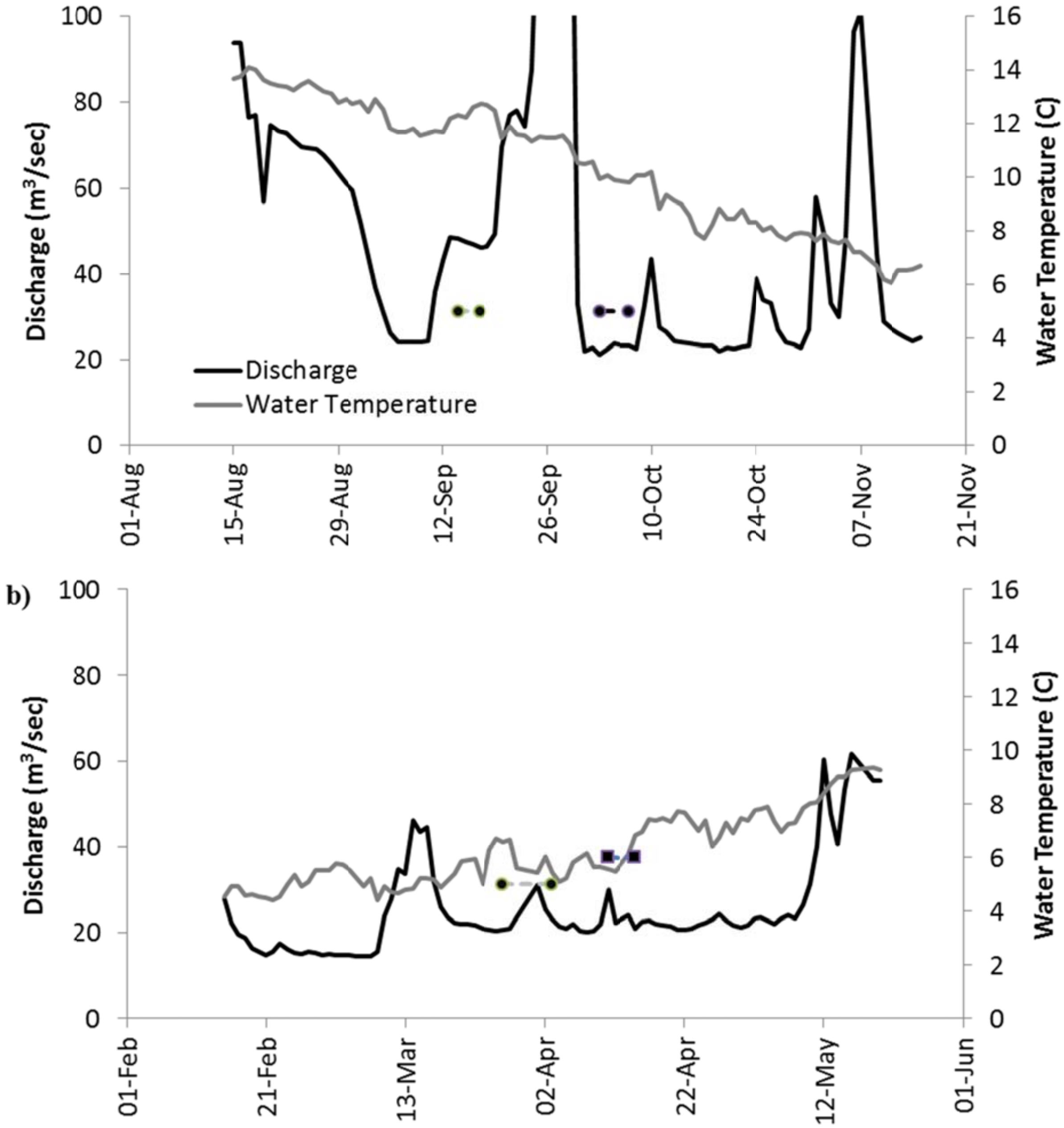

Figure 3.2. Discharge and water temperature at the Brackendale gauge (near Rotary Screw Trap) in the Cheakamus River during the fall 2010 (a) and spring 2011 (b). The horizontal lines show the fish sampling periods. In b), horizontal lines with circles and squares denote snorkeling and electrofishing sampling periods, respectively.

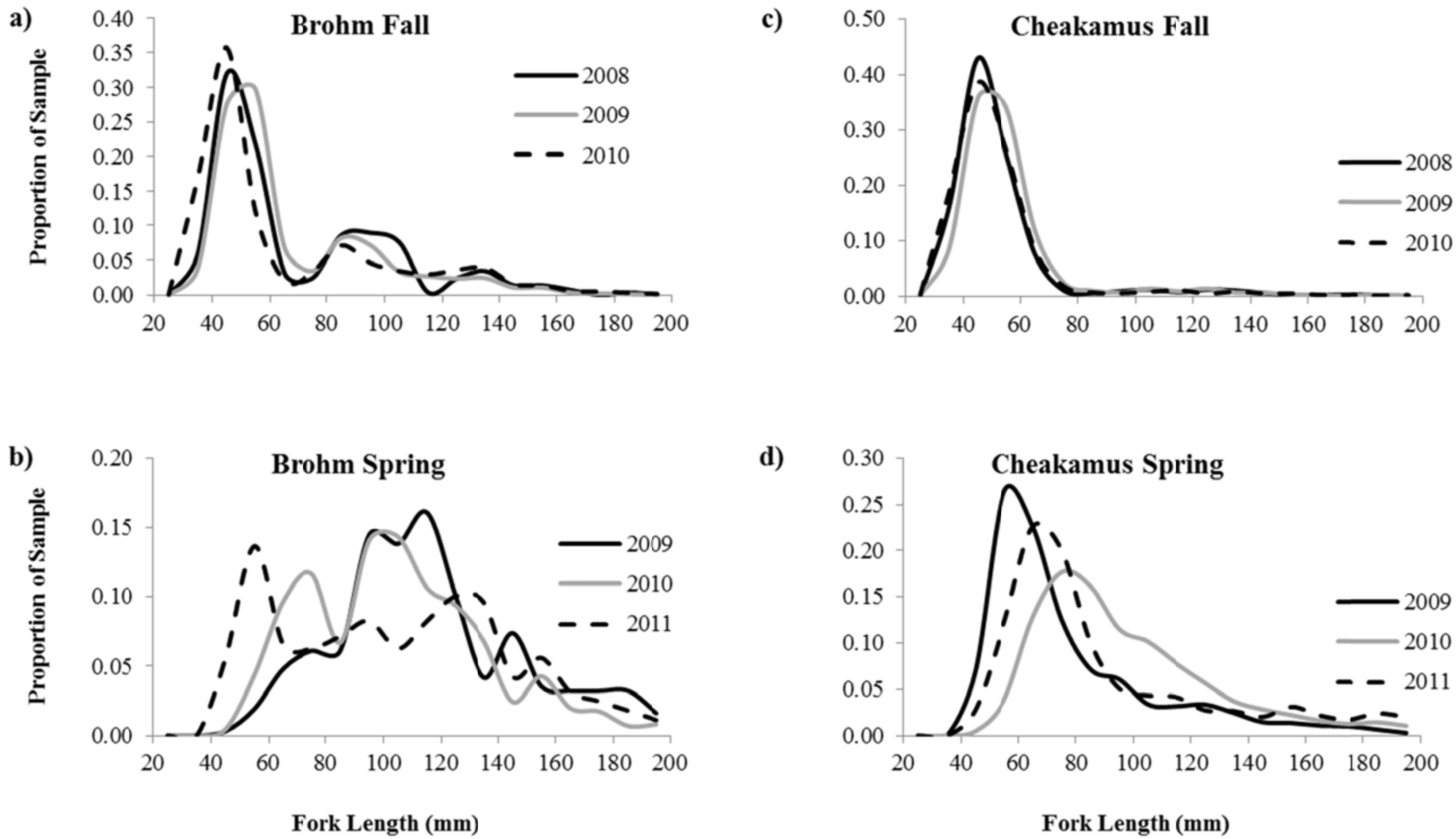

Figure 3.3. Interannual comparisons of length frequency distributions for juvenile steelhead between years within rivers and seasons. Distributions from fall samples are based on electrofishing only while distributions for spring samples are based on electrofishing and snorkelling for all Cheakamus River samples and Brohm 2010 and 2011 only (Brohm 2009 sample based on snorkeling only).

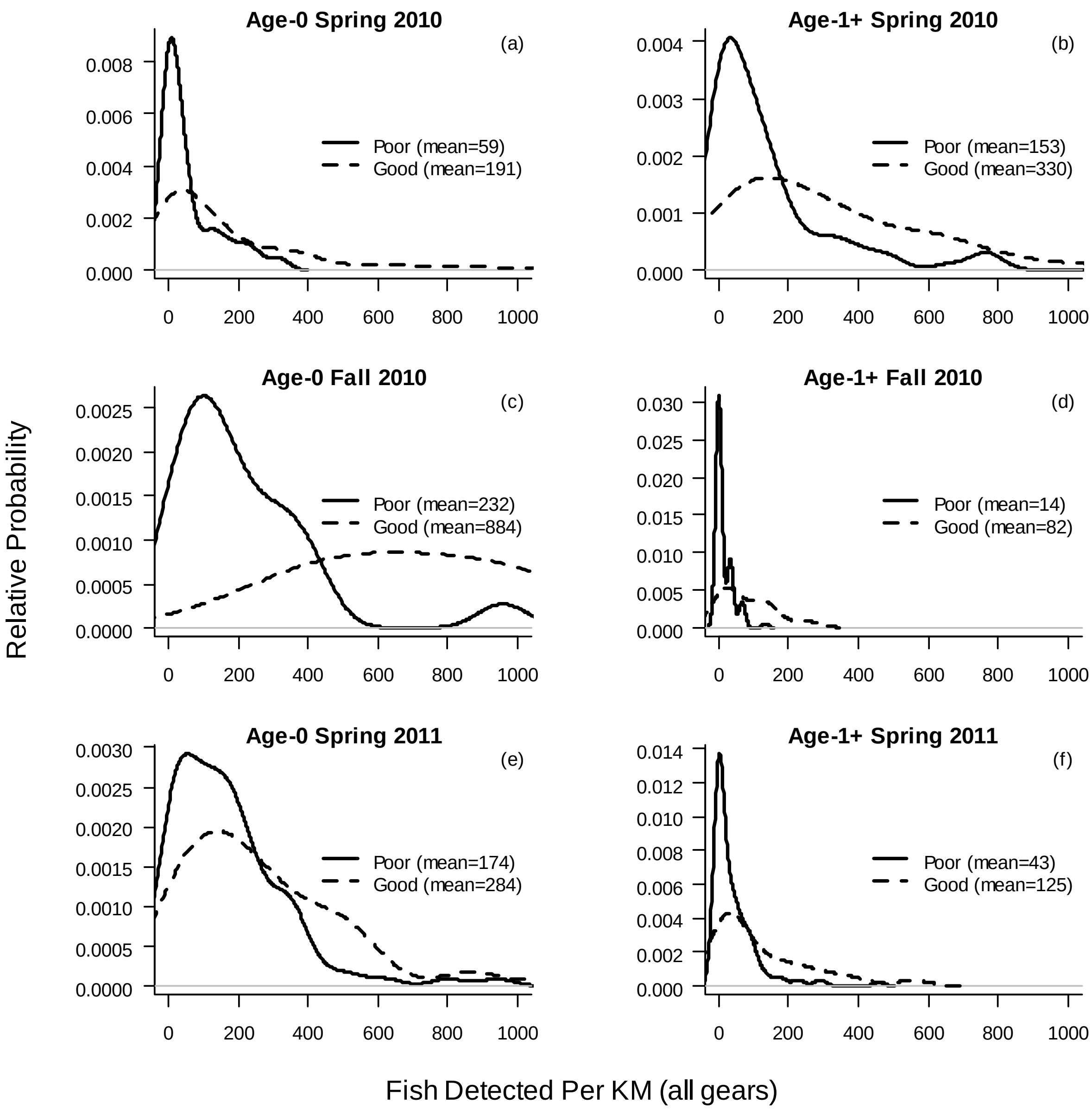

Figure 3.4. A comparison of probability distributions of catch per effort (CPE) of juvenile steelhead based on sites sampled in the Cheakamus River in spring 2010, fall 2010, and spring 2011 which were classified as having poor or good habitat. The values shown in the legend are the mean CPEs of the distribution for each habitat quality class.

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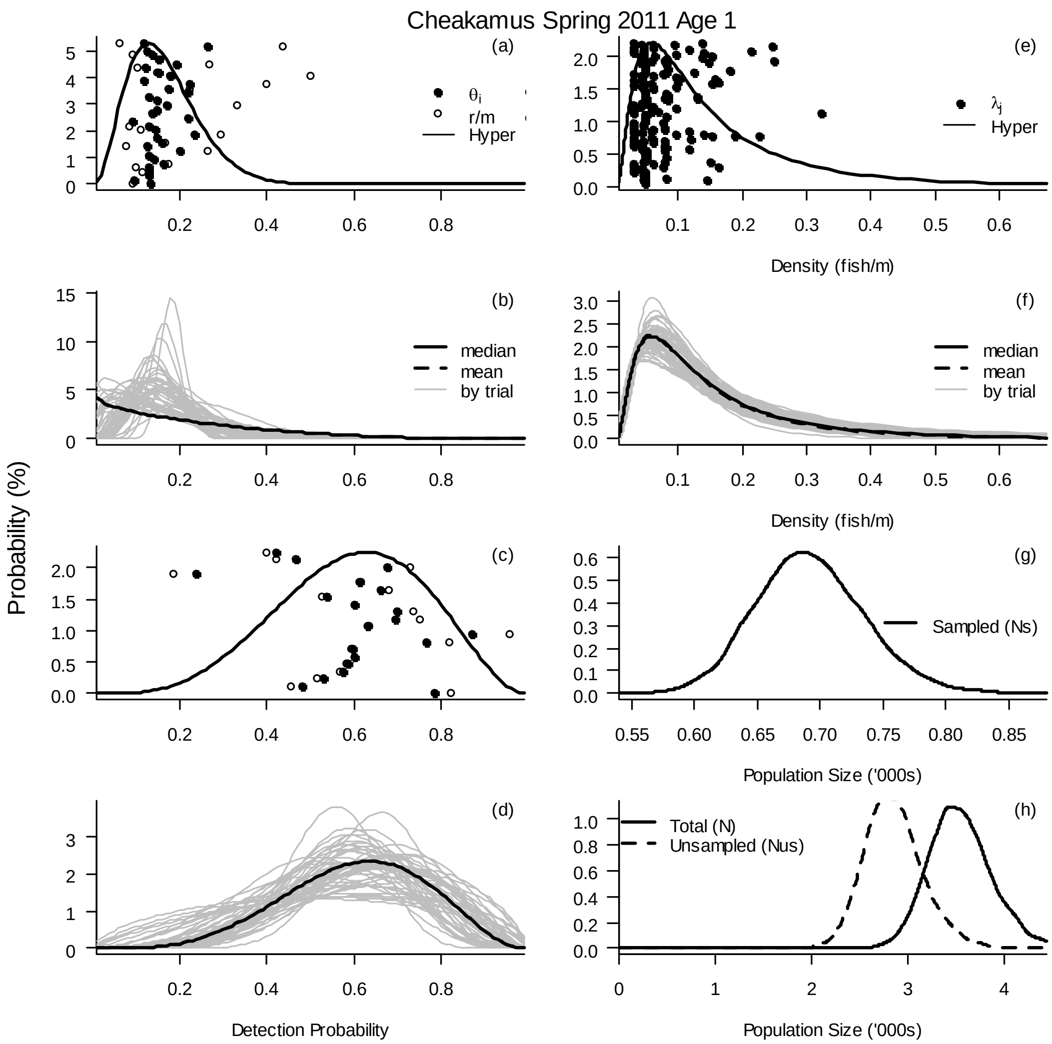

Figure 3.5. Graphical representation of output from the hierarchical Bayesian model that estimates juvenile steelhead abundance showing results for age 1+ fish in the Cheakamus River in spring 2011. a) and c) show the median hyper-distribution for detection probability, the median estimates of site-specific detection probability at mark-recapture sites (θ_i), and expected values (recaptures/marks or r/m) for electrofishing and snorkelling, respectively. The vertical order of site-specific estimates in b) is from earliest (lowest points on y-axis) to latest (see Table 3.6). b) and d) show the median and mean detection probability hyper-distribution and 50 randomly selected hyper-distributions from the posterior sample for these two gear types. e) shows the hyper-distribution for fish density and average site-specific estimates (λ_j), with the vertical order of site-specific estimates going from downstream (lowest y-axis value) to upstream. f) shows the median and mean hyper-distribution of fish density and 50 randomly selected hyper-distributions from the posterior sample. g) and h) show the posterior distribution of population size for the sampled shoreline, and the unsampled, and total shoreline, respectively.

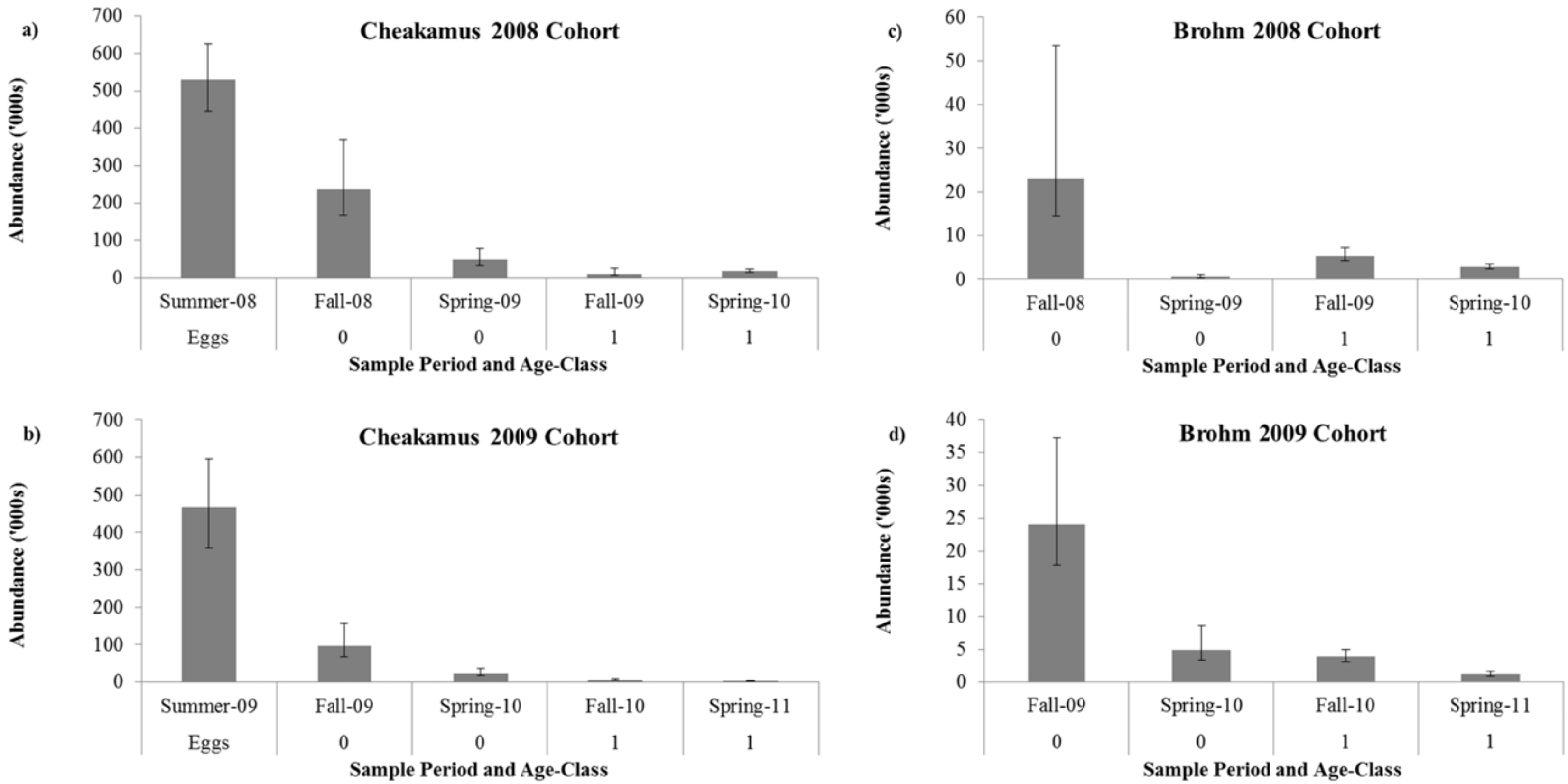

Figure 3.6. Change in abundance of 2008 and 2009 steelhead cohorts (year of spawning) in Cheakamus (a, b) and Brohm (c, d) Rivers. Bar heights represent the medians from the posterior distributions of the total abundance estimates from the HBM and error bars denote the 95% credible intervals. Egg deposition estimates for Cheakamus are based on annual escapement and mean fork length of spawners for each year.

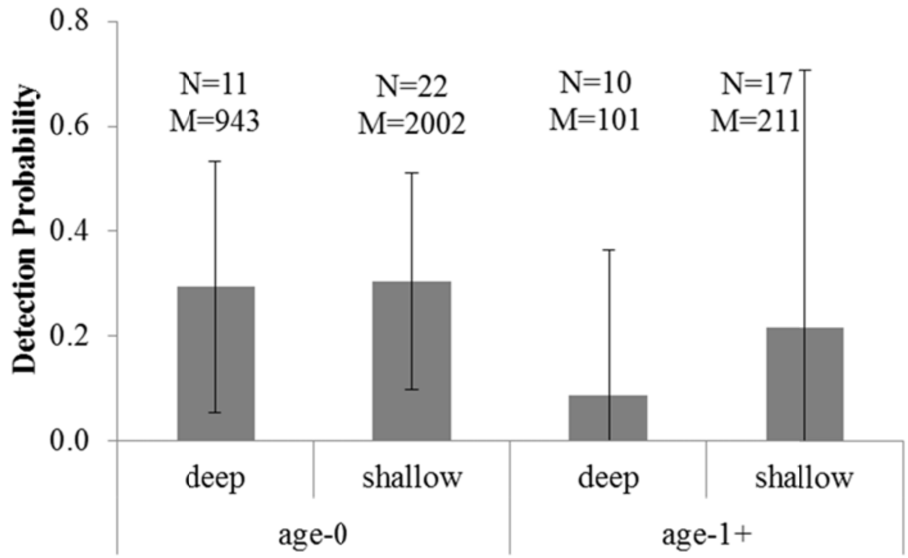

Figure 3.7. Average detection probability for electrofishing-based mark-recapture experiments for age-0 and -1+ steelhead by habitat type. Eror bars denote 95% confidence limits. Numbers at the top of the figure denote the number of experiments (N) and the total marks applied across all experiments (M).

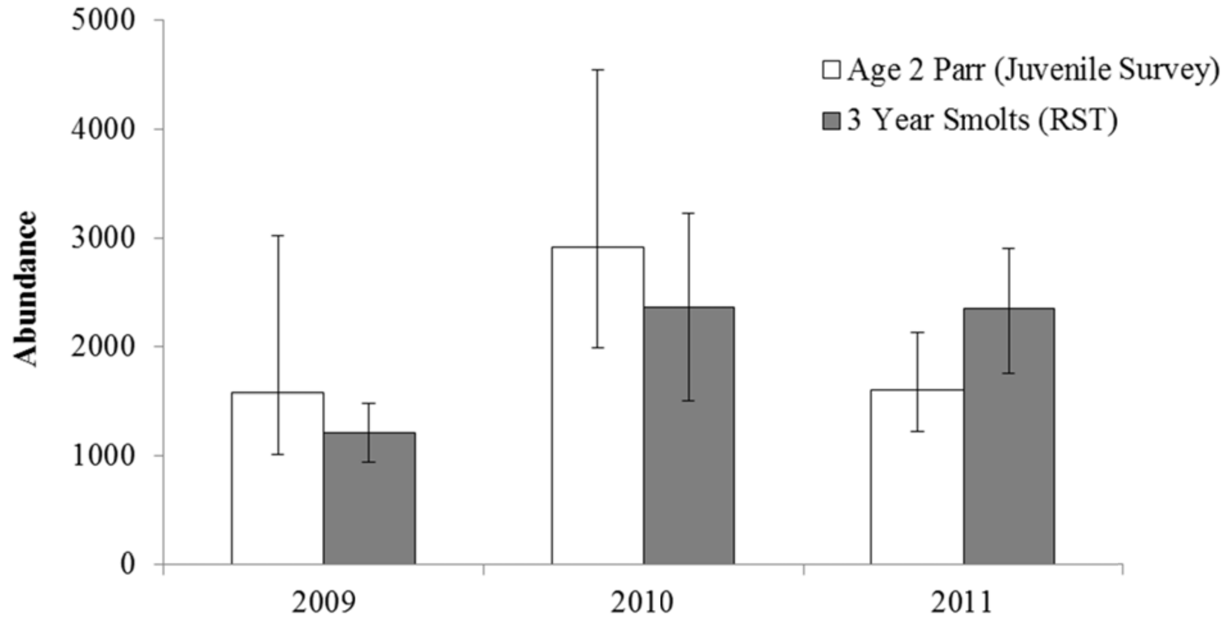

Figure 3.8. Comparison of abundance estimates of age 2 steelhead parr in the Cheakamus River above the Rotary Screw Trap (RST) in 2009-2011 based on juvenile surveys (based on HBM results developed in this report) with abundance of 3 year smolts at the RST in the same year (based on the pooled Peterson model). Error bars denote 95% confidence limits.