Cheakamus River Project Water Use Plan

Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey

Implementation Year 8

Reference: CMSMON-1B

Evaluations of the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Surveys from 2007-2015, and Chum Fry Production from 2001-2015

Study Period: 2014

C. Fell, D.J.F. McCubbing, L.J. Wilson and C.C. Melville

InStream Fisheries Research Inc

November 10, 2015

Evaluations of the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Surveys from 2007-2014, and Chum Fry Production from 2001-2015

Submitted by:

INSTREAM
Fisheries Research Inc.

C. Fell, D.J.F. McCubbing, L.J. Wilson, and C.C. Melville
InStream Fisheries Research Inc.

www.instream.net

EXECUTIVE SUMMARY

The Cheakamus River chum salmon adult escapement monitoring and mainstem spawning groundwater survey, implemented in 2007, and the chum fry outmigration estimates from the Cheakamus River juvenile salmonid outmigration enumeration monitor, implemented in 2001, are used in conjunction to evaluate the affects of discharge on groundwater upwelling, chum spawner site selection, incubation conditions and chum fry production. Egg-to-fry survival rates are used to evaluate the effects of discharge on spawning and incubation. The flow regime implemented in the water use plan in 2006 aimed to increase available spawning habitat for chum salmon and thus fry production in the Cheakamus River. This study has been evaluating whether the metrics used to calculate effective spawning area (based on depth, velocity and substrate) provide an accurate representation of chum salmon spawning site selection, and the availability of spawning habitat.

Discharge during chum spawning appears to affect site selection. At higher minimum discharges (near 25 m^3/s) a larger proportion of spawners utilize the side channels in the upper river. Egg-to-fry survival in these side channels is higher than in the mainstem; thus, when larger numbers of spawners utilize the side channel habitat, upper river productivity increases, as long as side channel carrying capacity is not surpassed. In years of moderate and high escapement when a reduction in the number of fry per spawner is observed and fry productivity decreases in the side channels, discharge rates during the spawning season may be more important for distributing spawners throughout the river to maximize productivity of chum salmon.

In 2013, discharge remained low throughout the spawning season and the high escapement of chum that returned did not distribute as far upstream as they did in 2012. Density dependent effects were observed in 2013 and egg-to-fry survival in the mainstem was low (0.3% including pre-spawn morality). Increased flow events occurred in 2012 prior to and during peak chum spawning, and chum spawners were surveyed up to river kilometer 16.5. This distribution of spawners increased egg to fry survival (3.6% including pre-spawn morality) and higher fry productivity was observed.

In 2014, multiple large discharge events occurred during and after the chum spawning season. The magnitude and frequency of these events impacted egg-to-fry survival in the mainstem. Scour in the area upstream of river kilometer 7 was substantial enough to dislodge 20 temperature loggers buried in redds and anchored into the substrate with rebar. Egg-to-fry survival including pre-spawn mortality was 0.3% in the mainstem in 2014 and only 8% of outmigrating fry were produced from the mainstem. The importance of side channel habitats for chum fry production as a buffer against these extreme events is emphasized.

In order to assess how discharge is affecting mainstem productivity, accurate annual egg deposition rates, including fecundity and pre-spawn mortality, need to be determined. After the third year of pre-spawn mortality surveys and fecundity evaluations, it is apparent that egg deposition varies both spatially and temporally. Tenderfoot Creek estimates (as well as the monitored side channels) need to be removed from the mainstem estimates annually in order to evaluate mainstem productivity and egg to fry survival. Productivity assessments from Tenderfoot Creek were implemented in 2012 and after another two years of evaluations, productivity from Tenderfoot Creek for Years 1-5 will be estimated and mainstem only productivity will be determined.

Groundwater appears to influence both site selection and productivity. Higher densities of chum salmon are surveyed in the groundwater-fed side channels than in the surface fed channels. One third of females radio tagged in the lower river spawned in know have groundwater upwelling in 2013. By comparing peak spawning times to peak fry outmigration times over seven years in the upper river, it appears that the

majority of outmigrating fry appear to be emerging from redds with groundwater influence. Groundwater could be included in models to predict effective spawning areas for chum salmon. To better understand the relationship between discharge and groundwater upwelling, radio telemetry will continue conducted for another two years.

The current flow regime was implemented aiming to increase available spawning habitat for chum salmon and thus fry production in the Cheakamus River. Since fry monitoring, annual fry production has varied greatly. Higher variation has been observed post-WUP (CV=0.63) than pre-WUP (CV=0.29). Reasons for this could include changes in spawner abundance, distribution patterns and changes in habitat conditions or river discharge. Despite the high variability, an increase of 22% in average annual fry production has been observed post-WUP. The key study goal is the ability to detect a linkage between discharge and a positive change in fry production of 75% or greater as predicted by the modeling work pre-WUP. At present the observed changes in fry abundance fall short of this level of increase.

ACKNOWLEDGEMENTS

We would like thank the following people for their cooperation and help over the years:

BC Hydro

Brent Mossop, Ian Dodd and Jeff Walker

❖

Cheakamus Centre (formerly, the North Vancouver Outdoor School)

Victor Elderton, Carl Halvorson and Jason Fullerton

❖

DFO Tenderfoot Hatchery

Peter Campbell, Brian Klassen and Jordan Uittenbogaard

❖

Squamish First Nations

Randal Lewis, Wylie George and Dustin Billy

❖

InStream Fisheries Research Inc.

Daniel Ramos-Espinoza, Jason Ladell, Heath Zander, Peter Mitchell,

Todd Moody, Stephanie Lingard and Neil Mackinnon

CITATION

C. Fell, D.J.F. McCubbing, L.J. Wilson, and C.C. Melville. 2015. Evaluations of the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Groundwater Survey from 2007-2014, and Chum Fry Production from 2001-2015. Cheakamus River Monitoring Program #1B. Technical report for BC Hydro – Coastal Generation. 80 p. + Appendices

Table of Contents

List of Tables

List of Figures

1.0 INTRODUCTION

1.1 Background History of Study

The Water Use Plan (WUP) for the Cheakamus River (BC Hydro 2005) includes a flow regime for the Cheakamus River designed to balance environmental, social and economic values. One of the fundamental objectives of the Cheakamus River WUP is to maximize wild fish populations, and the WUP recommended an operating alternative and associated river flow regime based in part on expected benefits to wild fish populations. However, the benefits to fish populations from the new flows were uncertain because benefits were modeled based on uncertain relationships between fish habitat and flow, and assumed relationships between fish habitat and fish production (Marmorek and Parnell 2002). To reduce this uncertainty, the Cheakamus WUP Consultative Committee recommended a number of environmental monitoring programs.

The Cheakamus River chum salmon population was identified during the consultative process as a keystone indicator species, and the effect of flow on chum salmon spawning and incubation was of particular concern. An important recommendation was to link adult chum salmon spawner escapement and juvenile outmigration data and use the resultant spawner-fry index (H') as an indicator of flow effects. The potential value of this index was highlighted during an exercise that modeled alternative monitoring designs (Parnell et al. 2003). BC Hydro has monitored Cheakamus River juvenile chum fry outmigration for the last 14 years (see Melville and McCubbing 2000-2013 and Lingard et al. 2014 and 2015) and monitoring of outmigration is ongoing (see CMSMON 01A, Melville and McCubbing 2012). An annual chum salmon spawner escapement study in the Cheakamus watershed commenced in 2007 (see Troffe and McCubbing 2008, Troffe et al. 2008-2010, McCubbing et al. 2011-2012, Fell et al. 2013). Chum salmon spawner escapement monitoring is also ongoing (see CMSMON 01B McCubbing et al. 2012). The linkages between adult escapement and juvenile outmigration will continue to be examined through these two research projects.

A further uncertainty identified during the consultative process was the relationship between river discharge and groundwater upwelling in mainstem spawning areas. The effective spawning area performance measure for chum salmon and other salmon species was influential in the selection of flow alternatives during the consultative process. The performance measure was calculated using a model based on River 2-D simulations, depth, velocity and substrate preference curves, and redd stranding calculations. This model identifies those areas where spawning is likely or unlikely to occur based on depth, velocity and substrate criteria, and thus the approach will likely overestimate the area of spawning habitat relative to empirical measures (Marmorek and Parnell 2002). The model does not predict the precise location of spawning. Thus, while the model is useful for comparing alternative flows, it does not provide precise measures of spawning habitat. Modeling suggested that lower and more stable flows during the fall relative to the existing Interim Flow Order (IFO) would provide a larger area suitable for spawning that would remain wetted during incubation. The result of this would be a relatively larger effective spawning area. This finding, and the modeling approach in general, was uncertain because chum spawning habitat selection may also be driven primarily by groundwater upwelling and not the surface flow characteristics of water depth/velocity and spawning gravel suitability. There was a suggestion within the committee that lower flows during the fall spawning period would result in reduced surface water-to-groundwater exchange, reduced upwelling, poorer spawning site selection and thus lower chum egg-to-fry survival. It was felt that the River 2-D modeling had greatly overestimated suitable spawning area under low flows. Data collected from 2008 through 2011 indicated that chum salmon do select areas of groundwater upwelling and that these are tempered by environmental conditions such as floods. Additionally, water temperature variances related to warmer upwelling groundwater were measured that may affect fry emergence timing. Additional data on site specific spawning at a greater range of escapements (in particular, high escapements) are required to assess whether groundwater upwelling areas are critical to fry production.

The chum adult monitoring program was developed to examine the effects of the WUP flow regime on chum salmon spawning and incubation in the mainstem of the Cheakamus River and major side channels (BC Hydro 2007). The monitor is composed of two components:

i) Estimating annual escapement of adult chum salmon in the Cheakamus River
ii) Examining the relation between discharge, groundwater upwelling and the selection of spawning habitat by chum salmon in the mainstem (BC Hydro 2007)

Data from the chum adult monitor is used in conjunction with data from the juvenile outmigration monitor (CMSMON 01A) to develop stock-recruitment relationships that are critical for separating effects of spawning escapement from flow-related changes in survival during incubation (Bradford et al. 2005).

‘The key management questions are:

1) What is the relation between discharge and chum salmon spawning site selection and incubation

conditions?

2) Do the models used during the WUP to calculate effective spawning area (based on depth, velocity and substrate) provide an accurate representation of chum salmon spawning site selection, and the availability of spawning habitat?
3) Are there other alternative metrics that better represent chum salmon spawning habitat? (BC Hydro 2007, pg 5)

The primary null hypotheses (and sub-hypotheses) associated with these management questions are:

H_1: Discharge during the chum salmon spawning and incubation period does not affect productivity, measured as the number of fry per spawner in the mainstem

This first hypothesis is general, and the specific hypotheses below will assist in diagnosing some likely reason(s) for any observed patterns.

H_2: Spawning chum salmon do not select areas of upwelling groundwater for spawning in the mainstem

Hypothesis 2 will be tested by overlaying mapping of chum salmon spawning distribution at a site with mapping of water upwelling to determine whether chum salmon spawn more frequently in upwelling areas. This commenced during the 2013 chum spawning season and will be repeated in the 2015 and 2016 spawning seasons.

H_3: Discharge during the chum salmon spawning and incubation period does not affect the upwelling of groundwater in mainstem spawning areas

This third hypothesis examines the link between discharge and surface-subsurface groundwater exchange.

Appropriate, ecologically based metrics of discharge during the incubation period that will be used to test these hypotheses might include peak discharge or minimum weekly discharge.
(BC Hydro 2007, p. 6)

1.2 Experimental Design

1.2.1 Adult Spawners

There are many challenges to estimating chum escapement and spawning distribution in the Cheakamus watershed due to its large size and environmental conditions which make traditional mark-recapture surveys difficult to carry out. These challenges include restricted water visibility, considerable downstream movement of spawned-out moribund fish among mainstem spawners and poor access to some river/channel reaches when river discharges are high (Melville and McCubbing 2000; Korman et al. 2002). Traditional visual tag mark recapture approaches that are commonly employed in smaller coastal systems would be difficult and expensive to effectively implement on the Cheakamus River.

Traditional live mark-carcass recapture surveys involve tagging salmon with external tags followed by carcass surveys of all possible spawning grounds. Instead, this monitor uses a passive mark-recapture technique in place of a traditional mark-recapture carcass recovery or visual estimation study methods. This passive tag recovery approach involves the use of fixed location resistivity fish counters to enumerate all fish entering selected side channels, coupled with Passive Integrated Transponder (PIT) scanning tag readers to scan for tags on all fish at these locations. The total number of fish entering each monitored channel and the total number of tagged fish entering each channel is recorded on the PIT logging equipment.

In this study one marking location was used in 2007 and two marking locations from 2008-2014 (Figure 1) combined with three side-channel detection locations in a design modeled after Schwarz and Taylor (1998). The marking site for the ‘whole river’ estimate, is located in the lower river at river kilometer (RK) 1.5, while the ‘upper river’ tagging site at RK 5.5 operated since 2008, provides a more robust estimate of the number of fish that spawn upstream of the mainstem juvenile (Rotary Screw Trap (RST)) monitoring site (Figure 1). At both sites internal PIT and external Peterson disk tags were applied to adult chum salmon with subsequent detections of tagged and untagged fish at three upper river side channel complexes with sizable chum spawning habitat (NVOS, BC Rail and Tenderfoot Creek, Figure 1). In addition, radio tags were gastrically implanted in a subsample of fish from 2007-2010 to: determine overall spawner distribution upstream and downstream of the current juvenile out-migration monitoring site, assess post tagging behaviour that may affect estimates, provide information on spawner distribution to assist with mainstem groundwater/spawner evaluations, as well as assisting in evaluating spawner residence time during the initial four years of the monitor. In 2013, radio tagging was reinstated in the lower river and a subsample of female chum salmon was tagged to: evaluate spawner distribution and determine areas of egg deposition in relation to know groundwater upwelling areas.

1.2.2 Juvenile Outmigration

Prior to the implementation of the new flow order (WUP) in 2006 the Juvenile Outmigration CMSMON 01A was limited to assessing the total production of juvenile salmon upstream of the RST site (Figure 1). Partitioning of side-channel and mainstem production was not included in the initial study design implemented in 2000. In 2007, the study was expanded to include population assessments of salmonids from key restoration side-channels and further expanded in 2013 to include Tenderfoot Creek. The study redesign was intended to better answer two key management questions:

1. What is the relation between discharge and juvenile salmonid production, productivity, and habitat capacity of the mainstem and major side-channels of the Cheakamus River?
2. Does juvenile chum fry yield or habitat capacity change following implementation of the WUP flow regime?

The expanded project includes detailed assessment of juvenile salmonid outmigration using estimated counts from mark-recapture studies (BC Hydro 2007).

2.0 METHODS

The methodology for estimating abundance of adult chum spawners and outmigrating chum fry has remained relatively consistent throughout the study period (2001-2013). For a more detailed explanation of the methodology in sections 2.1.1 to 2.1.3 and 2.2 to 2.3 refer to Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey 5 Year Program Review 2007-2011 (McCubbing et al. 2012). Detailed methodology is provided in Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Groundwater Survey 2001-2013 (Fell et al. 2013) for sections 2.1.4 to 2.1.7 which were added into this study in 2012 after the 5 year review process.

2.1 Adult Spawners

2.1.1 Mark-Recapture

From mid-October through late November chum salmon were tagged with internal PIT tags and Peterson disk tags at the lower river site (RK 1.5) and upper river site (RK 5.5) on the Cheakamus River. Sex, fork length and visual condition were recorded for each fish captured.

Visual condition was classified as follows:

- Condition 1: fish appeared to have entered the river recently, 'silver' and free of body decay.
- Condition 2: fish exhibited spawning colouration but free of extensive body decay.
- Condition 3: signs of spawning, fin wear, sunken abdomen and extensive body decay.

Only fresh condition fish were tagged (Condition 1 and 2) while fish exhibiting signs of spawning or excessive body decay (Condition 3) were not tagged. Fish were redetected upstream at three locations in the upper river (two side channels, NVOS and BC Rail, and Tenderfoot Creek, Figures 1 and 2). For spawner enumeration and PIT tag detection, the two side channels were set up with full span fish fences, fitted with Logie 2100C resistivity fish counters and full-duplex PIT tag detection and logging equipment. Counter efficiencies were evaluated using video validation, and recycling/pre-spawn migration behaviour and kelted spawner behaviour evaluated from the time-stamped PIT antenna data. Spawners that moved upstream and then downstream over the counter array in a period of less than 48 hours were assumed to be recycling or re-circulating and were not assumed to have spawned upstream of the counter. Fish that spent > 48 hrs above the counter and then dropped back were classified as kelts and assumed to have spawned upstream of the counter. The percentage of down counts that were classified as kelts are included in the total channel escapement calculation to ensure all fish that spawned upstream of the counter are enumerated (see methods in McCubbing et al. 2012). At Tenderfoot Creek chum salmon were enumerated manually by Department and Fisheries and Oceans (DFO) at their fish fence (methodology conceptualized in Figure 3). Spawner detection through resistivity counter monitoring/ trap operations was conducted from October 15 through to December 15.

2.1.2 Escapement Analysis

An abundance estimate for the entire river was derived from the fish marked at the 'lower river' tagging site and a population estimate for the upper river (above the RST site) was derived from the fish tagged at the 'upper river' tagging site (Figure 1). Tagged fish were recaptured/re-detected at three upstream side channels; the NVOS side channel, the BC Rail side channel and Tenderfoot Creek (Figure2). From 2007-2013, the total number of fish entering the individual channels was determined using resistivity counts at the NVOS and BC Rail side channels, and at the Tenderfoot Creek trap fish were counted manually. Pooled Peterson population estimates were calculated using the basic mark-recapture equation (Ricker 1975).

In 2014, stream walks were reinstated in the NVOS and BC Rail side channels due to the high water (three flow events greater than 200 m^3/s between October 21st and November 8th at the Water Survey of Canada (WSC) Brackendale Gauge (08GA043)) affecting counter efficiencies (Figure 4). Stream walks were conducted bi-weekly in conjunction with pre-spawn mortality surveys from mid-October to mid-December. All live fish were counted and all dead fish were counted and then cut in half to ensure they were only enumerated once. Stream walk efficiencies were calculated using previous years of stream walk and counter data (2007-2011).

At the end of the season in 2014, two additional directional antennas and a counter pad were installed and tested at the NVOS side channel. In previous years, accumulations of leaf litter on the fences have resulted in backwatering on the upstream side of the fence. This backwatering has created uneven flow across the counters, reduced counter efficiencies. This additional channel provides a greater area for water and debris to pass downstream and should allow for more laminar flows across all of the counters under fluctuating water conditions. This additional channel also opens up another passage for fish to move upstream. (Figure 5)

Resistivity counter efficiencies at NVOS and BC Rail side channels have normally been validated using video imagery. Additionally, kelting behaviour has been assessed annually at the NVOS and BC Rail side channels to account for fish that spawn upstream of the counters and then drop back down across them again. Using annual PIT tag detections, fish were classified as kelts that spent greater than 48 hours resident in the channel above the fish counter prior to a directional downstream outmigration. To determine the number of fish that spawn upstream of the counters (2007-2013), the total number of down counts were removed from the total number of up counts at each counters site. The down counts were scaled so that kelts were not removed from the net upstream spawner calculations.

2.1.3 Radio Telemetry

Radio telemetry was conducted from 2007-2011 and tags were applied to both male and female chum to evaluate spawner distribution and residence time (see McCubbing et al. 2012). Radio telemetry was reinstated in 2013 to assess spawner distribution and identify where eggs were deposited in relation to known groundwater upwelling areas. Three directional fixed station Lotek W31 radio receivers were installed to detect spawner movement, located at the confluence of the Cheakamus and Cheekye rivers (RK 3.2), at the juvenile monitoring RST site (RK 5.5), and 50 m downstream of the Bailey Bridge (RK 7) (Figure 1). Mobile tracking in the main river was performed by foot and raft every two to three days from road's end (RK 16.5) to the confluence of the Squamish and Cheakamus Rivers (RK 0). Since 2013 mobile tracking between fixed stations and upstream of the Bailey Bridge has been conducted every 2-3days to try and identify more precisely where spawners are building their redds.

2.1.4 Fecundity

Since 2012, InStream has been working with Tenderfoot Creek Hatchery DFO staff to sample the fecundity of female chum salmon caught at the Tenderfoot Creek fence. Females were sampled throughout the run. When the females are ready to spawn, they were killed and their eggs and ovarian fluid were collected. The ovarian fluid was temporarily drained off the eggs and total egg weight was determined. Then, a subsample was weighed (approximately 20g) and the eggs in the subsample were manually counted to obtain the individual egg weight. The total number of eggs in each female sampled was estimated by dividing the total egg weight by the weight of an individual egg for that female (Schroder and Ames 2004). To get representation of all females throughout the run, 30 females were sampled for fecundity at each egg take. Average fecundity for the run was determined by weighting the fecundity at each sampling session proportional to the abundance of females spawned at each session. In 2014, 206 females were sampled.

Additional information collected for each female included fork length to determine if a length fecundity relationship exists and scale samples to determine if an age fecundity relationship exists. Recent publications have indicated that egg per female fecundity may be a derivative of both fish age (3 or 4 years) and fish length (Kaev 2000). In addition, summer and fall migrants may have differing egg numbers (Salo 1991) and egg size may vary with body size (Kaev 2000, Salo 1991). Evaluations of these relationships will provide information that will allow for a more accurate estimate of the annual egg deposition used to calculate egg-to-fry survival rate.

2.1.5 Aging

During fecundity sampling conducted at Tenderfoot Hatchery, scale samples were collected from all females sampled to determine if age accounts for some of the variability in fecundity. Data from scales collected in tagging efforts from previous years of this study (2008-2012) are archived and could be analyzed to assess the age composition of returning adults. The methodology for aging chum salmon was the same as conducted by Seo et al. (2006) on chum salmon, which used the "year-olds" method developed by Salo (1991); this method determines the age by the number of winters from egg to adult. For example, if eggs were deposited in the gravel in the fall of 2007, the fry would emerge in the spring of 2008 and if they returned in the fall of 2012, they would be considered age-5 chum. The scale would show five periods of slowed growth. The first period of slowed growth is the transition from coastal water to ocean. The next periods of slowed growth are winters and another year is counted at the outer edge of the scale, when the salmon returns and completes its lifecycle (Figure 6).

2.1.6 Pre-spawn mortality

Pre-spawn mortality surveys assess the percentage of fish that die without any spawning, only partially spawned or completely spawned out. Since 2012, pre-spawn mortality surveys have been conducted on the mainstem and side channel habitats of the Cheakamus River from mid-October to the end of November in order to evaluate egg retention and egg deposition rates in deceased females. Mainstem bars were surveyed from road ends (RK 16.5) to the Cheakamus/Cheekye confluence (RK 3.2) (Figure 1). Side channel habitats above the RST site that were surveyed include the NVOS and BC Rail side channels, Tenderfoot Creek and Tenderfoot Pond, and BC Rail mile 49 (BC49) channel (located immediately upstream of the upper river tagging site on river left) (Figure 2).

Spawners were classified as follows:

- **spawned-out** = zero to 500 eggs
- **partially spawned** = over 500 loose eggs
- **unspawned** = intact skeins

Staff were familiarized to visually recognize 500 loose eggs (Figure 7). Fish with body cavities that appeared to be compromised, with slices or holes in the body cavity, were not used as part of the sample.

2.1.7 Egg Deposition Rates

Using the number of spawners classified into each spawner category during pre-spawn mortality surveys, egg deposition rates were calculated. Each pre-spawn mortality category was assigned an egg deposition percentage based on average fecundity; spawned-out females deposited 93% of their eggs, partial spawners deposited 43% of their eggs and unspawned females deposited 0% of their eggs.

Equations used to calculate egg deposition and egg retention are as follows:

% Eggs Deposited =

$$\left(\frac{(0.93C) + (0.43P) + (0.00U)}{S}\right) \times 100$$

Where:

C = # of complete spawners
P = # of partial spawners
U = # of unspawned females
S = total # of spawners sampled including complete spawners, partial spawners and unspawned females

2.2 Juvenile Outmigrants

2.2.1 Mark-Recapture

From 2000-2015 outmigrating juvenile chum were marked and recaptured in the mainstem, in the two main side channels upstream of the RST site (NVOS and BC Rail). Tenderfoot Creek enumeration was added in 2013 and monitoring continued in 2014 and 2015. Initially, two downstream traps (F9, and F10) were set up to enumerate outmigrating fry from Tenderfoot Creek, but in 2014 only F10 was operated as few salmon appear to spawn in the lower reaches of Tenderfoot Creek (Figures 1 and 2). In the mainstem, outmigrating juveniles were captured using RSTs. A maximum of 2,500 chum fry at each site were marked and then released upstream of the traps to be recaptured. In the side channels, the upstream fyke nets were used to capture chum fry to apply marks and the downstream fyke nets are used to recapture marked fish, as well as, count the number of unmarked chum migrating downstream.

2.2.2 Outmigration Estimate

Outmigration estimates were calculated using a Bayesian spline model described in Bonner (2008), Schwarz et al. (2009) and Bonner and Schwarz (2011). The key features of this model are the use of splines to model the general shape of the run and Bayesian hierarchical methods to share information on catchability and the shape of the spline among time strata. Population estimates were calculated for each of the side channels and for Tenderfoot Creek. An upper river estimate was calculated from the fish marked and recaptured at the RSTs. A mainstem and unmonitored side channel estimate was determined by removing the side channel and Tenderfoot Creek fish from the upper river estimate.

2.3 Evaluation of H' (Egg-to-fry Survival)

One of the primary goals of this project is to assess the potential relationship between egg-to-fry survival and river discharge. Egg-to-fry survival can be determined for all spawners above the RST or for each individual area (side channel or creek) where the numbers of adults and fry have been independently estimated.

In this case, H’ (egg-to-fry survival) was calculated through a number of steps:

1) Estimate spawner abundance (N_t)
2) Estimate female spawner ratio as a% (N_{tf})
3) Calculate egg deposition based on the numbers of eggs per female (N_{epf})
4) Calculate egg deposition rates as a% (N_{ed})
5) Estimate fry production (N_{tfry})
6) Evaluate H’ by dividing the fry outmigration estimates by the egg deposition rates

Thus,

$$H' = (N_t * N_{tf} * N_{epf} * N_{ed}) / N_{tfry}$$

Egg-to-fry survival was determined using the sex ratio of males to females caught at the Tenderfoot trap (Results Section 3.1.3). The fecundity of females has been determined by sampling at Tenderfoot Creek Hatchery since 2012. Egg deposition rates (2012-2014) were determined from pre-spawn mortality surveys (Results Section 3.1.9 and 3.1.8). For the purpose of comparisons with other literature values of egg-to-fry survival it is important to note that pre-spawn mortality is often not included in egg-to-fry survival estimates; but to evaluate the impact of flows on egg-to-fry survival it is important to determine the most precise egg deposition rates.

2.4 Temperatures in Redds

In 2014 on December 4th and 5th, 20 temperature loggers were buried at two sites above the Bailey Bridge (RK 7.0) to test the general hypothesis that river water temperatures do not differ from water temperatures observed in chum redds in the hyporheic zone. One site was located on bars immediately upstream of the Bailey Bridge (RK 7.0) and the other site was located on bars immediately downstream of road's end (RK 16.5). At each site 10 simulated egg capsules containing temperature loggers (Onset Tidbit UTBI-001) were buried over 2-3 bars. Temperature loggers were buried at 20 cm deep in suitable bed material and anchored in with rebar. Additional information collected at each site included water depth, dominant and subdominant bed material, average diameter of substrate in the 90th percentile (D_{90}) and water velocity. An additional temperature logger was installed upstream of the NVOS counter site to record surface water temperature in the NVOS side channel complex. For comparison to mainstem river temperatures, information from temperature loggers installed at the RST site (RK 5.5) and suspension bridge site (RK 15.0) were used.

3.0 RESULTS

3.1 Adult Spawners

3.1.1 Mark-Recapture

In 2014, 1,005 chum salmon were tagged with PIT and Petersen disk tags (Table 1). Over the past seven years of this study (2007-2014) a total of 9,816 chum salmon have been tagged (range 762-1907 per year). At the lower river tagging site 4,879 chum salmon have been tagged (range 5-970 per year) and at the upper river tagging site 4,862 chum salmon have been tagged (range 75-1017 per year) (Table 1). In 2014, only 5 chum were tagged at the lower river tagging site. Fish tagged in the lower river are used to generate the whole river escapement estimate and fish tagged in the upper river are used to generate the upper river escapement estimate.

3.1.2 Fork Length

Significant differences in fork length of female chum salmon at the upper river tagging site have been observed between years (ANOVA, $p<0.01$). Females tagged in the upper river in 2011 were significantly smaller (704mm) than all other years (post-hoc t-test, $p<0.01$) (Table 2). The size of females in the upper river has ranged from 704mm in 2011 to 745mm in 2014. Fork length of male chum salmon at the upper river tagging site were also significantly different between years (ANOVA, $p<0.01$). Similar to females, males tagged in 2011 were significantly smaller than all other years (post-hoc t-test, $p<0.001$). The size of males in the upper river has ranged from 732mm in 2011 to 792mm in 2014 (Table 2).

Significant difference in fork length of female chum salmon captured at the upper river tagging site and in the Tenderfoot Creek trap have been observed annually (all t-tests, $p<0.001$). The average fork length of females captured at the Tenderfoot Creek trap in 2014 was 31mm larger than the average fork length of females captured at the upper river tagging site. In 2013 and 2012, Tenderfoot Creek females were 29mm and 24mm larger than the females captured at the upper river tagging site, respectively.

3.1.3 Sex Ratio

The sex ratio of chum salmon captured at the Tenderfoot Creek trap is used to represent the sex ratio of the chum salmon spawners in the upper river of the Cheakamus for the egg-to-fry survival calculation (Table 3). A lower percentage of female chum spawners are captured by tangle net than by the Tenderfoot

Creek trap. In 2014, the M:F sex ratio at the Tenderfoot Creek trap was 1.6:1 (38% females). Male chum salmon have always been more abundant than females. The percentage of females captured at the Tenderfoot Creep trap over the course of this study has ranged from 21% to 41%, equivalent to a M:F sex ratio of 3.8:1 to 1.4:1, respectively (Table 3).

3.1.4 Radio Telemetry and Spawner Distribution

In 2014, high flows affected access to fish at the lower river tagging site where female chum were planned to be radio tagged. As a result, radio tagging was not conducted in 2014 and efforts were focussed on PIT tagging in the upper river. In 2013, one third (33%, 26 out of 79) of the females radio tagged spawned in the known groundwater upwelling areas (Moody's bar area, Tenderfoot channel, BC Rail side channel) (Figure 8). Twenty-two percentage (17 out of 79) of radio tagged female chum salmon spawned above the RSTs (Figure 8).

3.1.5 Fecundity

Thirty females are sampled at every egg take at the Tenderfoot Hatchery. In 2014, fecundity sampling was conducted seven times throughout the run. The mean weighted fecundity for the run was 3,325 eggs/female. Fecundity ranged from 1,596 to 5,051 eggs/female. The relationship between fork length and fecundity was statistically significant (F=37.7, p<0.001) although fork length only accounts for 15.7% of the variability in fecundity (Figure 9). The relationship between fork length and fecundity of age 4 female chum was stronger (R^2=0.35) than the relationship between fork length and fecundity of age 5 female chum (R^2=0.04).

Since fecundity sampling started in 2012, the weakest relationship between fork length and fecundity was observed in 2014. Stronger relationships between fork length and fecundity were observed in both 2013 and 2012 with fork length accounting for 38.6% and 22.5% of the variability in fecundity, respectively (Figure 10 and 11). Fecundity in both 2014 and 2013 were significantly lower than fecundity in 2012 (t-test, p=0.015 and p=0.013, respectively). There was no significant difference in fecundity between 2014 and 2013.

3.1.6 Age

One hundred female chum salmon caught at the Tenderfoot Creek trap were aged in 2014. Four year olds made up 42% (N=42) of the population and five year olds made up 56% (N=55) of the population (Figure 12). Only 2% (N=2) of female chum spawners were age 3. In 2013, the majority, 85% (N=85) of the female chum were four years old chum and only 15% (N=15) were five year old chum. In 2012, 65% (N =60) of females were five years olds, 24% (N=22) were four years olds and 12% (N=11) were three years old (Figure 11). The mean age of female chum salmon in 2014 (4.4) was significantly higher than the mean age in 2013 (4.15) (t-test, $p<0.001$) but not significantly different than the mean age in 2012 (4.53).

3.1.7 Pre-Spawn Mortality

Pre-spawn mortality surveys assess the percentage of fish that die without spawning or only partially spawn and the percentage that completely spawn out. Surveys have been conducted on chum salmon on the mainstem and side channel habitats of the Cheakamus River in since 2012. In the mainstem habitats in 2014, 98.2% of females spawned out (Table 4). In 2013 and 2012, the percentages of females that were completely spawned out were 87.1% and 89.0%, respectively (Table 4). Pre-spawn mortality in the mainstem habitats was significantly different between 2014 and both 2013 and 2012 (Chi-Squared Tests: 2014 and 2013: $\chi^2=26.4$, $p<0.001$; 2014 and 2012: $\chi^2=20.2$, $p<0.001$). No significant difference was observed between pre-spawn mortality in the mainstem habitats in 2013 and 2012.

Significant differences between pre-spawn mortality in the side channel habitats and the mainstem habitats were observed in all years (Chi-Squared Tests: 2012: $\chi^2=27.9$, $p<0.001$; 2013: $\chi^2=151.4$, $p <0.001$; 2014: $\chi^2=27.9$, $p<0.001$). Lower percentages of females appear to completely spawn out in the side channel habitats. In 2012, 82.9% of females spawned out in the side channel habitats. In 2013, 64.1% of females spawned out in the side channel habitats and in 2014, 91.7% of females spawned out in the side channel habitats (Table 4).

Annual differences in pre-spawn mortality have been observed within individual side channels. Significant differences in pre-spawn mortality in both the BC Rail side channel and Tenderfoot Creek have been observed between 2013 and 2014 (Chi-Squared Tests: BC Rail: $\chi^2=198.0$, $p<0.001$; Tenderfoot Creek: $\chi^2=40.2$, $p<0.001$). In 2014, a larger percentage of female spawners completely spawned out in BC Rail side channel (88.3%) and Tenderfoot Creek (98.1%) (Table 5). Sample sizes in BC Rail in 2012 were too low to statistically compare and surveys were not completed in Tenderfoot Creek in 2012.

Significant differences in pre-spawn mortality have been observed among all year in both the BC 49 side channel (Chi-Squared Tests: 2014 and 2013: χ^2=67.1, p<0.001; 2014 and 2012: χ^2=24.9, p<0.001; 2013 and 2012: χ^2=11.0, p<0.001) and the NVOS side channel complex (Chi-Squared Tests: 2014 and 2013: χ^2=68.7, p<0.001; 2014 and 2012: χ^2=5.5, p =0.019; 2013 and 2012: χ^2=29.7, p<0.001) (Table 5). The percentage of females in BC 49 side channel and the NVOS side channel complex that completely spawned out was highest in 2014 (BC 49: 95.0% and NVOS: 91.0%) and lowest in 2012 (BC 49: 68.1% and NVOS: 73.6%) (Table 5).

Within the NVOS side channel complex, the largest numbers of female chum spawners assessed during annual pre-spawn mortality surveys have been surveyed in the Upper Paradise channel, Upper Upper Paradise channel and Kisutch channel (Table 6). Annual differences in pre-spawn mortality have been observed within these channels. In the Upper Paradise and Upper Upper Paradise channels, significantly higher pre-spawn mortality rates were observed in 2013 compared to both 2012 and 2014 (Chi-Squared Tests: χ^2=14.4, p<0.001; χ^2=20.3, p<0.001, respectively). However, no significant differences were observed in either of these channels between 2012 and 2014. In the Kisutch channel, significant differences in pre-spawn mortality have been observed among all years (Chi-Squared Tests: 2014 and 2013: χ^2=37.5, p<0.001; 2014 and 2012: χ^2=9.8, p=0.002; 2013 and 2012: χ^2=11.8, p<0.001).

Differences in pre-spawn mortality between channels in the NVOS side channel complex have also been observed annually. In both 2012 and 2013, Kisutch channel had significantly higher pre-spawn mortality than Upper Paradise and Upper Upper Paradise channel (Chi-Squared Tests: χ^2=11.4, p<0.001; χ^2=28.8, p<0.001, respectively). In 2014, however, no significant difference was observed between Kisutch channel (90.4% spawned out) and Upper Paradise channel (90.5% spawned out) or Upper Upper Paradise channel (95.5% spawned out) (Table 6).

3.1.8 Egg Deposition Rates

Area specific egg deposition rates were calculated for mainstem habitat and monitored side channel habitats to be used in the egg-to-fry survival calculations. In 2014, egg deposition rates in the mainstem were high at 92.1% (Table 7). Egg deposition rates were 5.4% and 6.5% lower in 2012 (86.7%) and 2013 (85.6%), respectively. The highest egg deposition rate among the side channel was observed in Tenderfoot Creek in 2014 (92.0% egg deposition). The percentage of egg deposited by female chum spawners was 16.1% higher in Tenderfoot Creek in 2014 than in 2013 (75.9% egg deposition). In the BC

Rail side channel, egg deposition was 26.0% higher in 2014 (87.1%) than 2013 (61.2%). Because BC Rail side channel was only surveyed once in 2012 and Tenderfoot Creek was not surveyed in 2012, egg deposition rates could not be determined and the average egg deposition rates for all side channel habitats were used for egg-to-fry survival calculations in 2012 for these channels.

In 2014, the egg deposition rate for the NVOS side channel complex was 88.4% (range 80.0-93.0%), which was 8.9% higher than the 2013 egg deposition rate (79.5%) and 2.2% higher than the 2012 egg deposition rate (86.2%) (Table 7). Within the NVOS side channel complex the highest variation in egg deposition rates have been observed in Kisutch channel. In 2014, egg deposition rates in Kisutch channel were 87.5%, 17.4% higher than deposition rates in 2013 (70.1%) and 5.9% higher than egg deposition rates in 2012.

3.1.9 Kelt Behaviour

Kelting behaviour was assessed at the NVOS and BC Rail side channels. Kelts were assigned as fish that spent greater than 48 hours resident in the channel above the fish counter prior to a directional downstream outmigration. From 2007-2013, the total down counts removed from the total up counts on the fish counters at each site was scaled so that kelts were not removed from the net upstream spawner calculations. At both channels scaling values were used based on annual tagging data, although this value changed only slightly each survey year at BC Rail channel. In previous years there has been high variance in kelting behaviour at the NVOS channel site. This was likely due to the greater variance in flows this channel experiences during mainstem high water events throughout the spawning season. High water events likely assist in the flushing out of kelts and provide a greater area for fish passage in a downstream direction.

In 2014, high flows were experienced early in the spawning season and during the first week of peak spawning. The percentage of kelts was determined to be low in both the NVOS side channel complex, 14% of spawners kelted and in the BC Rail side channel 14% of spawners kelted (Table 8). However, these values were not used in the 2014 escapement estimates for the channels due to changes in the enumeration methodology (stream walks).

3.1.10 Validation of Counters

Video validation evaluations have been conducted at both side channel counter sites annually. Counter efficiency has varied annually with fish numbers, river discharge and site set-up. In 2014, validation at the BC Rail counter site during normal flows indicated that the counter was 87% efficient at counting up counts and 104% efficient at counting down counts (i.e. the counter missed 13% of spawners swimming up and over counted spawner swimming down by 4%) (Table 9). There were multiple events, however, when the counter was either offline or likely ineffective due to high water events backwatering into this groundwater fed channel. The BC Rail counter was taken offline at 1730 hrs on October 31st during the 295 m^3/s event (Brackendale Gauge, Figure 4) and reconnected on November 1st at 1830 hrs. On November 6th at 1800 hrs a 227 m^3/s high water event began (Brackendale Gauge, Figure 4) and the BC Rail video was removed, the trap was overtopped and the counter was likely ineffective until approximately November 8th at 0400 hrs. On November 27th (142 m^3/s Brackendale Gauge, Figure 4)

Because NVOS side channel complex has flow-through channels connected to the mainstem, the high water events during the 2014 spawning season had a bigger impact on water levels at the NVOS counter site than the BC Rail counter site. Video footage from the cameras at the NVOS counter site during low water events was not representative of the counter efficiency throughout the season. On October 21st the counter was taken offline at 1830 hrs due to a high water 312 m^3/s high water event (Brackendale Gauge, Figure 4). The counters were reconnected on October 26th at 1700 hrs. The counters were again taken offline on October 30th at 1630 hrs due to high water and reconnected on November 2nd at 1030 hrs. The third high water event likely caused the counters to be ineffective from November 4th to 6th when they were again taken off line until November 8th at 1000 hrs. The peak of the run was most likely missed by November 8th. The counters were likely ineffective during the final high water event of the spawning season on November 27th and 28th.

The third channel at the NVOS counter site was activated on November 19th (Figure 5). Preliminary assessments indicate that the interference among PIT readers does not seem to be a problem. Further evaluations on this channel and the counter efficiency will be carried out at the beginning of the 2015 chum spawning season.

3.2 Escapement Estimates

3.2.1 Adult Spawners

3.2.1.1 Upper River Estimate

Upper river estimates were derived from marking at the upper river tagging site (Figure 1) and recapturing/re-detecting them at three upstream side channels (the NVOS side channel, BC Rail side channel and Tenderfoot Creek (Figure 2)) (Section 2.1.2). In 2014, the adult chum escapement estimate in the upper river was 52,202 spawners. The estimate was 4 times greater than the lowest upper river escapement estimate (2010) and 26% of the highest upper river escapement estimate (2012) (Table 10 and Figure 13). Distribution within the river could not be evaluated but over the previous three years (2011-2013) the average percentage of whole river spawners that utilized the upper river habitat has remained relatively consistent ranging from 40% to 42% (Figure 13).

The lowest spawning escapement to both the whole river and the upper river was observed in 2010. The estimate of chum salmon in the upper river of 12,827 spawners was 15% of the total river spawner estimate (Table 10 and Figure 13). Prior to the Cheekye Creek washout in 2007 and 2008, the proportion of the run that used the upper river habitat for spawning was estimated as 16% and 20%, respectively (Figure 13).

High upper river escapement was estimated in 2009, 2012 and 2013, with the highest escapement of 198,420 chum salmon spawners returning in 2013 (Table 10 & Figure 14). In 2012, the upper river estimate of chum spawners in the Cheakamus River of 138,485 chum salmon. Notably in 2009, a large upper river spawner abundance of 105,540 chum salmon was also observed but in this case this was the result of a change in the distribution of spawners not of a particularly high chum salmon spawner return. A higher than average percentage, 65%, of total spawners utilized the upper river habitat in 2009 (Figure 13) after a summer storm event resulted in the backwatering of a substantial area of spawning habitat above the Cheekye confluence for some 1.5 km upstream (Figure 1). This new backwatered area had previously been observed in 2007 and 2008 as a reach of high chum spawner density based on visual and radio tag observations and the loss of this suitable habitat in 2009 likely influenced a large number of spawners to move farther upstream.

When total escapement was high (greater than 100,000 chum salmon in the upper river), greater numbers of salmon were enumerated at the upstream monitoring sites (BC Rail side channel and Tenderfoot Creek) (Table 10). In 2012, 138,485 chum spawners were estimated in the upper river and chum salmon were observed and assessed for pre-spawn mortality up to river kilometer (RK) 16.5 in the mainstem. In 2013, when the upper river escapement estimate was the highest estimate over 8 years (198,420 chum salmon), fewer fish were visually observed and present to be assessed for pre-spawn mortality above the Bailey Bridge (RK 7) and none were assessed as far upstream as RK 16.5 (ie. in 2012, 98 female chum were surveyed between RK 11.3 and 16.5 while in 2013, no females were present in this area to be surveyed).

A six day increased flow event (>25 m^3/s at Brackendale Gauge) during peak spawning (November 1st to 15th) occurred in 2012 while in 2013, flows during peak spawning were below 25 m^3/s at Brackendale Gauge and there were only two days when average daily discharge was greater than 20 m^3/s (Table 11). Relatively high escapement was also estimated in the upper river in 2009 (105,540 chum spawners in the upper river) but low numbers of spawners were observed above the Bailey Bridge. Flows during peak spawning in 2009 were higher than both 2012 and 2013. During peak spawning in 2009, there were 14 days when average daily discharge was greater than 20 m^3/s and eleven days when average daily discharge was greater than 25 m^3/s.

In 2014, although escapement was low to moderate in the upper river, 30 live chum salmon were visually observed between RK 16.5 and RK 15.0 during the mainstem pre-spawn mortality surveys on November 13th. Five percent (1/21) of the females available for assessment between RK 16.5 and RK 3.0 were present in this upper reach (RK 15.0-16.5). Between RK 11.3 and 7 (Bailey Bridge), approximately 75 live chum salmon were observed, but no moribund females. Average daily discharge during peak spawning in 2014 remained over 45 m^3/s until November 11th.

3.2.1.2 Whole River Estimate

From 2007- 2013, whole river chum salmon spawner estimates were derived from marking at the lower river tagging site (Figure 1) and recapturing/re-detecting them at three upstream side channels (NVOS side channel, BC Rail side channel and Tenderfoot Creek (Figure 2)) (Section 2.1.2). In 2014, after multiple high water events early in the season hindered access to fishing areas in the lower river, the field crew concentrated efforts on tagging chum salmon in the upper river to ensure enough tags were put out to produce a strong upper river escapement estimate. A whole river Pooled Peterson Estimate for chum salmon was not able to be produced in 2014. However, assuming that the proportion of chum salmon that spawned in the upper river was similar to what was observed in the previous three years (average 41%) (Figure 13), the whole river escapement estimate could be approximated at 104,323 chum salmon. This estimate would be at the low to moderate range of escapement in the Cheakamus River compared to the last 7 years.

In both 2013 and 2012, high escapements estimates of chum salmon were derived from the mark-recapture study on the Cheakamus River. In 2013, the whole river estimate was 468,511 chum salmon and in 2012, the whole river escapement was 327,804 chum salmon (Table 10 & Figure 14). A large escapement of chum salmon spawners also returned to the Cheakamus River in 2007 when a whole river estimate was 267,574 chum salmon (Table 10 & Figure 14). In 2010 and 2011, chum returns to the Cheakamus River were the weakest of the 8 study years with whole river estimates of only 85,461 and 73,377 chum salmon returning, respectively. In 2008 and 2009, the returns were moderate in the time series, estimated as 117,780 and 165,318, respectively (Table 10 & Figure 14).

3.2.1.3 Side Channel Estimates

Side channel escapement estimates were based on resistivity counts at the NVOS side channel and the BC Rail side channel and manual counts at Tenderfoot Creek fish fence (Figure 2). BC Rail and Tenderfoot Creek are both groundwater fed channels, as are the most selected areas for chum spawning within the groundwater and surface water fed NVOS side channel complex (Kisutch and Upper Upper Paradise channels). The number of spawners returning to side channel habitats to spawn is strongly correlated (R=0.93) with the total number of upper river spawners (Figure 15). With larger upper river returns, higher numbers of spawners are estimated to spawn in the side channel habitats (Table 10 and 12).

In 2012, low numbers of spawners (683 chum salmon) were found in the BC Rail side channel, despite a high escapement of spawners returning to the upper river and other side channel habitats (Table 11). Prior to the chum salmon run in 2012, a habitat restoration project had been undertaken to improve access to Tenderfoot Creek which also altered access to the BC Rail side channel. Large escapements into Tenderfoot Creek occurred 2012 and 2013, following the habitat restoration. Escapement into Tenderfoot Creek in 2013 and 2013 was 5,419 spawners (3.9% of upper river spawners) and 7,643 spawners (3.9% of upper river spawners), respectively. BC Rail escapement was much improved in 2013, with 3,331 spawners using the BC Rail side channel (Table 12).

In 2014, prior to the first large rainfall event which began increasing discharges in the Cheakamus River watershed on October 20th, both Tenderfoot Creek and BC Rail side channel were disconnected from the mainstem due to low flows in these side channels. Tenderfoot Pond was disconnected from Tenderfoot

Creek and within Tenderfoot Creek, pocket pools remained wetted but in sections that are typically shallower, the creek was dry. There were no inflows from the pond into the Creek until October 22nd when discharge in the mainstem had increased and access from the Cheakamus River, through Tenderfoot Creek and into Tenderfoot pond was restored. In 2014, a lower than average proportion of upper river spawner (2014: 2.5%; 2007-2013 average: 4.7%) were enumerated at the Tenderfoot fish fence. Two high water events during the season (October 31st and November 7th) did, however, prevent the trap from holding fish back for 1-2 days during each event. The proportion of upper river chum spawners that utilized the BC Rail side channel in 2014 (2.9%) was higher than average (2.5%).

The proportion of upper river spawners utilizing all these monitored side channels (by comparing resistivity counts and manual counts to upper river estimates) has varied over the study period. The percentage of upper river chum spawners that utilized the side channel habitats has ranged from 10% to 33% (mean 17%, Figure 16). A strongly positive correlation exists (R=0.74) between the percentage of side channel spawners and minimum discharge during peak spawning (November 1 to November 15) (Figure 17). When minimum discharge was between 15 m^3/s and 20 m^3/s, on average 13% of spawners utilized side channel habitats; however, when minimum discharge was greater than 24 m^3/s, the average percentage of spawners that utilized side channel habitats was on average 21% (Figure 17).

A strong correlation exists (R=0.80) between the proportion of spawners utilizing the groundwater and surface water fed NVOS side channel complex and minimum discharge (Figure 18). The largest proportion of spawners that utilized the NVOS side channel complex occurred in 2010 when minimum discharge during peak spawning was 24.3 m^3/s. In 2010, the upper river escapement was 12,827 chum spawners and 21% of upper rivers spawners utilized side channel habitats. The majority of those spawners, 16% of upper river spawners utilized the NVOS side channels, the most downstream monitored side channel habitat (Figure 16 and 17, and Table 10).

A correlation also exists (R=0.69) between the proportion of spawners utilizing the groundwater-fed BC Rail side channel (Figure 19). In 2008, when minimum discharge during peak spawning was 24.6 m^3/s and the upper river escapement was 24,059 chum spawners, the largest proportion of spawners were estimated in both of the most upstream monitored side channel habitats. Fourteen percent of upper river spawners (3,309 chum salmon) utilized Tenderfoot Creek and 5% of upper river spawners (1,279 chum salmon) utilized the BC Rail side channel (Figure 16 and 18 and Tables 10 and 12).

3.2.2 Outmigrant Fry

Chum fry production has been monitored on the Cheakamus River at the RST site (RK 5.5) since 2001. Fry migration is generally either just commencing or has not yet started when sampling begins on February 15th (Appendix A Figures 1A-14A). In 2015, peak run timing, defined as the Julian day when 50% of fry have outmigrated past the RSTs, occurred on the 83rd Julian day (March 24th), a week earlier than any other year. The next earliest peak outmigration also occurred post-WUP in 2011 on the 90th day Julian day (March 31st). The most delayed peak outmigration occurred pre-WUP in 2003. Half of the fry had outmigrated by the 113th day in 2003. In 2002, discharge early in the chum spawning season was the lowest of the fourteen years. The average daily discharge from October 15th to November 6th was 10.9 m^3/s (range 10.0 to 12.5 m^3/s). Prior to the implementation of the WUP (pre-WUP) from 2001 to 2006, peak fry outmigration occurred between the 91st and the 113th day. After the implementation of the WUP (post-WUP) from 2007 to 2014, peak fry outmigration has occurred between the 83rd and the 104th. Peak outmigration post-WUP has been occurring on average 6.4 days earlier than per-WUP.

Estimated fry production has varied from a low of 1,685,668 in 2001 to a high of 10,795,444 chum fry in 2013 (Figure 20 and Table 13). The average annual fry production pre-WUP (2001-2006) was 3,705,110 chum fry/year. The average annual fry production post-WUP (2007-2015) was 2,054,657 chum fry/year. An increase in average annual fry production of 22% has been observed since the introduction of the WUP, although, in four of the nine post-WUP years, fry production was less than the pre-WUP average. Higher variance in annual fry production has been observed post-WUP than pre-WUP. The coefficient of variation among annual fry production pre-WUP was 0.29 and post-WUP was 0.63.

Estimates of chum fry production have been derived annually from 2008 through 2015 for the BC Rail and NVOS side channels. In the NVOS side channel complex the estimates have ranged from a low of 557,908 chum fry in 2011 to a high of 2,428,254 chum fry in 2013 (Table 14). In 2015, the outmigration estimate was 1,240,328 chum fry. In the BC Rail side channel, the estimates range from a low of 23,022 chum fry in 2011 to a high of 459,562 chum fry in 2013 (Table 14). From 2008 to 2014, fry production from NVOS and BC Rail side channels combined had represented between 27% and 43% of the total production annually above the RST site (Figure 21). In 2015, fry production from NVOS and BC Rail side channels combined made up 92% of the total fry production above the RSTs. In 2013, 45% of the total chum fry were produced in the NVOS and BC Rail side channels. Fry production from Tenderfoot Creek has been monitored since 2013. In 2013 and 2014, Tenderfoot Creek contributed 26% and 42% of the total yield in the upper river, respectively (Figure 17). In 2014, an outmigration estimate of chum fry was not able to be produced in 2014. A total of 1,643 chum fry were caught and 681 were marked, but none were recaptured.

3.3 Juvenile Outmigrant Bio-sampling

Mean fork length of juvenile chum fry from 2001 to 2015 was 39 mm (Table 15). An analysis of variance of the fork length of juvenile chum fry from 2001 to 2015 revealed that there was a significant difference among years (ANOVA: F=60.14, p<0.001). The size of juvenile chum was significantly larger pre-WUP (39 mm) than post-WUP (38 mm) (F-Test: two-sample for variances, F=2.30, p<0.001; t-Test: unequal variances, p<0.001).

3.4 Index of Productivity H', (Egg-to-fry Survival)

Egg-to-fry survival, H' was calculated based on the estimated number of spawners for each area, the sex ratio of chum captured in the Tenderfoot trap, the fecundity of females sampled at Tenderfoot Creek and area specific egg deposition rates. For the entire area above the RSTs and without accounting for site specific pre-spawn mortality, egg-to-fry survival, H' in 2015 was 3.1% (Table 16). The egg-to-fry survival estimate was 1.6% in 2014 and 5.7% in 2013. Accounting for pre-spawn mortality egg-to-fry survival in the mainstem and unmonitored side channels above the RST site only, was calculated to be 0.3% in 2015, 0.3% in 2014 and 3.6% in 2013 (Table 16).

Egg-to-fry survival was also calculated independently for the NVOS side channel complex, the BC Rail side channel and Tenderfoot Creek upstream of the fish fence. In 2015, egg-to-fry survival (accounting for pre-spawn mortality) in the NVOS side channel complex was 17.9%. In 2014 egg-to-fry survival was 34% lower than the 2015 value and in 2013 egg-to-fry survival was 29% higher than the 2015 value. In 2014 egg-to-fry survival was 11.8% while in 2013 egg-to-fry survival was 23.1% (Table 16). In the BC Rail side channel, egg-to-fry survival (accounting for pre-spawn mortality) in 2015 was 37.5%, 4.5 times greater than egg-to-fry survival in 2014 (8.3%) (Table 16).

Annual comparisons to the 2013 data from BC Rail side channel and Tenderfoot Creek do not account for pre-spawn mortality because strong data is not available. In the BC Rail side channel, egg-to-fry survival in 2013 (49.0%) was 46% higher than the 2015 value (33.6%). In Tenderfoot Creek upstream of the fish trap, egg-to-fry survival was 25% lower in 2014 than in 2013. Egg-to-fry survival in 2014 was 20.5%, compared to 45.5% in 2013 (Table 16). Egg-to-fry survival could not be determined for 2015 due to low re-capture rates in Tenderfoot Creek.

3.5 Spawner-Fry Relationship

The relationships between the number of chum spawners and the number of outmigrating fry appear to follow polynomial curves in the both NVOS and BC Rail side channels (Figures 21 and 22). Fry production was highest from the NVOS side channel complex in 2009/10 and 2012/13 when the numbers of chum spawners using the habitat were 9,357 and 8,859, respectively (Table 12 and 14, Figure 21). Higher spawner densities in 2013 (13,213) resulted in reduced survivorship and lower fry productivity in 2014. In 2013/14, the lowest number of fry per spawner was observed; 126 fry were produced per spawner. The numbers of fry per spawner has ranging from a low of 126 fry per spawner in 2013/14 to a high of 445 fry per spawner in 2007/08 (Table 12 and 14, Figure 21).

In 2014/15, 6,169 chum spawners utilized the NVOS side channel and 1,240,328 fry were produced which was equivalent to 201 fry per spawner (Table 12 and 14, Figure 21). This is the second lowest number of fry per spawner recorded since side channel monitoring began. In 2007/08, 2008/09, 2010/11 and 2011/12, chum escapement was below 3,500 spawners and fry production was under 1,000,000 chum fry (Table 12 and 14 Figure 21).

The number of fry per spawner in the BC Rail side channel has ranged from a low of 63 fry per spawner in 2010/11 to a high of 673 fry per spawner in 2012/13 (Table 12 and 14, Figure 22). In 2014/15, 426 fry were produced per spawner. In 2014, 1,523 chum spawners spawned in the side channel and in 2015, the largest outmigration of fry (649,368 chum fry) was produced. Reduced survivorship and lower productivity were observed in both 2013/14 and 2009/10 when over 3,000 chum spawners utilized the side channel habitat. The number of fry produced per spawner in 2009/10 and 2013/14 was 83 and 69, respectively. The lowest number of fry per spawner (63) was observed in 2010/11 when the lowest escapement of spawners was observed (367 chum salmon). Low escapement in 2011 also resulted in a relatively low number of fry per spawner (130). In 2007/08, 2008/09, and 2012/13, the number of fry produced per spawner was relatively high at 300, 306 and 673 fry per spawner, respectively (Table 12 and 14, Figure 22).

3.6 Incubation Temperature

Of the twenty temperature loggers that were implanted in redds upstream of the Bailey Bridge (RK 7.0) on December 3rd and 4th in 2014, only two were recovered on February 2nd, 2015. All temperature loggers and stakes used to anchor them into the bed material were scoured out during the 400 m^3/s event on December 10th and 11th. Data from the two recovered temperature loggers does not provide enough information to determine the temperature regime in the redds above the Bailey Bridge.

Average incubation temperature in redds was approximated by comparing peak migrations times of returning chum spawners to outmigrating fry. The Julian day when 50% of chum spawners had passed over the NVOS counter pads was used to indicate peak chum spawning. The Julian day when 50% of chum fry had outmigrated downstream past the RSTs was used to indicate peak chum fry outmigration. Chum salmon require 850-900 accumulated thermal units to emerge from the gravel (Tenderfoot Hatchery data). The average number of thermal units accumulated daily was 5.6-6.0º C (Table 17). Average temperature in redds is approximately 1.5-2º C warmer than the river temperature (Table 17).

4.0 DISCUSSION

The primary goal of this monitor is to evaluate the total spawner escapement and potential egg deposition of chum salmon to the Cheakamus River, in particular the numbers utilizing the area above the juvenile monitoring site located at RK 5.5 and the BC Rail and NVOS spawning channels. Egg deposition data can then be linked with fry production data (Melville and McCubbing 2012, Bonner and Schwartz 2012) to determine egg-to-fry survival rates to evaluate if spawning and incubation periods are affected by post-WUP related changes in river discharge. Also, spawner distribution is evaluated in order to identify key spawning areas and how discharge affects spawner distribution.

Chum spawning in the Cheakamus River falls into three main locations for this study: below the RST juvenile monitoring site, above the RST site (mainstem) and in the side channels above the RST site. Where and in what density fish spawn, will affect egg deposition densities and potentially egg-to-fry survival rates and thus fry production. As we only have data on fry production from above the RST site, total river escapement data is only useful as a general indicator of fish abundance and stock health. Over the eight year of enumeration, a large range in escapement has been observed in the whole river from a high of 468,511 chum salmon to a low of 85,461 chum salmon. High escapement was estimate in 2007, 2012 and 2013. Escapement in 2010 and 2011 to was relatively low and escapement in 2008 and 2009 was moderate. Using the previous three year's distribution data, the 2014 whole river escapement was likely low to moderate in comparison to the previous year's abundance estimates.

After the third year of fecundity analysis, it is apparent that the fecundity of female chum salmon in this watershed varies annually. Female chum salmon sampled in 2014 and 2013 were significantly less fecund ($p=0.015$ and $p=0.013$, respectively) than females sampled in 2012. Significant relationships between length and fecundity have been observed in all years. The amount of the variability in fecundity that is account for by length has ranged from 15.7% in 2014 to 38.3% in 2013. In age 4 spawners in 2014, a stronger relationship between length and fecundity was observed with length accounting for 35.1% of the variability in fecundity.

Annual variance in age cohort representation could help explain this variability, as significant differences in population age structure were observed between years. Recent publications have indicated that egg per female fecundity may be a derivative of both fish age (3 or 4 years) and fish length (Kaev 2000). Length, weight and fecundity have also been liked to run size (Volobuev 2000). With additional years of fecundity, length and age information, fecundity of females in years 1 to 5 (2007-2012) will be estimated using these biological parameters. Significant differences in the size of females have been observed. Age structure could be determined for Years 1-5 from archived scales, if appropriate.

Pre-spawn mortality surveys conducted since 2012 have revealed that egg deposition varies both spatially and temporally in both the mainstem and side channel habitats. The highest egg deposition rates were observed in 2014 which coincided with high flows early in the spawning season and low to moderate densities. Higher densities of spawners in 2013 and 2012 may have increased pre-spawn mortality. The highest pre-spawn mortality was observed in 2013 when the highest densities of spawners were observed in side-channels. Variables that have been linked to higher egg retention and pre-spawn mortality include temperature, time of freshwater entry and density dependent population mechanisms (Kolski 1975, Schroder 1981). Other causes associated with pre-spawn mortality include fish stranding, disease, lack of passage at culverts or dams and low water conditions (Wild Fish Conservancy 2008). The assessment of pre-spawn mortality rates in Years 6-10 will be used to help derive an estimate of pre-spawn mortality rates for Years 1-5 when pre-spawn mortality surveys were not conducted; thus current egg-to-fry survival data are provisional at this time.

Egg-to-fry survival in side channel habitats is higher than in the mainstem. Distribution of spawners into these habitats is correlated with both density (R=0.96) and discharge during peak spawning (most strongly to minimum discharge (R=0.73)). When minimum flows during peak spawning were higher (>25 m^3/s), a larger proportion of the upper river chum spawners utilized side channel habitats. Higher overall discharge in the river increases flows in the flow-through NVOS channel which may draw a larger proportion of spawners into the channel. In the groundwater-fed BC Rail side channel, increased discharge in the mainstem provides better access into this channel. In years of low to moderate escapement in the upper river, these side channel habitats, where egg-to-fry survival is high, are particularly important for fry productivity from the upper river. Additional years of data at higher flows (particularly with minimum flows between (>20 m^3/s and <24 m^3/s) would provide more insight into this relationship between discharge and side channel site selection.

When escapement into the upper river was high (2009, 2012 and 2013), the NVOS and BC Rail side channel habitats may reach and even surpass their habitat carrying capacity. In NVOS in 2013 and in BC Rail in 2009 and 2013, lower numbers of fry per spawner were observed and fry production was reduced compared to years when moderate densities were observed in the side channels. Further evaluations will be conducted on habitat carrying capacity and the relationships between density dependent and independent factors.

In years of high escapement, discharge rates during the spawning season may be more important for distributing spawners throughout the river to maximize productivity of chum salmon. Discharge during the 2013 spawning season was low and a large proportion of the chum salmon in the upper river (198,420) spawned between the Bailey Bridge (RK 7) and the RST site (RK 5.5). Egg-to-fry survival in 2013/14 was very low. In comparison, in 2012 and 2014 there were higher flows during peak spawning and fish were observed farther upstream during pre-spawn mortality surveys. Egg-to-fry survival was 10 times higher in 2012 than 2013. Additional increased flow events (either natural or operational) may have helped distribute these fish throughout the river and increase egg-to-fry survival. Hunter (1959) noted that stream discharge was an important factor in controlling the upstream movement of chum salmon in coastal British Columbia streams.

Literature reviews conducted by both Banks (1969) and Jonsson (1991) concluded that spawning migrations are associated with increased water flows. Telzlaff et al. (2005) found a complex relationship between hydrological variability and movement of adult Atlantic salmon spawners moving upstream in late October to mid-November. In years when discharge prior to spawning was low fish movement was increasingly triggered by suboptimal flow increases as spawning time approached and in wet years with numerous increased flow events fish were found more evenly distributed immediately after fish entry (Telzlaff et al. 2005). Additional years of directed radio telemetry observations on female fish will provide us with a better understanding of the relationships between discharge, distribution and upstream movement of female chum spawners.

During the spawning season in 2014, discharge was high and spawners were observed above the Culliton Creek confluence (RK 13). However, the magnitude and frequency of the high flow events (one discharge event > 400 m^3/s and another three discharges events > 200 m^3/s) appears to have had a large impact on egg-to-fry survival in the mainstem. Twenty temperature loggers buried on December 4th and 5th upstream of the Bailey Bridge to measure temperatures within redds were all scoured out during the 400 m^3/s discharge event on December 10th and 11th. In 2014/15, the importance of side channel habitats for chum fry production as a buffer against these extreme events is emphasized. Fry production from the BC Rail and NVOS side channels made up 92% of the total yield above the RSTs site in 2015.

Including fecundity estimates and pre-spawn mortality surveys into the overall study design have provided better egg deposition estimates for all the areas assessed and thus more confidence in the egg-to-fry survival estimates from which they are calculated. Mainstem egg-to-fry survival rates in 2014/13 and

2013/14 without accounting for pre-spawn mortality were very low at 0.3% and 0.2%, respectively. Egg-to-fry survival rates without accounting for pre-spawn mortality in 2012/13 were 10-16 times higher but also low at 3.1%. Parker (1962) observed a broad range of survivorship in chum salmon, 1-22% from 14 years of sample data on Hooknose Creek, BC. Bradford (1995) looked at multiple rivers along the Pacific west coast and average egg-to-fry survival of chum salmon was 7% to 9%. Egg-to-fry survival rate for chum salmon were reported between 6% and 35% by Beacham and Starr (1982) after 19 years of research on the Fraser River, BC. High densities of spawners in the mainstem areas likely affected survival in both 2012 and 2013. The frequency and magnitude of high flow events affected mainstem egg-to-fry survival in 2014. It is apparent that chum salmon egg-to-fry survival rates in the Cheakamus are highly variable among habitat types and ongoing work will establish the temporal and spatial trends and explore how they may be affected by discharge.

Peak fry outmigration occurs earlier (between the 83rd and the 104th Julian day) since the implementation of the WUP in 2007. Prior to the WUP, peak fry outmigration occurred annually between the 91st and the 113th Julian day. In two of the six pre-WUP years, peak fry outmigration occurred later than the 104th Julian day. The latest peak fry outmigration occurred following a spawning season during which flows had remained low (average discharge 10.9 m^3/s) from October 15th to November 6th. Low flows between 10.0 and 12.5 m^3/s may affect access for migration chum spawners. Spawning timing in conjunction with water temperature during incubation and emergence is the primary factor regulating migration timing of chum fry.

Using upstream movement of spawners at NVOS and outmigration timing of chum fry in the mainstem as an indication of peak spawning and peak fry outmigration the average incubation temperature was approximated to be between 5.6 and 6.0º Celsius. Temperatures in redds are 1.5 to 2.0º C warmer than the temperatures in the river. This indicates that the majority of outmigrating fry are emerging from redds with groundwater influence. Further analysis of groundwater and river temperatures will provide more insight into incubation temperatures and the influences of discharge on these relationships.

Chum fry outmigration estimates calculated since 2001 on the mainstem indicates that chum fry production has varied greatly from year to year. Comparisons of variation pre-WUP (CV=0.29) and post-WUP (CV=0.63) indicate that higher annual variation in chum fry production has been observed post-WUP. Reasons for this could include changes in spawner abundance, distribution patterns and changes in habitat conditions or river discharge (e.g., the influence of the Cheekye Creek washout in 2009). Despite the high variability, an increase of 22% in average annual fry production has been observed post-WUP.

The key study goal is the ability to detect a linkage between discharge and a positive change in fry production of 75% or greater as predicted by the modeling work pre-WUP (Marmorek and Parnell 2002). At present the observed changes in fry abundance fall short of this level of increase.

The body size of juvenile chum was significantly larger pre-WUP (39 mm) than post-WUP (38 mm) ($p<0.001$). Size of alevin and fry is influenced by both egg size and incubation temperature (Beacham and Murray 1986 and 1987, Weatherley and Gill 1995). Beacham and Murray (1987) found a change in incubation temperature from 4 to 8ºC corresponded with a 2mm increase in fry length. Water temperature pre-WUP was significantly higher than post-WUP, although, this is based on only 2 years of water temperature data (2001 and 2005) (McCubbing et al. 2012). Also, no egg size data is available prior to 2012. Post-WUP evaluations of these relationships will continue to be monitored and additional evaluations of groundwater influences on incubation could provide further insight.

4.1 Management Questions

4.1.1 What is the relation between discharge and chum salmon spawning site selection and incubation conditions?

There appears to be a correlation between side channel distribution and minimum discharge. When minimum discharge was near 25 m^3/s, a larger proportion of spawners utilized side channel habitats (particularly NVOS side channel habitat). Egg-to-fry survival in side channel habitats is higher than in the mainstem, therefore, it appears that increasing the number of side channel spawners could increase upper river productivity as long as side channel carrying capacity is not surpassed. This theory will continue to be evaluated over the next two years of this study. Additional years of higher minimum flows (>20 m^3/s) would provide more insight into the relationships between discharge and distribution in both side channels and the mainstem habitat.

4.1.2 Do the models developed during the WUP to calculate effective spawning area (based on depth, velocity and substrate) provide an accurate representation of chum salmon spawning site selection, and the availability of spawning habitat?

A large area of habitat upstream of the Bailey Bridge (RK 7.0) was classified as effective spawning area in the original model. Chum spawners have only been observed utilizing this area in large numbers in one year (2012). In 2012, high numbers of spawners did returned to the Cheakamus River and to the upper river but even higher numbers of chum spawners returned in 2013 and chum salmon did not distribute as far upstream in 2013. This difference in distribution could be related to discharge during the chum salmon run. In 2012, the average discharge was higher than in 2013, which could have drawn chum spawners farther upstream. This hypothesis will be further evaluated over the next two years using radio telemetry and by surveying the area to assess pre-spawn mortality of females. Further evaluation of temperature in redds upstream of the Bailey Bridge (RK 7.0) will provide insight into the temperature regimes in the areas classified as effective spawning area.

4.1.3 Are there other alternative metrics that better represent chum salmon spawning habitat?

Groundwater appears to be important to chum salmon site selection. During pre-spawn mortality surveys, chum spawners have been found to concentrate in the groundwater fed side channels. To test if redds in the mainstem were influenced by groundwater upwelling, in 2010 temperature loggers were buried in the hyporheic zone within redds at Moody's Bar and at the Gauge pool (upper river tagging site) and compared to two independent stilling wells measuring river water temperature (Figure 1) (McCubbing et al. 2011). River water temperatures loggers showed high daily and weekly variation over the egg incubation period from lows near 0.5° C during early January and late February to highs of over 5° C in December and mid-February, 2011. In the majority of redds there was significantly less daily variation in temperature and the water temperature was 3-5^{0} C warmer in redds than the surface water. Most temperature loggers recorded temperatures between 5 and 8^{0} C after late December (McCubbing et al. 2011).

By calculating the average temperature required to accumulate 850-900 ATUs from peak spawning to peak fry outmigration, it appears that the majority of outmigrating fry are emerging from redds with groundwater influence. By using the temperature data collected upstream of the NVOS counter site in conjunction with peak upstream migration across the counters and peak out migration from the channel, the influence of groundwater on production in the NVOS side channel complex will be assessed over the next two years.

Chum salmon selection preference for groundwater in the mainstem spawning areas will be further evaluated over the next two years by mapping the site selection of radio tagged chum spawners and overlaying know groundwater upwelling areas (Moody's bar, BC Rail side channel, Upper Upper Paradise and Tenderfoot Creek). In 2013, 33% of females spawned in know groundwater upwelling areas.

4.1.4 What is the relationship between discharge and juvenile salmonid production, productivity, and habitat capacity of the mainstem and major side-channels of the Cheakamus River?

Discharge affects the distribution of spawners. At higher minimum discharges (near 25 m^3/s), a larger proportion of spawners utilized side channel habitats. Side channel habitats are more productive than mainstem habitats and in 2014, when mainstem conditions were affected by multiple high water events, the side channel habitats produced 92% of the total yield of chum fry in the upper river.
Increasing the number of side channel spawners increases upper river productivity as long as side channel carrying capacity is not surpassed. This theory will continue to be evaluated over the next two years of this study. Additional years of higher minimum flows (>20 m^3/s) would provide more insight into the relationships between discharge and distribution in both side channels and the mainstem habitat.

The upstream distribution of spawners also affects productivity above the RST site. In years of high escapement and low flows, high numbers of chum spawners do not appear to distribute upstream past the Bailey Bridge (RK 7). High densities of spawners in the 1.5 km stretch in the mainstem above the RSTs in 2013 resulted in low egg-to-fry survival and low productivity. The carrying capacity of this area was surpassed in 2013. In contrast, in 2012, there were higher flows during peak spawning and the large escapement of spawners that returned to the upper river distributed from the RST site (RK 5.5) to Road's End (RK 16.5). The highest outmigration of fry over the 15 years of this study was enumerated in 2013. Egg-to-fry survival was 10 times higher in 2012 than 2013.

4.1.5 Does juvenile chum fry yield or habitat capacity change following implementation of the WUP flow regime?

There has been higher variance in chum fry production observed since the implementation of the WUP. Pre-WUP variance was 29%, while post-WUP variance has been 63%. A positive change in fry production of 75% or greater was predicted by the modeling work that was conducted. To date, a 22% increase in average annual fry production has been observed.

4.2 Null Hypotheses (and sub-hypotheses)

4.2.1 H_1: Discharge during the chum salmon spawning and incubation period does not affect productivity, measured as the number of fry per spawner in the mainstem

In order to test this hypothesis, the number of fry per spawner in the mainstem must be determined. Prior to 2012 RST mainstem fry production estimates include Tenderfoot Creek fry data. Since the 5 year review process in 2012, the productivity of Tenderfoot Creek has been evaluated and it was very productive in 2013 and 2014. In 2013 and 2014, Tenderfoot Creek contributed 26% and 42% of the total yield in the upper river, respectively. In 2015, low numbers of natural spawners utilized the habitat and productivity could not be determined due to the low recapture rates of outmigrating fry.

In 2013 and 2014, pre-spawn mortality surveys were conducted in Tenderfoot Creek to determine egg deposition rates. Egg deposition and productivity will continue to be evaluated in Years 9 and 10. Using these estimates and the known adult escapement above the DFO fish fence, productivity of Tenderfoot Creek for Years 1-5 could be estimated and removed from the mainstem fry production estimates.

The fecundity evaluations at Tenderfoot Hatchery and pre-spawn mortality surveys in the mainstem and side channel habitats have shown that egg deposition varies both temporally and spatially. Further evaluations of these variables will aid in the development of accurate egg-to-fry survival rates for Years 6-10 and help estimate deposition rates for Years 1-5.

4.2.2 H_2: Spawning chum salmon do not select areas of upwelling groundwater for spawning in the mainstem

In 2010, temperature loggers were buried in redds at Moody's bar area and on the bar upstream of the RST site (upper river tagging site) which revealed that the majority of redds were built in areas of groundwater influence in these areas (McCubbing et al. 2011). See Section 4.1.3 for more details. In 2013, 80 radio tags were implanted on female chum salmon entering the river to spawn. One third (33%) of the females successfully radio tagged spawned in the known groundwater upwelling areas (Moody's bar area, Tenderfoot channel, BC Rail side channel). Radio tagging females over the next three years will provide more insight into site selection of female chum spawners and the relationship between site selection and groundwater upwelling. Further evaluation of temperature in redds upstream of the Bailey Bridge (RK 7.0) will provide insight into the temperature regimes in the areas classified as effective spawning area that chum are not consistently utilizing. Current evidence suggests this hypothesis may be incorrect.

4.2.3 H_3: Discharge during the chum salmon spawning and incubation period does not affect the upwelling of groundwater in the mainstem spawning areas

With a better understanding of site selection in the mainstem, the relationship between discharge and groundwater upwelling can be further analysed.

5.0 Recommendations

5.1 Temperature Loggers in Side Channels

To evaluate whether eggs are incubating in groundwater or surface water in the NVOS side channel, temperature loggers should be used to record the water temperature in the side channel through the spawning season and during incubation and emergence over the next two years. Peak upstream migration can be determined from the NVOS counter and peak downstream migration can be determined from the BTSPAS weekly abundance estimates for the fyke at the mouth of the channel (fyke 1, F1) (Figure 2). Chum salmon require 850-900 accumulated thermal units from egg deposition to emergence. Knowing the number of days between peak spawning and peak outmigration, the average daily thermal units required could be determined.

5.2 Temperature Loggers above Bailey Bridge (RK 7)

To determine if there is a groundwater influence upstream of the Bailey Bridge, temperature loggers should be buried in spawning gravel upstream of the Bailey Bridge from the end of the spawning season, through incubation and emergence over the next two years. The areas upstream of the Bailey Bridge were initially identified by the model as suitable spawning habitat. However, chum spawners do not often utilize this habitat. If chum salmon are keying into the groundwater upwelling areas and there is not groundwater influence upstream of the Bailey Bridge, this could provide insight into why they are not selecting this habitat.

5.3 Using Minipiezometers to Measure Groundwater-Stream Water Exchange

To measure groundwater-stream water exchange, minipiezometers should be installed throughout the mainstem of the river and in the side channel habitats to estimate hydraulic conductivity. Methodologies could be used similar to those described in Baxter and Hauer (2003). Measurements should be done in areas where chum spawning is concentrated (i.e. Moody's, Upper Upper Paradise and Kisutch channels) as well as in habitats that are not regularly selected for by chum (i.e. in the mainstem upstream of the Bailey Bridge and in the Baby Gorbuscha and Big Gorbuscha channels). This technique could identify differences in the groundwater-stream water exchange between selected and non-selecting habitat. Additionally, groundwater-stream water exchange should be measured under different flow conditions to evaluate the influence of stream flow on hydraulic conductivity.

6.0 TABLES

Table 1. Numbers and distribution of PIT tags applied to chum salmon adults on the Cheakamus River, 2007-2014

Year	Total # Fish Tagged		Lower River Tagging Site					Upper River Tagging Site			
			Totals	Males	Females	% Females		Totals	Males	Females	% Females
2007	870		795	349	446	56%		75*	45	30	40%
2008	951		569	328	241	42%		382	252	130	34%
2009	762		391	224	165	42%		371	261	110	30%
2010	914		537	334	204	38%		377	292	85	23%
2011	1,890		970	766	204	21%		920	763	157	17%
2012	1,517		722	379	343	48%		795	587	208	26%
2013	1,907		890	515	375	42%		1,017	795	222	22%
2014	1,005		5*	4	1	20%		1,000	730	270	27%

* small sample size

able 2. Mean fork length ± standard deviation (mm) of tagged adult chum salmon at the lower river tagging site and the upper river tagging site, Cheakamus River 2007-2014

Year	Lower River Tagging Site		Upper River Tagging Site	
	Female	Male	Female	Male
2007	750 ± 40	802 ± 42	Sample size too small	
2008	718 ± 43	765 ± 52	720 ± 43	760 ± 52
2009	720 ± 33	765 ± 45	729 ± 30	760 ± 45
2010	729 ± 42	765 ± 49	732 ± 41	768 ± 58
2011	702 ± 35	728 ± 46	704 ± 33	732 ± 47
2012	726 ± 37	778 ± 52	739 ± 43	785 ± 49
2013	719 ± 34	764 ± 45	721 ± 35	774 ± 47
2014	Sample size too small		745 ± 40	792 ± 47

Table 3. Percentages of females, Male:Female (M:F) sex ratio and total number (N) of chum spawners captured by tangle netting at the upper river tagging site on the Cheakamus River and at the Tenderfoot Creek fish fence (operated by DFO) 2007-2014

Year		Upper River Tagging Site				Tenderfoot Fish Fence		
		% Females	M:F Sex Ratio	N		% Females	M:F Sex Ratio	N
2007		40%	1.5:1	75*		23%	3.3:1	1557
2008		34%	1.9:1	382		36%	1.8:1	3308
2009		30%	2.3:1	371		38%	1.6:1	2935
2010		23%	3.3:1	377		23%	3.3:1	293
2011		17%	4.9:1	920		21%	3.9:1	690
2012		26%	2.8:1	795		40%	1.5:1	5396
2013		22%	3.5:1	1017		41%	1.4:1	7643
2014		27%	2.7:1	1000		38%	1.6:1	1329

*small sample size

Table 4. The number (N) and percentage of spawned out female chum salmon in each habitat type surveyed on the Cheakamus River in 2012-2014

Location	2012		2013		2014	
	N	Spawned Out	N	Spawned Out	N	Spawned Out
Mainstem Habitat	602	89.0%	744	87.1%	342	98.2%
Side Channel Habitat	773	82.9%	1775	64.5%	1383	91.7%

Table 5. The number (N) and percentage of spawned out female chum salmon in each surveyed side channel on the Cheakamus River 2012-2014

	2012		2013		2014	
Location	**N**	**Spawned Out**	**N**	**Spawned Out**	**N**	**Spawned Out**
BC 49 side channel	262	81.7%	339	68.1%	300	95.0%
BC Rail side channel	40	45.0%	268	37.1%	375	88.3%
Tenderfoot Creek	Not surveyed		292	66.4%	105	98.1%
NVOS side channels	458	86.7%	810	73.6%	603	91.0%

Table 6. The number (N) and percentage of spawned out female chum salmon in the NVOS side channel complex from 2012 to 2014

Location	2012		2013		2014	
	N	Spawned Out	N	Spawned Out	N	Spawned Out
Baby Gorbushca	41	82.9%	10	60.0%	7	100.0%
Big Gorbushca	0	No female chum	52	55.8%	11	100.0%
Kisutch	123	77.2%	100	55.0%	115	90.4%
Sues	41	90.2%	65	76.9%	50	74.0%
Upper Paradise	151	90.1%	231	74.0%	222	90.5%
Upper Upper Paradise	102	93.1%	352	81.0%	198	95.5%

Table 7. The percentage of eggs deposited by female chum salmon by area in the Cheakamus River from 2012 to 2014

	Eggs Deposited		
Location	**2012**	**2013**	**2014**
Mainstem Habitat	**86.7 %**	**85.6 %**	**92.1 %**
Side Channel Habitats	**84.4 %**	**74.8 %**	**88.8 %**
BC 49 side channel	83.8 %	76.1 %	90.5 %
BC Rail side channel	65.5 %*	61.2 %	87.1 %
Tenderfoot Creek	Not surveyed*	75.9 %	92.0 %
NVOS side channel complex	86.2 %	79.5 %	88.4 %

* egg deposition rate for all side channel habitats used

Table 8. Percentage of PIT tagged fish that kelted, total number of PIT tagged spawners in channel and portion of PIT tagged male and female spawners that kelted in the side channels from 2007 to 2014

NVOS	% Kelts	Total	PIT Tagged Kelts Males	PIT Tagged Kelts Females		BC Rail	% Kelts	Total	PIT Tagged Kelts Males	PIT Tagged Kelts Females
2007	31%*					**2007**	13%*			
2008	38%	82				**2008**	10%	41		
2009	53%	49	26	0		**2009**	16%	25	2	1
2010	11%	53	5	1		**2010**	14%	14	1	1
2011	22%	130	26	2		**2011**	13%	40	5	0
2012	20%	54	9	2		**2012**	17%	18	1	2
2013	14%	110	12	3		**2013**	4%	28	1	0
2014	16%	75	10	2		**2014**	10%	30	3	0
PIT Tagged Kelt Total (98)			88	10		**PIT Tagged Kelt Total (17)**			13	4
Average Kelts			25%			**Average Kelts**			12%	

*averaged from 2008-2011

Table 9. Resistivity fish counter efficiency based on video validation for the NVOS side channel complex and BC Rail side channel from 2007 to 2014

NVOS				BC Rail		
Year	**Up**	**Down**		**Year**	**Up**	**Down**
2007	96%	99%		**2007**	No video	
2008	72%	84%		**2008**	100%	95%
2009	85%*	74%*		**2009**	68%*	52%*
2010	71%	68%		**2010**	75%	78%
2011	68%	69%		**2011**	66%	78%
2012	49%**	75%**		**2012**	80%	71%
2013	74%	101%		**2013**	77%	77%
2014	High water			**2014**	87%*	104%*

*at normal flows
**large range in counter efficiency

Table 10. Pooled Petersen Estimates (PPE) of chum salmon spawner abundance for the Cheakamus River upstream of the RST site and for the full river, 2007-2014 with 95% confidence limits (CL)

	PPE	95% CL		PPE	95% CL	
Year	Upper River	Lower CL	Upper CL	Total River	Lower CL	Upper CL
2007	42,011	22,506	75,020	267,574	163,234	431,396
2008	24,059	20,206	28,639	117,780	86,066	160,776
2009	105,540	81,235	136,954	165,318	120,309	226,566
2010	12,827	10,002	16,434	85,461	51,453	139,344
2011	29,041	24,610	34,264	73,377	56,861	94,590
2012	138,485	112,254	170,765	327,804	234,250	457,195
2013	198,420	166,661	236,549	468,511	352,072	622,397
2014	52,202	44,998	60,554	no PPE available		

Table 11. Discharge (m^3/s) during peak chum spawning on the Cheakamus River (November 1st to November 15th) from 2007 to 2014

Date	2007	2008	2009	2010	2011	2012	2013	2014
01-Nov	20.4	31.1	49.1	57.9	23.3	54.9	17.8	171.0
02-Nov	18.6	67.4	23.0	49.3	17.6	42.3	18.6	104.0
03-Nov	18.7	92.1	19.0	33.2	16.7	79.9	16.7	50.0
04-Nov	24.1	28.9	20.1	30.1	16.0	80.9	15.9	136.0
05-Nov	20.7	25.5	31.2	48.5	15.9	70.9	16.0	62.9
06-Nov	19.0	25.2	43.0	96.5	16.5	32.4	16.5	163.0
07-Nov	19.4	24.6	32.2	101.0	16.8	21.2	21.5	227.0
08-Nov	19.3	70.5	27.5	74.7	16.3	17.9	18.0	101.0
09-Nov	38.9	118.0	44.9	44.8	16.5	16.6	15.1	68.3
10-Nov	46.7	91.7	34.2	28.9	21.4	17.3	15.3	45.4
11-Nov	35.2	33.8	28.6	27.4	22.3	17.3	15.4	30.8
12-Nov	71.5	56.1	22.2	26.2	19.7	16.9	18.7	28.1
13-Nov	39.8	67.2	29.3	25.2	17.0	16.5	20.3	26.8
14-Nov	28.6	36.6	71.2	24.3	16.1	16.1	16.5	25.9
15-Nov	38.1	26.0	50.3	25.1	16.4	16.1	16.6	24.9
Average	**30.6**	**53.0**	**35.1**	**46.2**	**17.9**	**34.5**	**17.3**	**84.3**
Minimum	**18.6**	**24.6**	**19.0**	**24.3**	**15.9**	**16.1**	**15.1**	**24.9**
Maximum	**71.5**	**118.0**	**71.2**	**101.0**	**23.3**	**80.9**	**21.5**	**227.0**
Median	**24.1**	**36.6**	**31.2**	**33.2**	**16.7**	**17.9**	**16.6**	**62.9**

Table 12. Estimates of the number of chum salmon spawner utilizing NVOS and BC Rail spawning channels, and Tenderfoot Creek, 2007-2014

	Year							
Location	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
BC Rail side channel	522	1,279	3,243	367	754	683	3,331	1,523
Tenderfoot Creek	1,555	3,309	3,003	293	713	5,419	7,643	1,329
NVOS side channel	2,170	3,263	9,357	2,048	2,915	8,859	13,213	6,169
Total Channels	4,247	7,851	15,603	2,708	4,382	14,961	24,187	9,021

Table 13. Number of juvenile chum caught, marked and recaptured at the rotary screw trap on the Cheakamus River from 2001-2015 and Bayesian Time-Stratified Population Analysis System population estimates with upper and lower confidence limits (CL), standard deviation (SD) and coefficient of variation (CV). Bold = post-WUP estimates

Coefficient of Variation > 0.3 = Poor precision.

Year	Total Caught	Total Marked	Total Recap	BTSPAS Estimate	95% CL		SD	CV
					Upper CL	Lower CL		
2001	122,044	43,520	3,557	1,685,668	1,798,406	1,595,828	52,172	0.03
2002	105,221	23,685	1,101	4,173,706	4,836,441	3,642,305	311,447	0.07
2003	50,143	11,537	181	4,501,682	6,620,388	3,335,970	898,827	0.20
2004	126,216	63,006	2,775	3,699,539	4,001,317	3,461,175	138,533	0.04
2005	174,469	62,312	4,425	4,101,706	5,073,701	3,548,635	654,281	0.16
2006	355,391	94,235	7,998	4,608,359	4,751,038	4,477,697	69,200	0.02
2007	**382,087**	**82,802**	**6,746**	**5,842,755**	**6,097,001**	**5,618,684**	**121,051**	**0.02**
2008	**81,115**	**35,469**	**1,878**	**3,806,330**	**5,014,920**	**3,261,866**	**497,455**	**0.13**
2009	**283,383**	**48,382**	**6,759**	**3,024,765**	**3,329,535**	**2,793,071**	**136,382**	**0.05**
2010	**366,185**	**94,647**	**10,102**	**7,264,443**	**7,825,972**	**6,735,949**	**280,858**	**0.04**
2011	**188,897**	**59,734**	**7,718**	**1,882,688**	**1,973,763**	**1,804,029**	**43,817**	**0.02**
2012	**186,073**	**42,369**	**4,350**	**2,760,670**	**2,913,866**	**2,619,252**	**74,013**	**0.03**
2013	**897,121**	**92,212**	**10,165**	**10,795,444**	**11,077,880**	**10,521,160**	**143,849**	**0.01**
2014	**402,910**	**88,537**	**10,301**	**4,207,889**	**4,303,532**	**4,115,233**	**48,069**	**0.01**
2015	**332,573**	**70,931**	**11,849**	**2,054,657**	**2,094,276**	**2,016,513**	**19,934**	**0.01**

Table 14. Chum Fry Production on the Cheakamus River upstream of the RST site 2008-2015

BTSPAS Estimate of Chum Fry Abundance					
Year	**All Chum Fry Above RST Site**	**Mainstem**	**Tenderfoot Creek**	**NVOS Side Channels**	**BC Rail Side Channels**
2008	**3,806,330**	2,684,494	not assessed 2008-2012	965,096	156,740
2009	**3,024,766**	1,709,022		924,726	391,018
2010	**7,264,444**	5,008,836		1,986,853	268,755
2011	**1,882,689**	1,301,759		557,908	23,022
2012	**2,760,670**	1,994,304		668,231	98,135
2013	**10,795,444**	5,053,570*	2,854,058	2,428,254	459,562
2014	**4,207,889**	529,632*	1,787,587	1,662,267	228,403
2015	**2,054,657**	164,961	poor estimate	1,240,328	649,368

* Tenderfoot Creek estimate removed
(all other Mainstem estimates include Tenderfoot Creek)

Table 15. Summary of mean chum fry lengths (mm) 2001-2015 from the Cheakamus River. Bold = post-WUP

Year	N	Mean Length (mm)	Range
2001	352	40	31-50
2002	414	39	30-53
2003	276	41	33-55
2004	223	39	32-50
2005	200	39	31-55
2006	224	39	30-54
2007	**425**	**38**	**30-54**
2008	**459**	**39**	**31-49**
2009	**400**	**39**	**34-57**
2010	**400**	**38**	**31-48**
2011	**465**	**39**	**35-45**
2012	**405**	**37**	**30-41**
2013	**448**	**38**	**27-42**
2014	**373**	**38**	**31-49**
2015	**527**	**39**	**28-50**

Table 16. Egg-to-fry survival by habitat area for outmigration years 2013-2015 (with and without accounting for site specific egg deposition rates from pre-spawn mortality (PSM) surveys)

Location	Egg to Fry Survival			Egg to Fry Survival - without PSM		
	2013	2014	2015	2013	2014	2015
All area above RST				5.7%	1.6%	3.1%
Mainstem above RST	3.6%	0.3%	0.3%	3.1%	0.2%	0.3%
NVOS Side Channel	23.1%	11.8%	17.9%	19.9%	9.4%	15.9%
BC Rail Side Channel	58.0%	8.3%	37.5%	49.0%	5.1%	33.6%
Tenderfoot Creek Natural Spawners	53.9%	27.0%		45.5%	20.5%	

Table 17. Annual incubation temperatures in redds compared to river temperatures (2007-2013)

	Julian Day			Average Daily Temperature in Redds (ºC)		Average Daily Temperature in River (ºC) (RST Logger)
Spawner Year	Peak Chum Spawning	Peak Fry Outmigration	Days of Incubation	850 ATU	900 ATU	
2007	313	104	156	5.4	5.8	4.2*
2008	312	93	146	5.8	6.2	3.6**
2009	310	91	146	5.8	6.2	4.5
2010	305	90	150	5.7	6.0	3.9
2011	313	98	150	5.7	6.0	3.8
2012	303	94	156	5.4	5.8	4.6
2013	313	103	155	5.5	5.8	4.1
Average	**310**	**96**	**151**	**5.6**	**6.0**	**4.1**

* missing 3 weeks of temperature data in December 2007

** missing one week of temperature data in March 2009

7.0 FIGURES

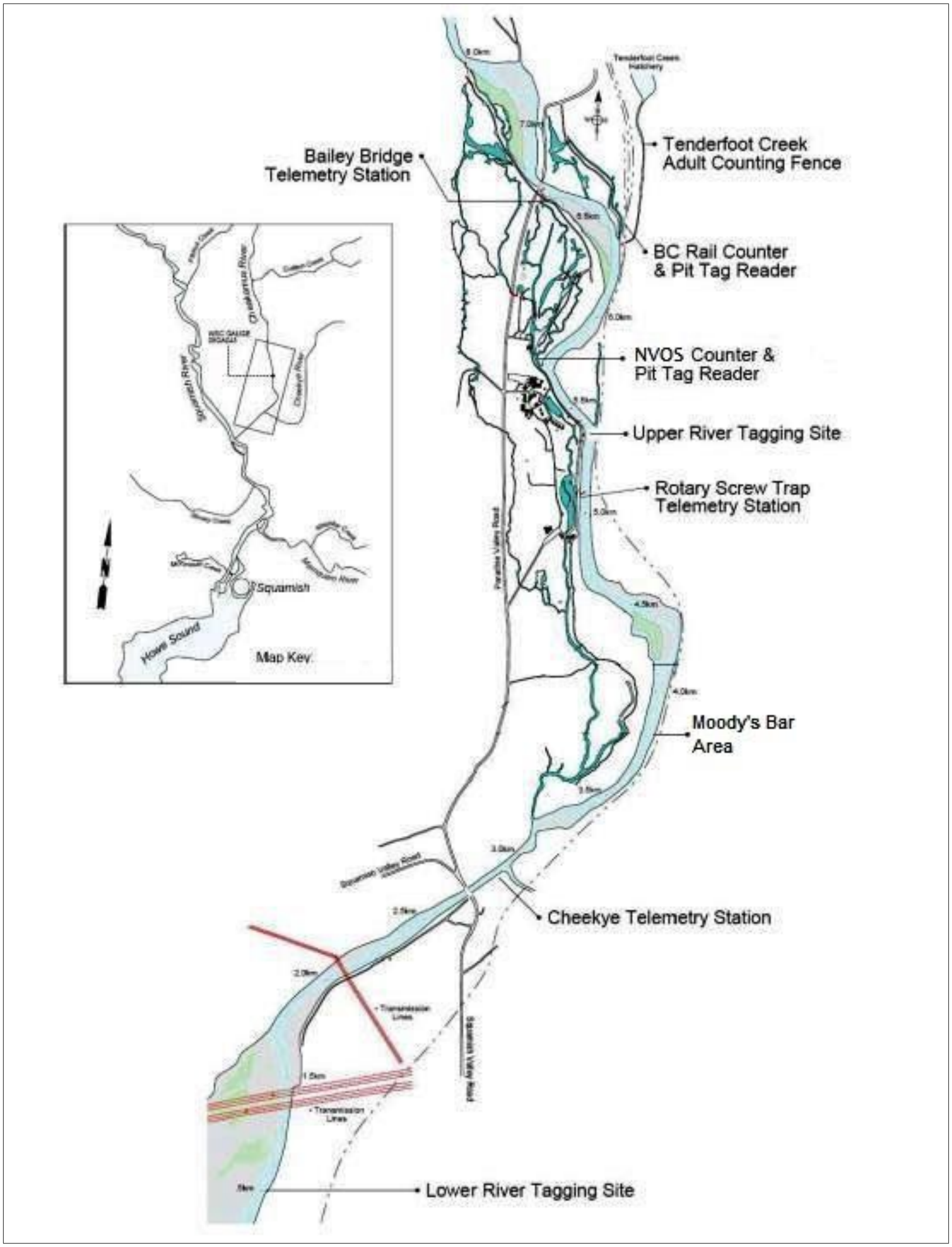

Figure 1: Study area for Cheakamus River chum salmon escapement monitoring (River KM 0.5-8.0)

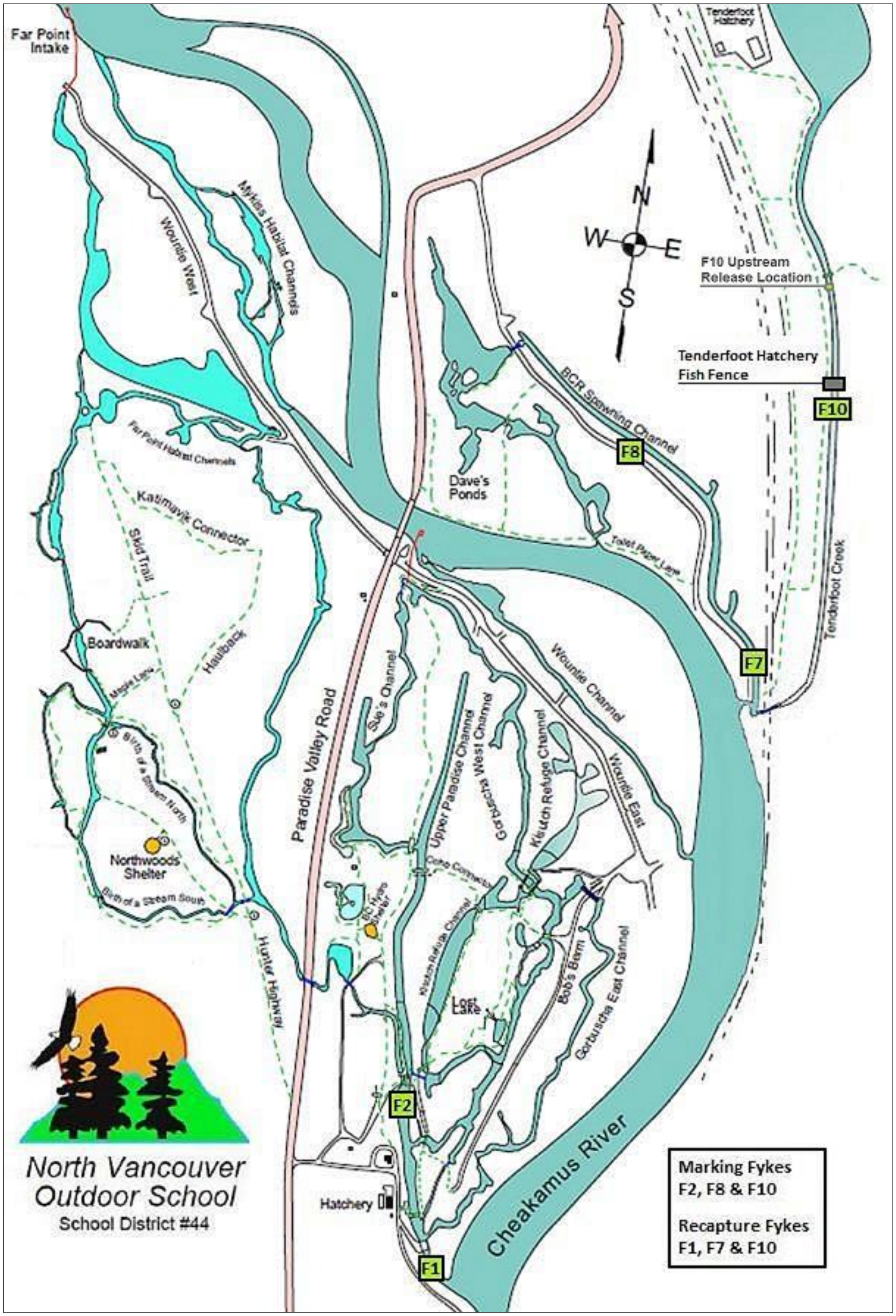

Figure 2. Site map showing the marking and recapture fyke net trap locations and the network of side channels upstream of the RST site (Figure 1)

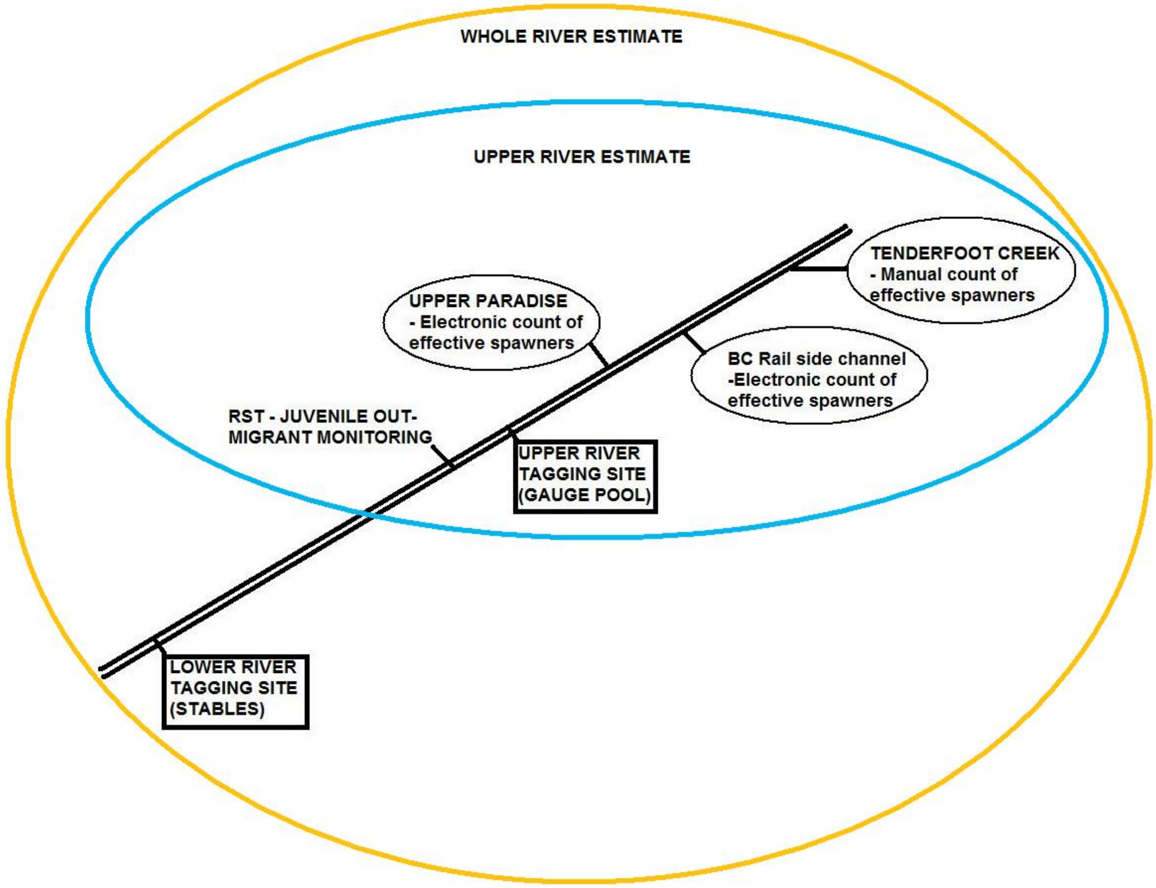

Figure 3. Conceptual diagram of the Cheakamus River chum salmon spawner enumeration monitor illustrating the spatial relationship of tagging and monitoring locations. Whole river (yellow ellipse), Upper river (blue ellipse), and individual side channel (black ellipses) spawner estimates are highlighted

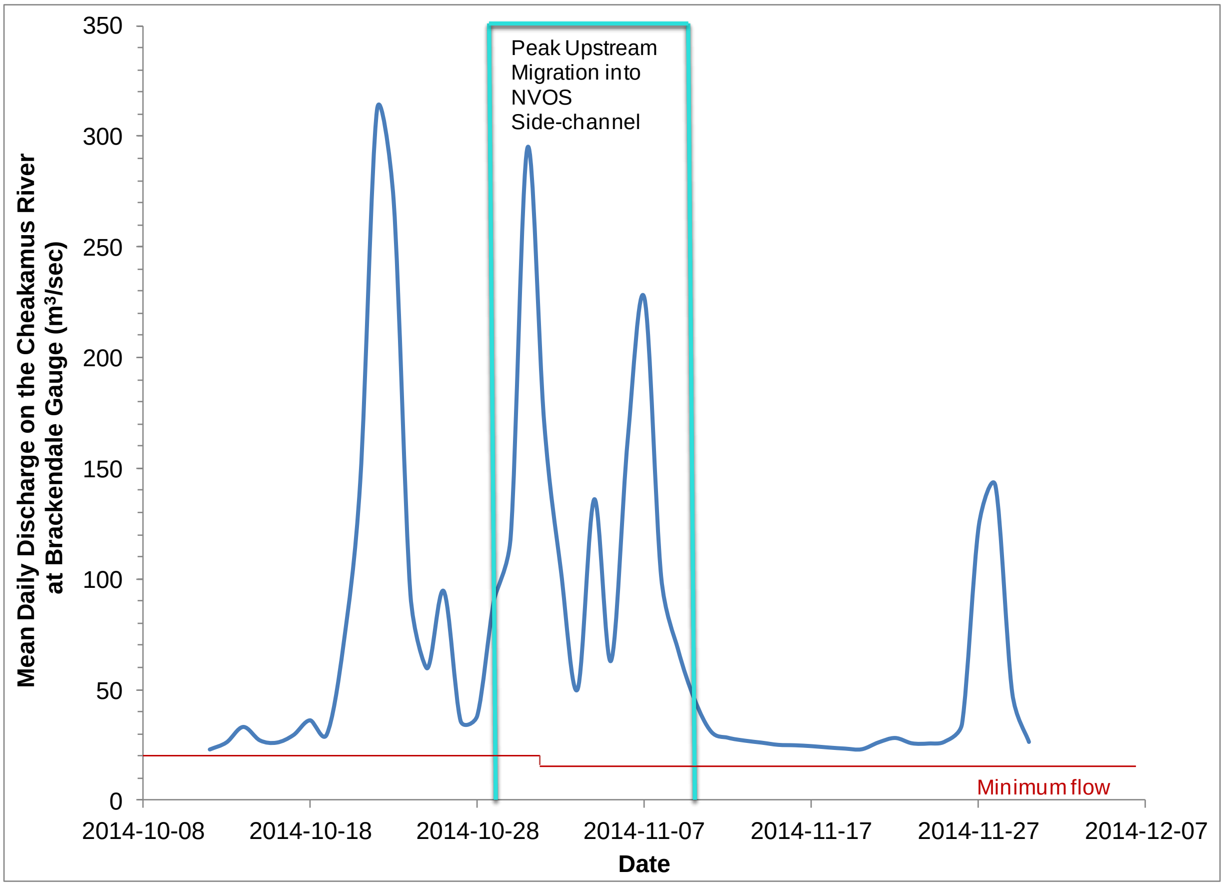

Figure 4. Mean daily discharge from the Water Survey of Canada Brackendale Gauge (08GA043) throughout the chum spawning season on the Cheakamus River in 2014

Figure 5. Downstream photo of the NVOS counter site showing the new middle channel made up of two directional antennas (one upstream and one downstream) and a resistivity counter pad

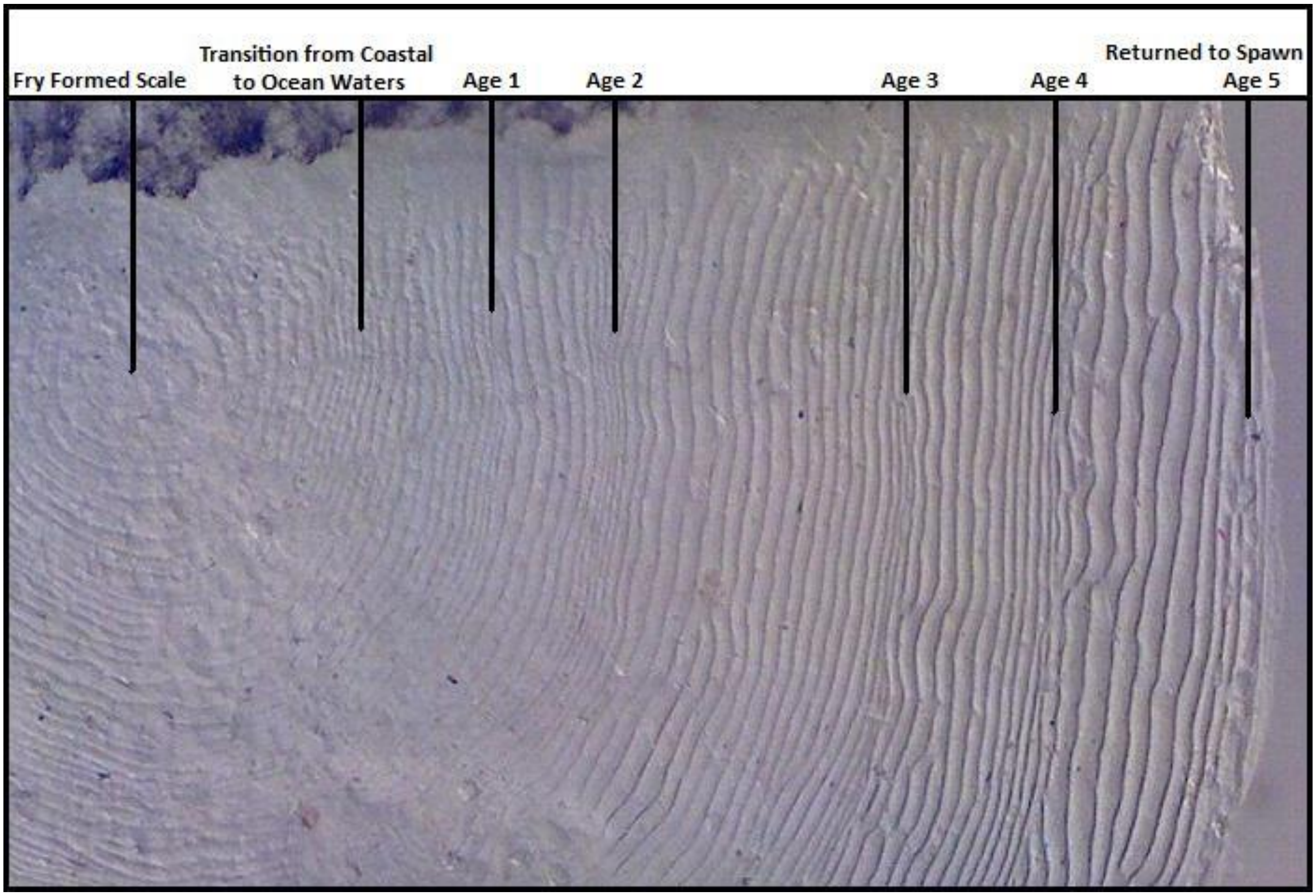

Figure 6. Magnified chum scale (200x) showing periods of slowed growth during the transition from coastal to ocean waters and winter periods at age 1,2,3,4, and returning to spawn at age 5

Figure 7. An example of what 500 eggs looks like for differentiating between the pre-spawn mortality classifications of spawned-out (zero to 500 loose eggs) and partially spawned (over 500 loose eggs) female chum

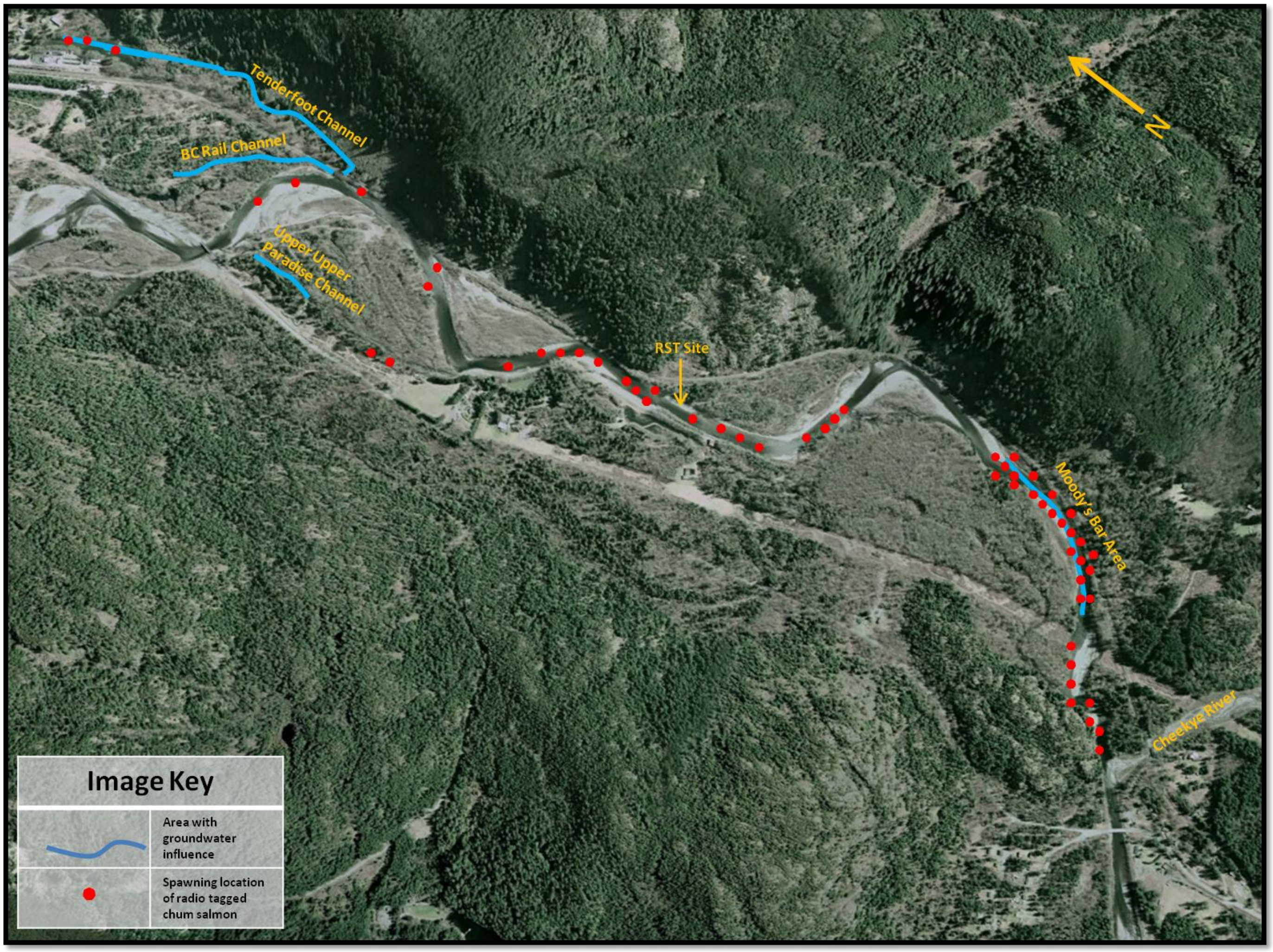

Figure 8. Spawning locations of radio tagged chum salmon in 2013 and areas with groundwater influence

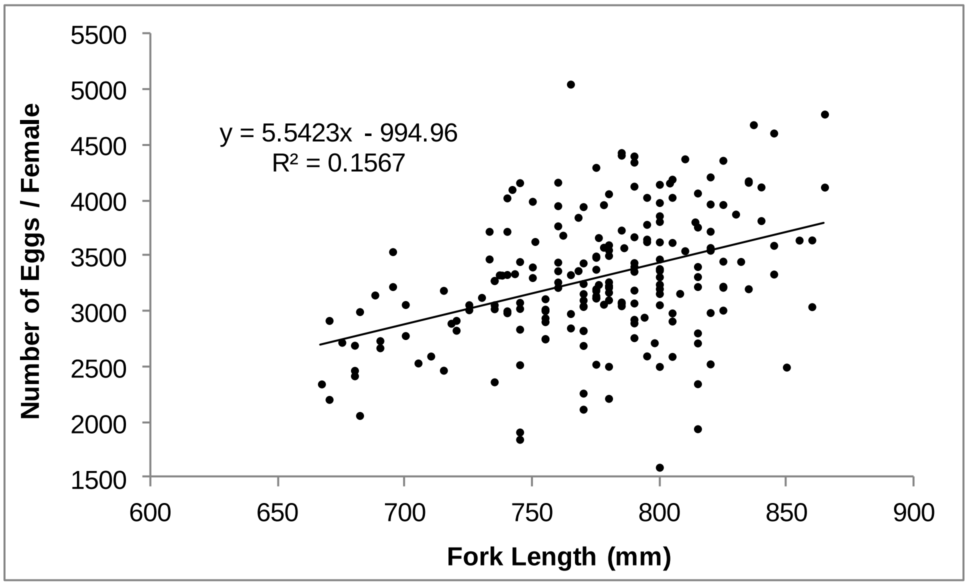

Figure 9. Annual fecundity (number of eggs/female) vs. fork length (mm); female chum salmon from Tenderfoot Creek, 2014

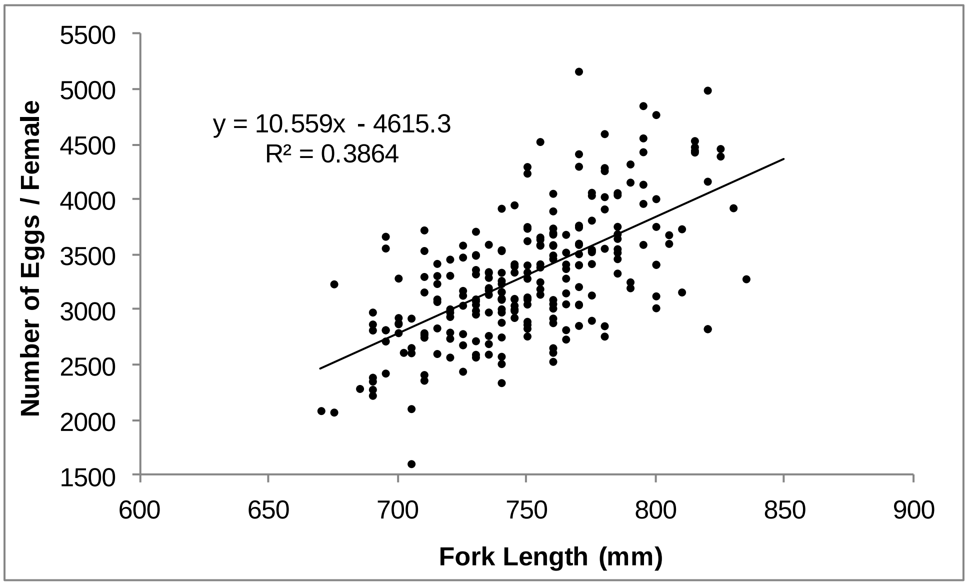

Figure 10. Annual fecundity (number of eggs/female) vs. fork length (mm); female chum salmon from Tenderfoot Creek, 2013

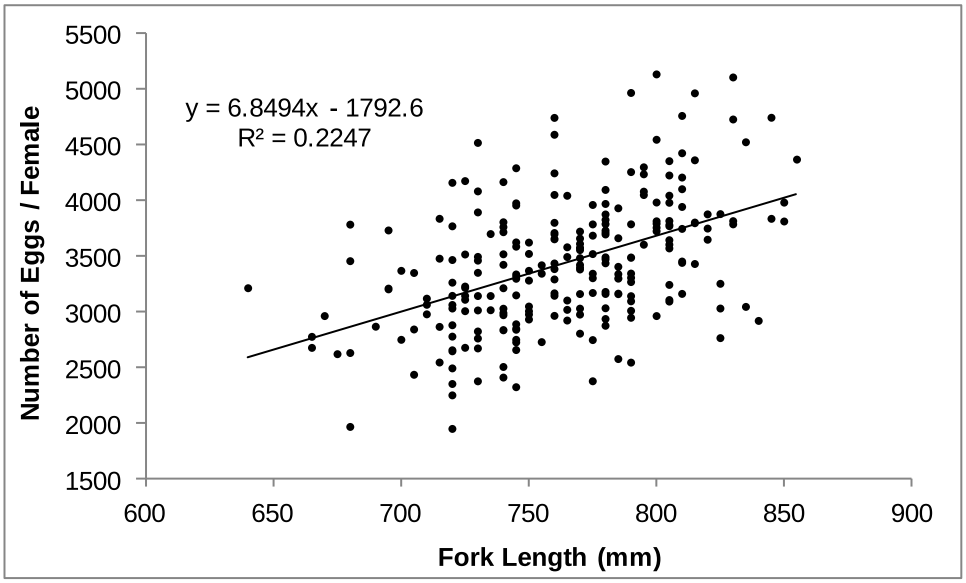

Figure 11. Annual fecundity (number of eggs/female) vs. fork length (mm); female chum salmon from Tenderfoot Creek, 2012

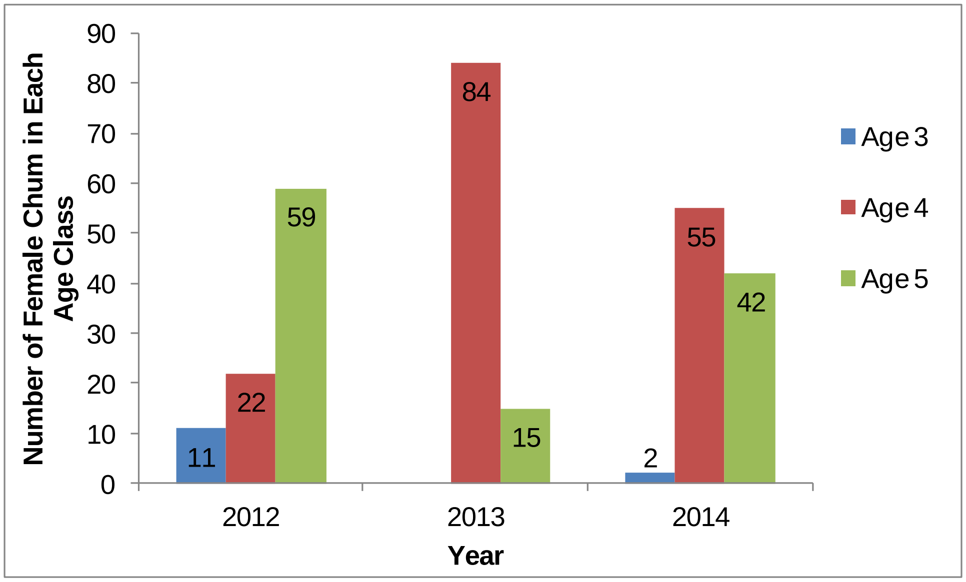

Figure 12. Annual age distribution of female chum spawners caught at the Tenderfoot Creek trap 2012-2014

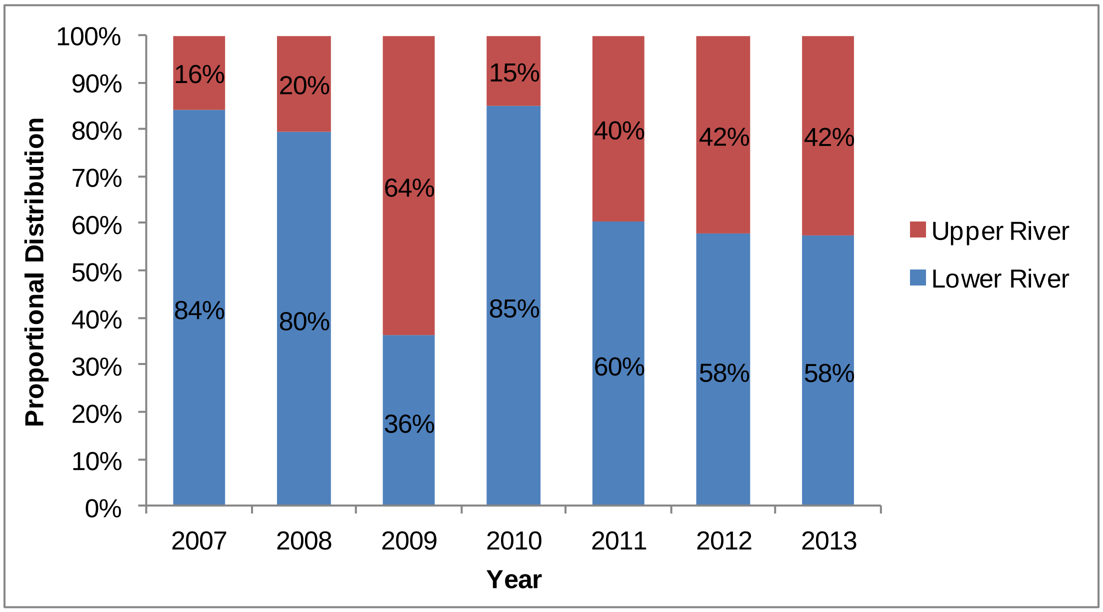

Figure 13. Distribution of chum spawners in the upper and lower river habitat areas from 2007 to 2013

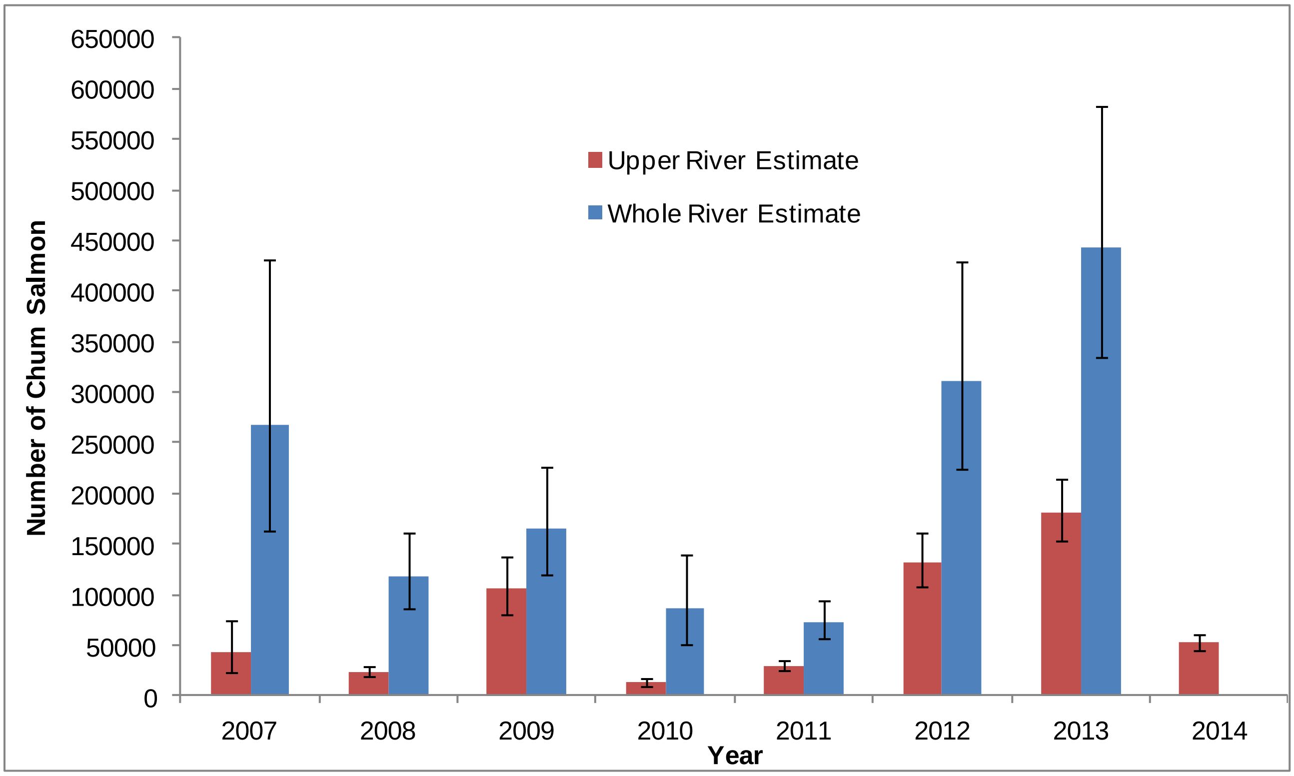

Figure 14. Pooled Petersen Estimate of chum spawner escapement in the upper portion of the Cheakamus River and whole river estimate with 95% confidence limits from 2007-2014

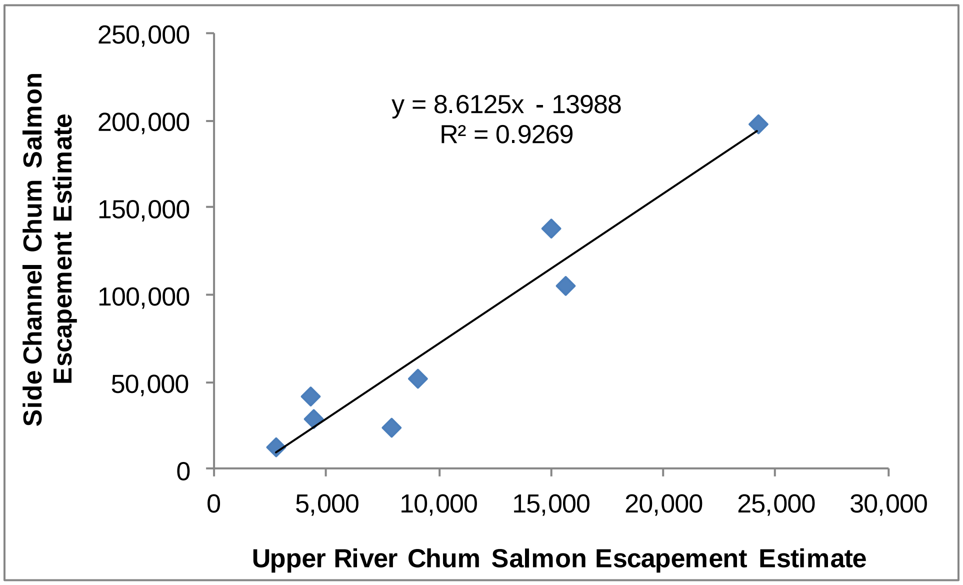

Figure 15. The relationship between the number of side channel chum salmon spawners and the number of upper river chum salmon spawners, showing data from 2007-2014

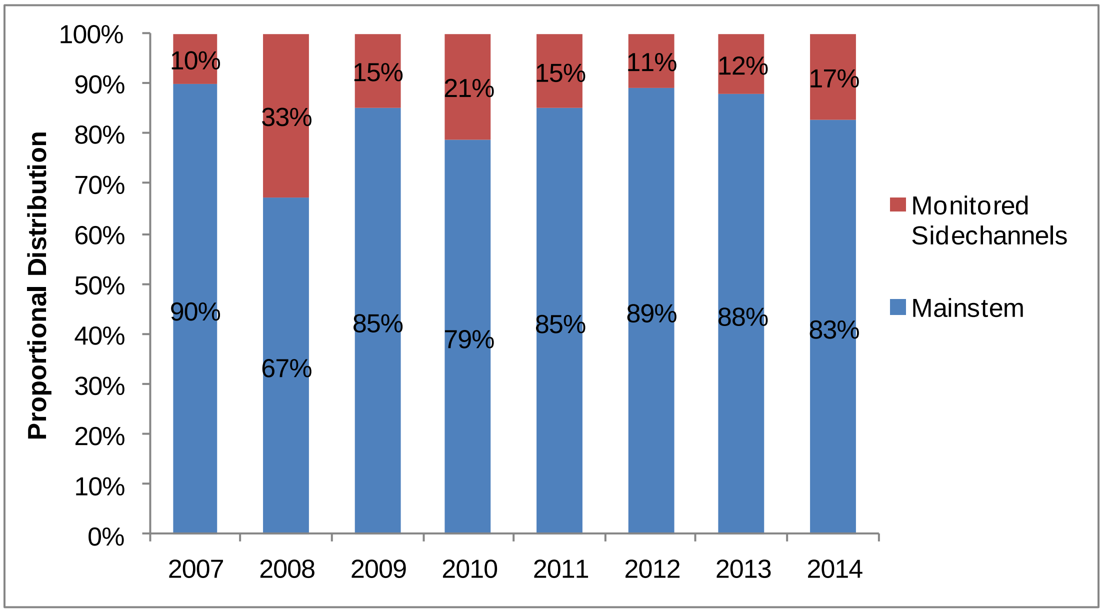

Figure 16. The proportion of upper river chum spawners utilizing monitored side channel habitats and those utilizing the mainstem and unmonitored side channel habitats from 2007 to 2014

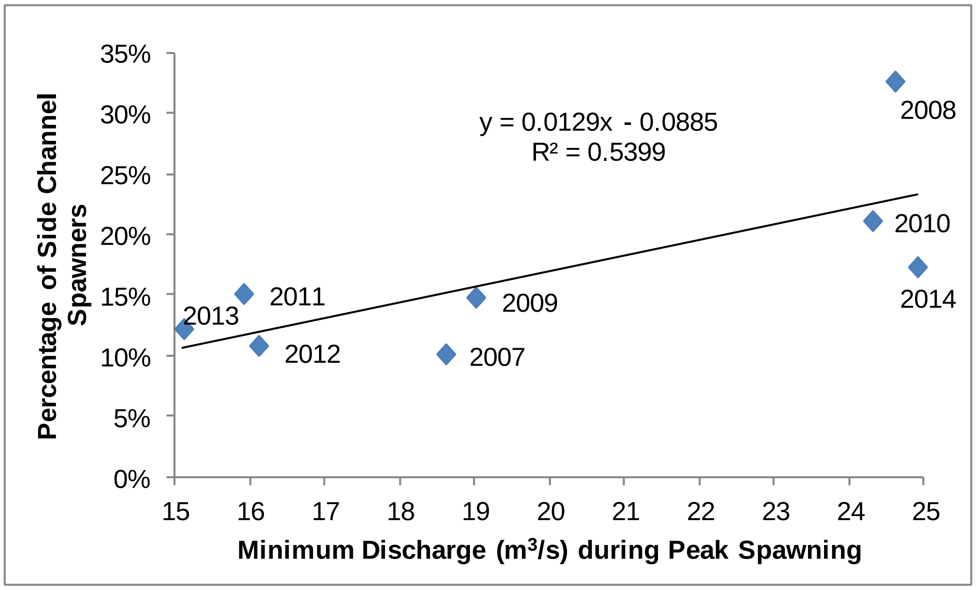

Figure 17. The relationship between the percentage of side channel spawners and the minimum discharge during peak spawning, showing data from 2007-2014

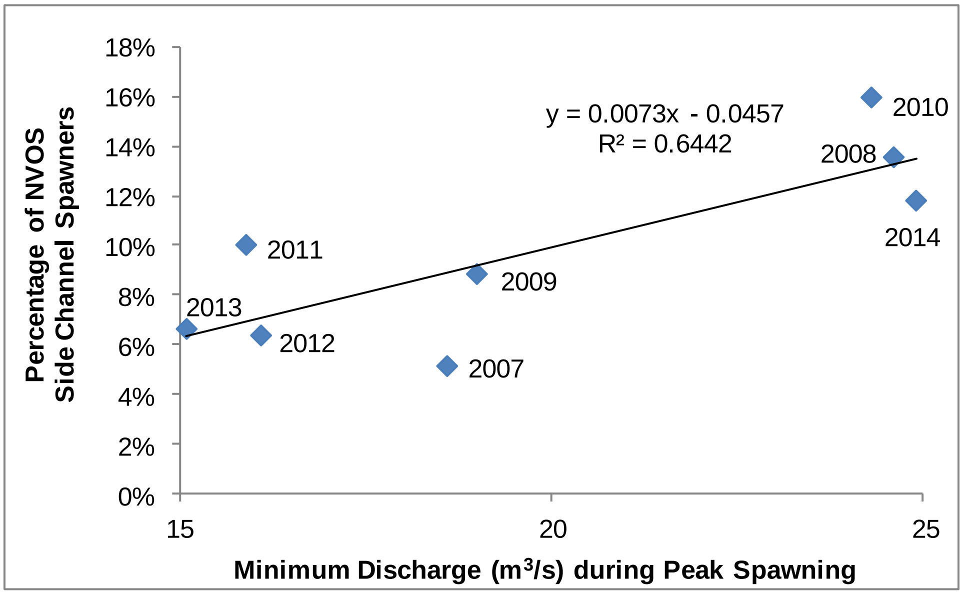

Figure 18. The relationship between the percentage of NVOS side channel spawners and the minimum discharge during peak spawning, showing data from 2007-2014

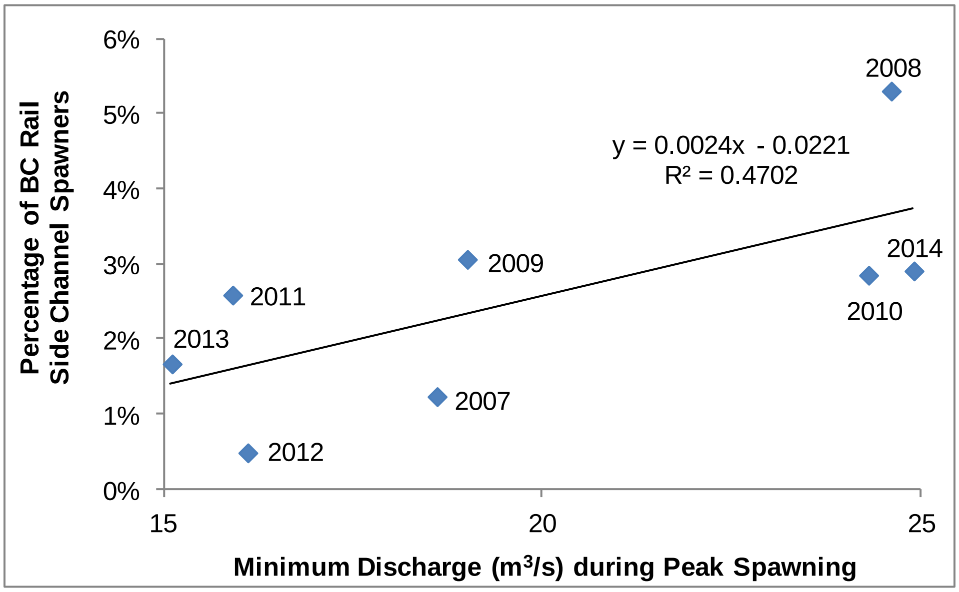

Figure 19. The relationship between the percentage of BC Rail side channel spawners and the minimum discharge during peak spawning, showing data from 2007-2014

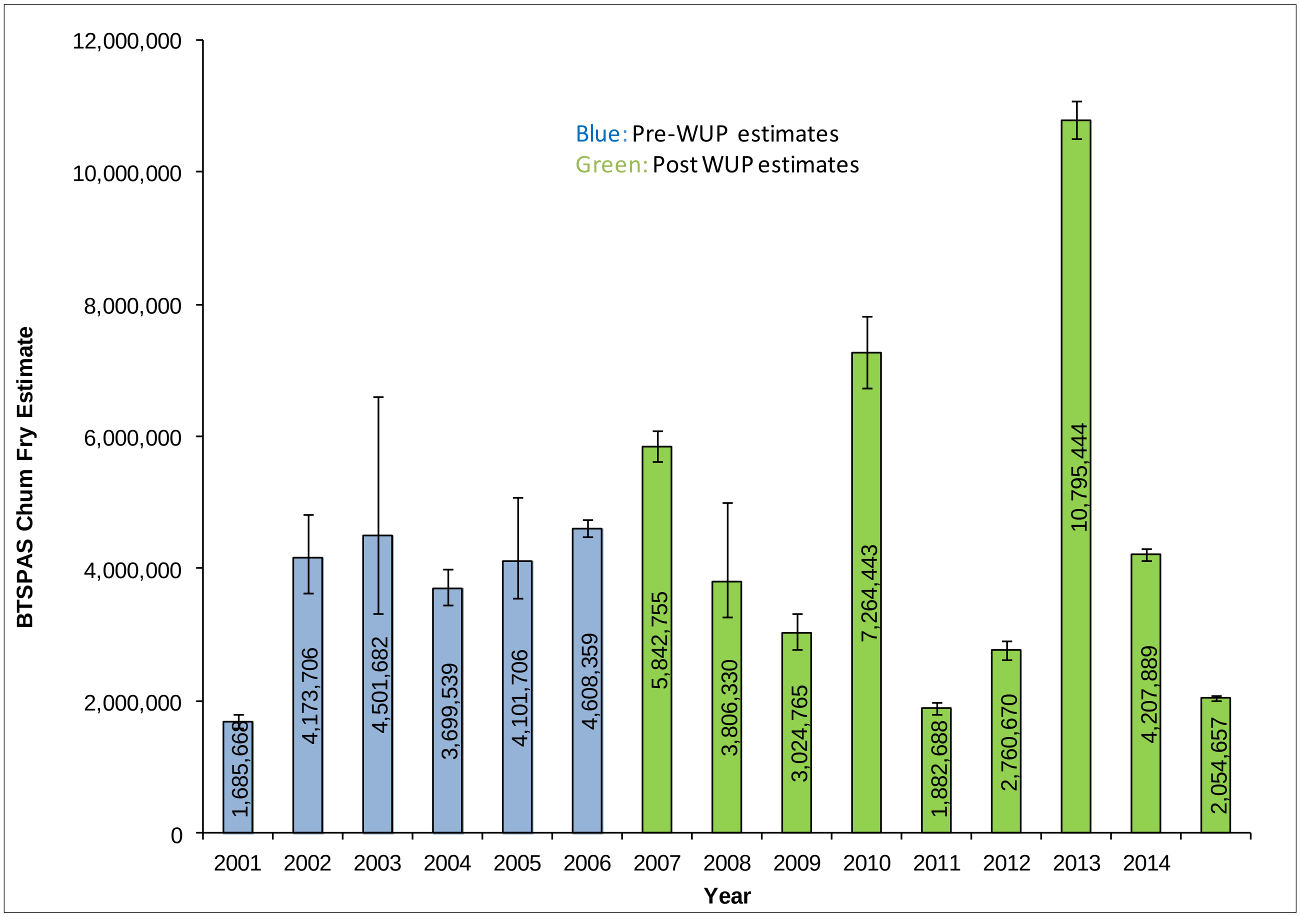

Figure 20. Bayesian Time-Stratified Population Analysis System (BTSPAS) Estimate of chum fry outmigrating from upstream of the Rotary Screw Traps on the Cheakamus River from 2001-2015 including 95% confidence limits

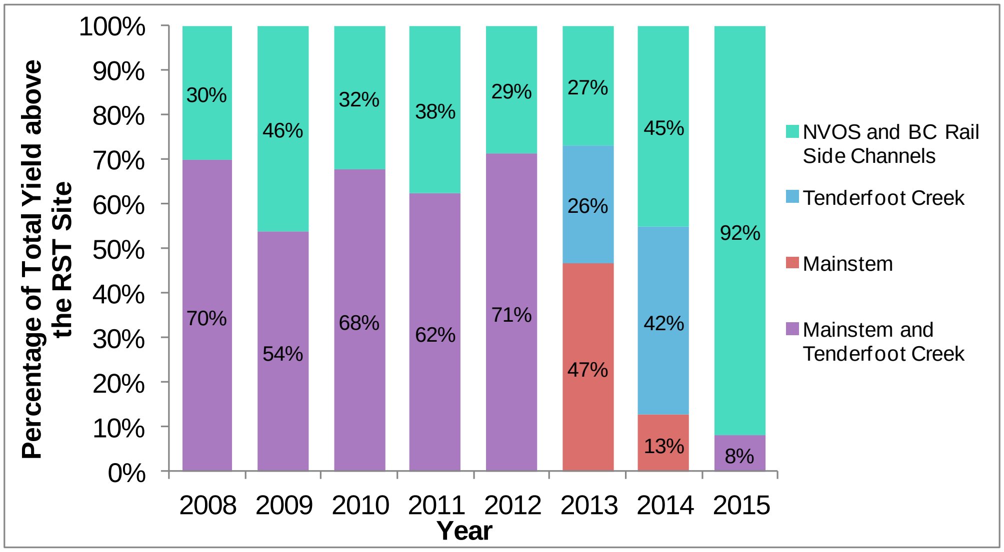

Figure 21. Yield of chum fry from the mainstem habitat, NVOS and BC Rail side channels and Tenderfoot Creek (2013 and 2014) in the Cheakamus River 2008-2015

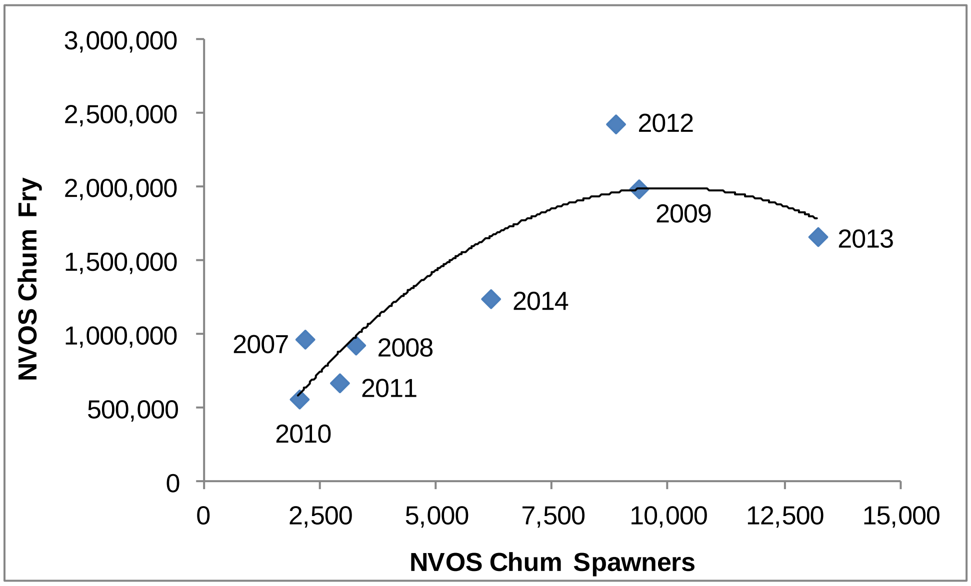

Figure 22. The spawner-recruit curve for the NVOS side channel complex; years indicating brood year 2007-2014

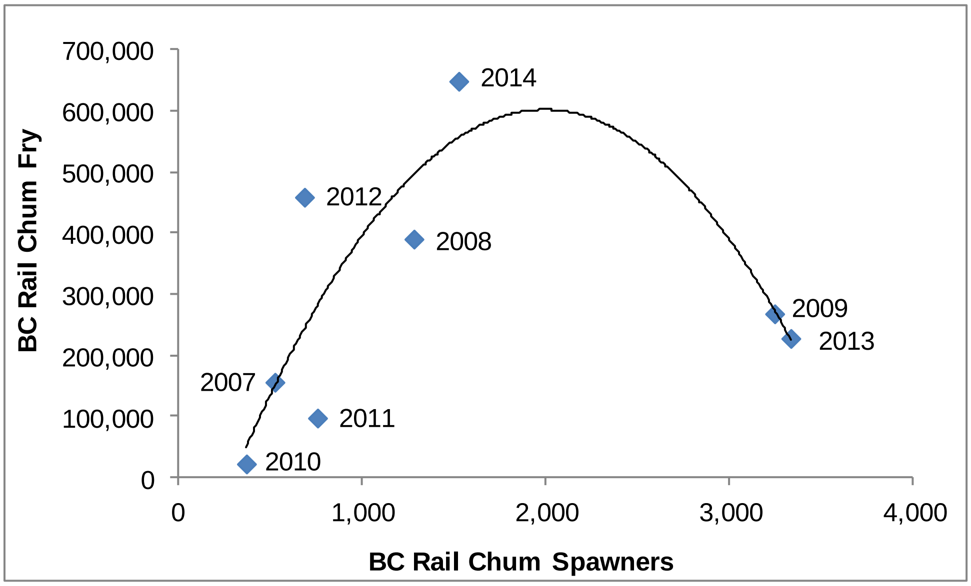

Figure 23. The spawner-recruit curve for the BC rail side channel; years indicating brood year 2007-2014

8.0 REFERENCES

Banks, J.W. 1969. A review of the literature on the upstream migration of adult salmonids. J. Fish Biol. 1:85-136.

Baxter, C. and F.R. Hauser. Measuring groundwater-stream water exchange: new techniques for installing minipiezometers and estimating hydraulic conductivity. T. Am. Fish. Soc. 132:493-502.

BC Hydro. 2005. Cheakamus Project Water Use Plan. Revised for Acceptance by the Comptroller of Water Rights. October 1, 2005. 38pp.

BC Hydro. 2007. Cheakamus Project Water Use Plan. Monitoring Program Terms of Reference. Cheakamus River chum salmon escapement monitoring and mainstem spawning groundwater survey. February 22, 2007. 15 pp.

Beacham, T.D. and C.B. Murray. 1986. Comparative developmental biology of chum salmon (*Oncorhynchus keta*) from the Fraser River, British Columbia. Can. J. Fish. Aquat. Sci. 43:252-262.

Beacham, T.D. and C.B. Murray. 1987. Adaptive variation in body size, age, morphology, egg size and developmental biology of chum salmon (*Oncorhynchus keta*) in British Columbia. Can. J. Fish. Aquat. Sci. 44:244-261.

Beacham, T.D., and P. Starr. 1982. Population biology of chum salmon (*Oncorhynchus keta*) from the Fraser River, British Columbia. Fishery Bulletin. 80: 813-825.

Bonner, S. J. (2008). Heterogeneity in capture-recapture: Bayesian methods to balance realism and model complexity. PhD thesis, Simon Fraser University, Burnaby, BC, Canada.

Bonner, S. J. and Schwarz, C. J. (2011). Smoothed estimates for time-stratified mark-recapture experiments using Bayesian p-splines. Biometrics 67, 1498-1507.

Bradford, M. J. 1995. Comparative review of Pacific salmon survival rates. Can. J. Fish. Aquat. Sci. 52:1327–1338.

Bradford, M.J., J. Korman and P.S. Higgins. 2005. Using confidence intervals to estimate the response of salmon populations (*Oncorhynchus spp.*) to experimental habitat alterations. Can. J. Fish. Aquat. Sci. 62:2716-2726.

Fell, C., D.J.F. McCubbing, L.J. Wilson, and C.C. Melville. 2013. Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Groundwater Survey 2001-2013. Cheakamus River Monitoring Program #1B. Technical report for BC Hydro – Coastal Generation.44 p. + Appendices.

Hunter J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. J. Fish. Res. Board Can. 16:835-886.

Jonsson, N. 1991. Influence of water flow, water temperature and light on fish migration in rivers. Nord. J. Freshw. Res. 66:20-35.

Kolski, K.V. 1975. The survival and fitness of two stocks of chum salmon (*Oncorhynchus keta*) from egg deposition to emergence in a controlled-stream environment at Big Beef Creek. Ph.D. thesis. University of Washington, Seattle, WA. 212 pp.

Kaev, A.M. 2000. Recent reductions in chum salmon (*Oncorhynchus keta*) growth and its consequences for reproduction. North Pacific Anadromous Fish Commission Bulletin No. 2. p. 247-254.

Korman, J., R.N.M. Arhens, P.S. Higgins, and C.J. Walters. 2002. Effects of observer efficiency, arrival timing, and survey life on estimates of escapement for steelhead trout (*Oncorhynchus mykiss*) derived from repeat mark-recapture experiments. Can. J. Fish. Aquat. Sci. 59: 1116-1131.

Lingard, S., C.C. Melville and D.J.F. McCubbing. 2014. Assessment of the 2014 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. In Progress.

Marmorek, D.R. and I. Parnell. 2002. Cheakamus River water use plan: report of the consultative committee. B.C. Hydro. Burnaby, B.C. 235p.

McCubbing, D.J.F., L.J. Wilson, C. Fell and C.C Melville. 2012. Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey 5 Year Program Review 2007-2011. Cheakamus River Monitoring Program #1b. Technical report for BC Hydro – Coastal Generation. 69p.

McCubbing D.J.F., L.J Wilson and C.C. Melville. 2011. Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey 2010. Report to BC Hydro. 58p.

Melville, C.C. and D. McCubbing. 2000. Chinook spawning migration in the Cheakamus River, based on radio tracking observations in the summer of 1999. BC Hydro contract report. 36p.

Melville C.C. and D.J.F. McCubbing. 2001. Assessment of the 2000 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 42p.

Melville C.C. and D.J.F. McCubbing. 2002a. Assessment of the 2001 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 53p.

Melville C.C. and D.J.F. McCubbing. 2002b. Assessment of the 2002 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 36p.

Melville C.C. and D.J.F. McCubbing. 2003. Assessment of the 2003 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report.

Melville C.C. and D.J.F. McCubbing. 2005. Assessment of the 2004 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 80p.

Melville C.C. and D.J.F. McCubbing. 2006. Assessment of the 2005 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 76p.

Melville C.C. and D.J.F. McCubbing. 2007. Assessment of the 2006 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 71p.

Melville C.C. and D.J.F. McCubbing. 2008. Assessment of the 2007 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 104p.

Melville C.C. and D.J.F. McCubbing. 2009. Assessment of the 2008 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 103p.

Melville C.C. and D.J.F. McCubbing. 2010. Assessment of the 2009 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 103p.

Melville C.C. and D.J.F. McCubbing. 2011a. Assessment of the 2010 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 111p.

Melville C.C. and D.J.F. McCubbing. 2011b. Assessment of the 2011 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report. 95p.

Melville C.C. and D.J.F. McCubbing 2012. Juvenile Salmonid Outmigration Enumeration Assessment Summary Report 2001-2012. BC Hydro WUP Report. 92p.

Melville C.C. and D.J.F. McCubbing. 2013. Assessment of the 2013 Juvenile Salmon Migration from the Cheakamus River, using Rotary Traps. BC Hydro WUP Report.

Parker, R.R. 1962. A concept of the dynamics of pink salmon populations, p. 203-211. In Wilimovsky, N.J. (ed.), Symposium on pink salmon. H.R. MacMillan Lectures in Fisheries. UBC, Vancouver.

Parnell I.J., D.R. Marmorek, B. Lister and J. Korman. 2003. Cheakamus Water Use Plan: Quantitative evaluation of the statistical and cost performance of alternative salmonid monitoring design options. Final report prepared by ESSA Technologies Ltd., Vancouver, BC. for BC Hydro, Burnaby, BC. 81p.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Brd. Can. 191: 382p.

Salo, E.O. 1991. Life history of chum salmon. In C. Groot and L. Margolis, Pacific salmon life histories (pp. 231-309).Vancouver, BC: UBC Press.

Seo, H., S. Kim, K. Seong and S. Kang. 2006. Variability in scale growth rates of chum salmon (*Oncorhynchus keta*) in relation to climate change in the late 1980s. Prog. Oceanogr. 68: 205-216.

Schroder, S.L. 1981. The role of sexual selection in determining overall mate choice in chum salmon. Ph.D. thesis. University of Washington, Seattle, WA. 274 pp.

Schroder, S. and J. Ames. 2004. Summer Chum Salmon Conservation Initiative: An Implementation Plan To Recover Summer Chum Salmon in the Hood Canal and Strait of Juan de Fuca Region. Supplemental Report No. 6. Protocols for Summer Chum Salmon Supplementation Recovery Projects. Washington Department of Fish and Wildlife. Olympia, Washington. 39p.

Schwarz, C.J. and C.G. Taylor. 1998. Use of the stratified Peterson estimator in fisheries management: estimating the number of pink salmon (*Oncorhynchus gorbuscha*) spawners in the Fraser River. Can. J. Fish. Aquat. Sci. 55:281-296.

Schwarz, C.J., D. Pickard, K. Marine and S.J. Bonner. 2009. Juvenile Salmonid Outmigrant Monitoring Evaluation, Phase II, Version 1 – May 2009. Draft report prepared for the Trinity River Restoration Program, Weaverville, CA.

Tetzlaff, D., c. Soulsby, A.F. Youndson, C. Gibbins, P.J. Bacon, I.A. Malcolm and S. Langan. 2005. Variability in stream discharge and temperature: a preliminary assessment of the implications for juvenile and spawning Atlantic salmon. Hydrol. Earth Syst. Sci. 9:193-208.

Troffe, P.M. and D. McCubbing. 2008 Cheakamus River Water Use Plan Monitoring Program: 2007 Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey. Report to BC Hydro. 46p.

Troffe, P.M., D. McCubbing and C.M. Melville. 2009 Cheakamus River Water Use Plan Monitoring Program: 2008 Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey. Report to BC Hydro. 46p.

Troffe, P.M., D. McCubbing and C.M. Melville. 2010. Cheakamus River Water Use Plan Monitoring Program: 2009 Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey. Report to BC Hydro. 58p.

Volobuev. V.V. 2000. Long-term changes in the biological parameters of chum salmon of the Okhotsk Sea. N. Pac. Anadr. Fish Comm. Bull. No. 2:175-180.

Weatherley, A.H. and H.S. Gill. 1995. Growth. In C. Groot, W.C. Clarke and L. Margolis, Physiological Ecology of Pacific Salmon (pp 102-158). Vancouver, BC:UBC Press.

Salo, E.O. 1991. Life history of chum salmon. In C. Groot and L. Margolis, Pacific salmon life histories (pp. 231-309).Vancouver, BC: UBC Press.

Wild Fish Conservancy. 2008. Coho prespawning mortality assessment in Washington and Oregon. EPA Assistance ID: X5-96007 101-0. Final Report. 29p

APPENDIX A. Supplemental Data

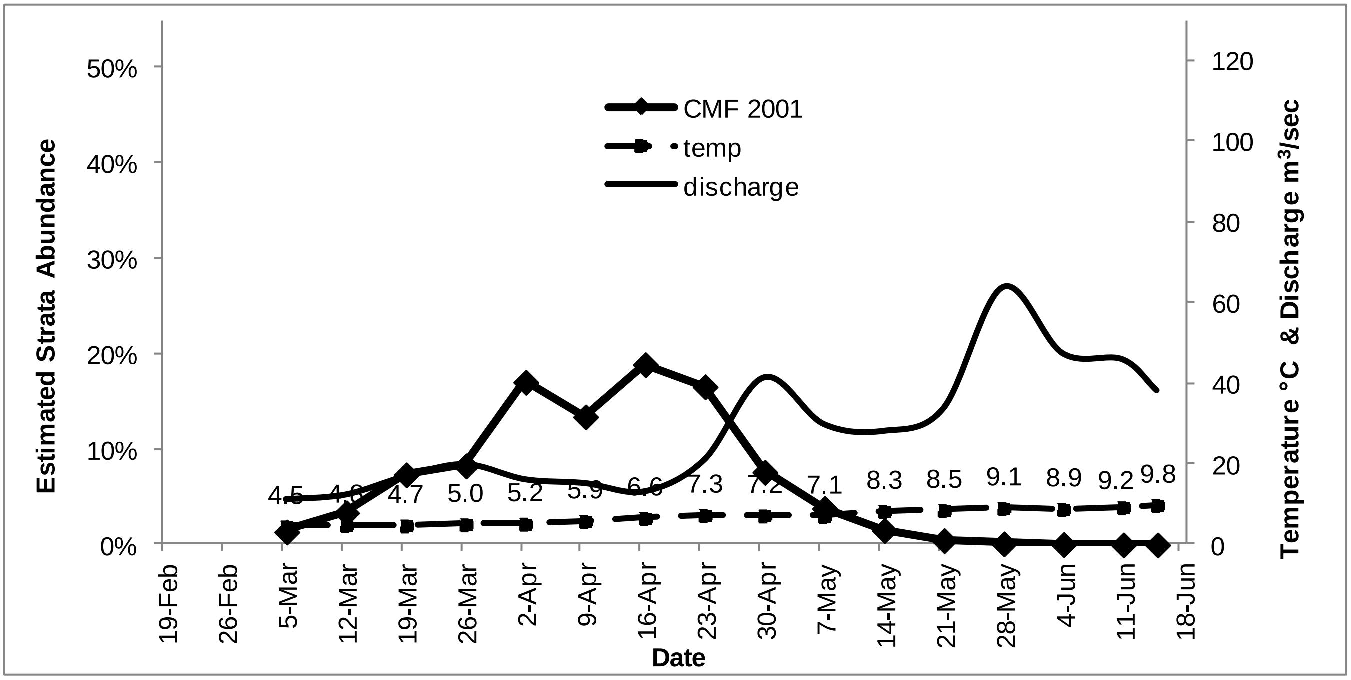

Figure 1A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2001 (Pre-WUP)

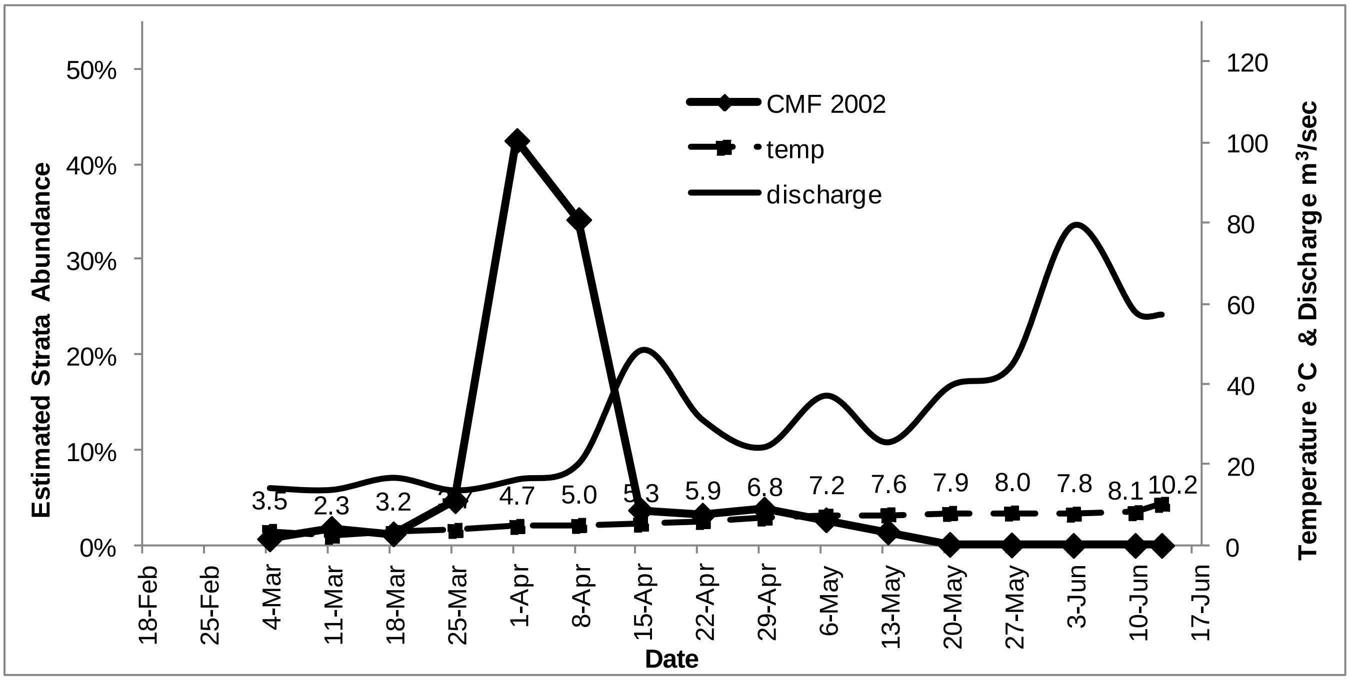

Figure 2A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2002 (Pre-WUP)

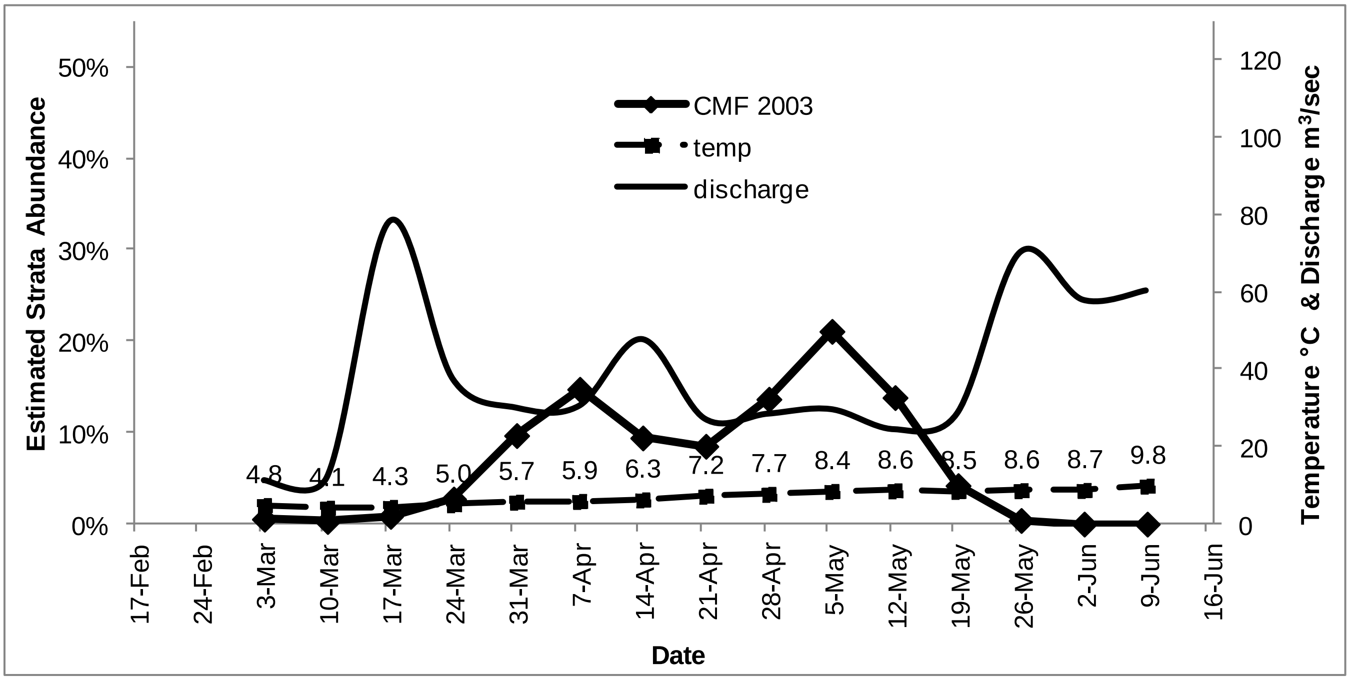

Figure 3A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2003 (Pre-WUP)

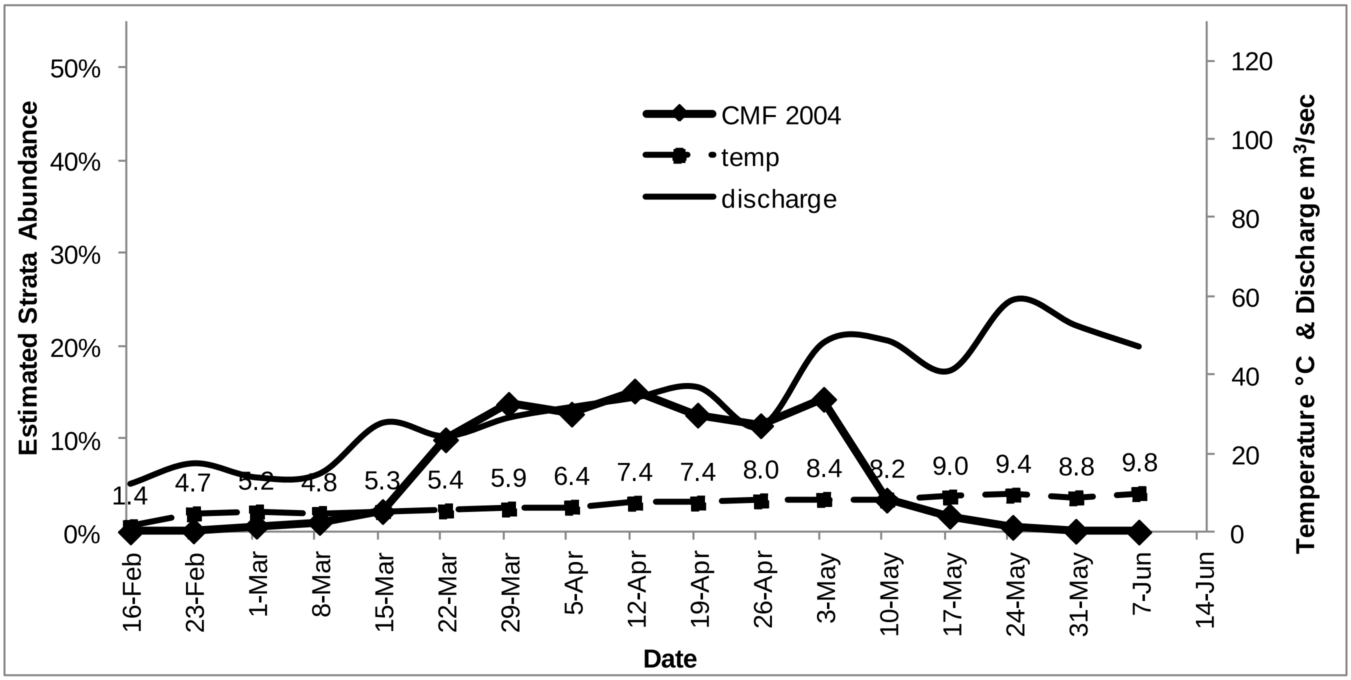

Figure 4A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2004 (Pre-WUP)

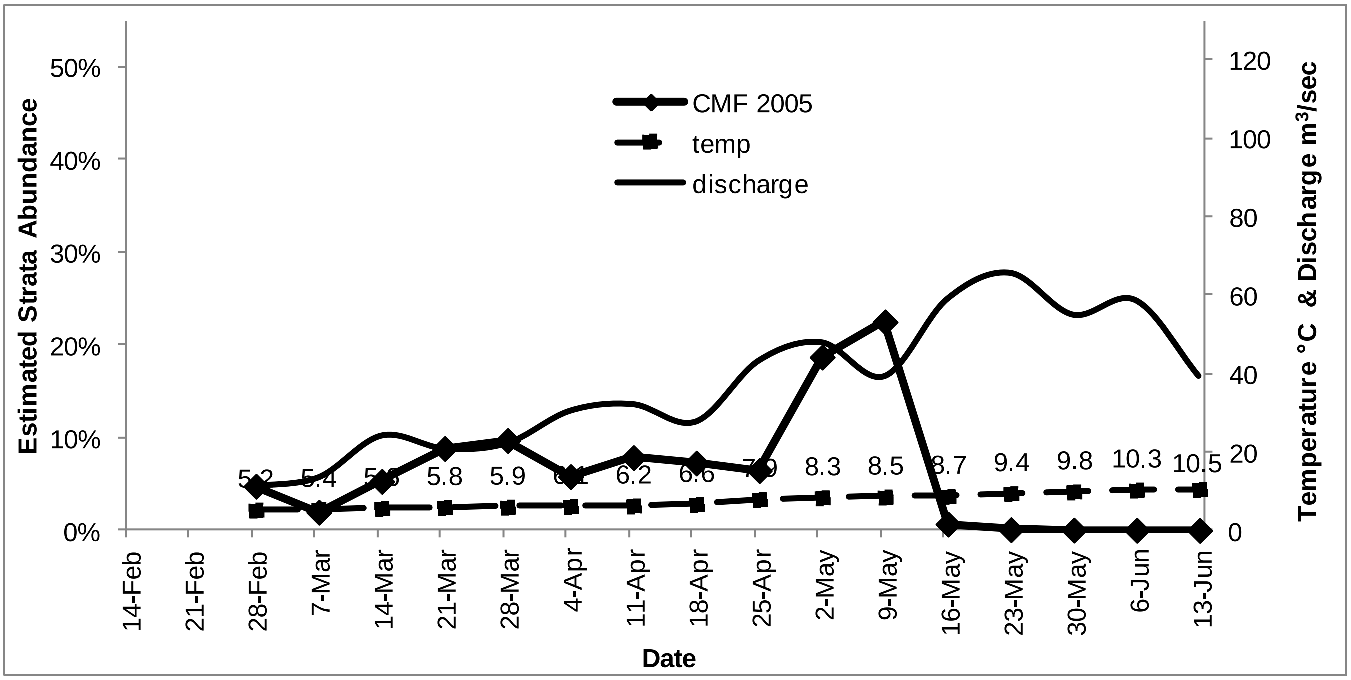

Figure 5A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2005 (Pre-WUP)

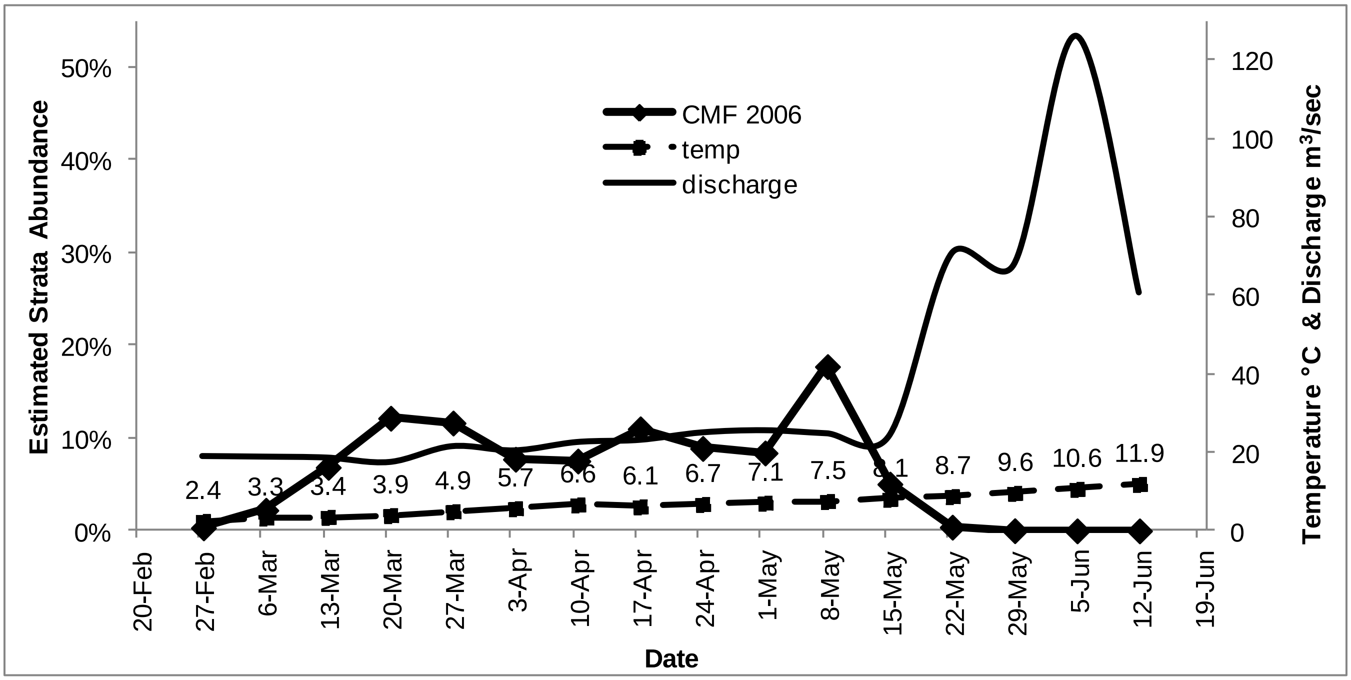

Figure 6A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2006 (Post-WUP)

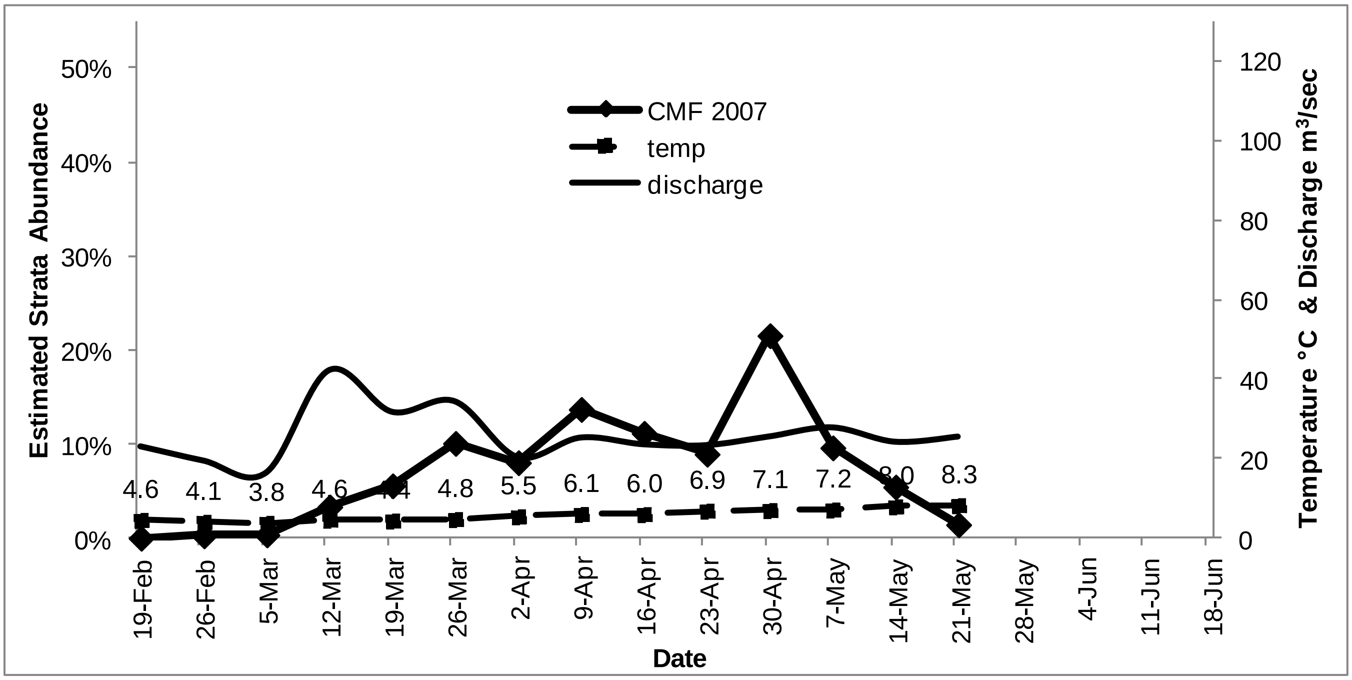

Figure 7A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2007 (Post-WUP)

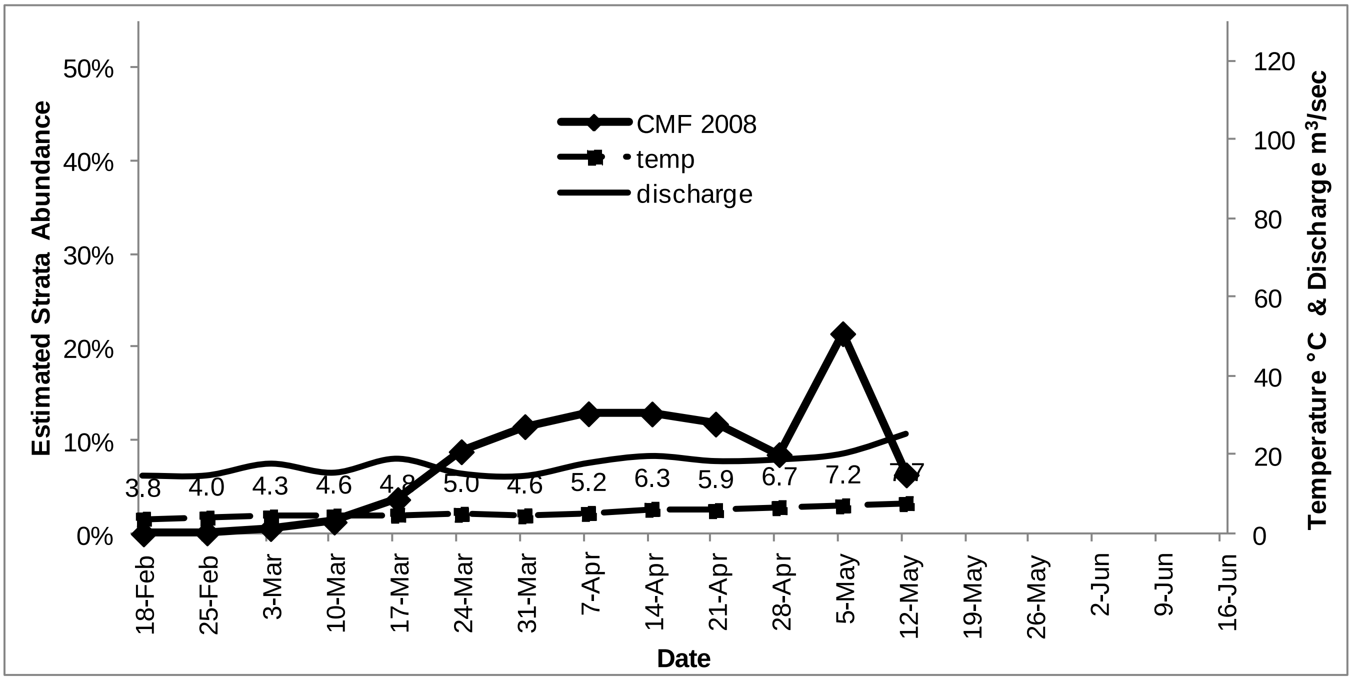

Figure 8A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2008 (Post-WUP)

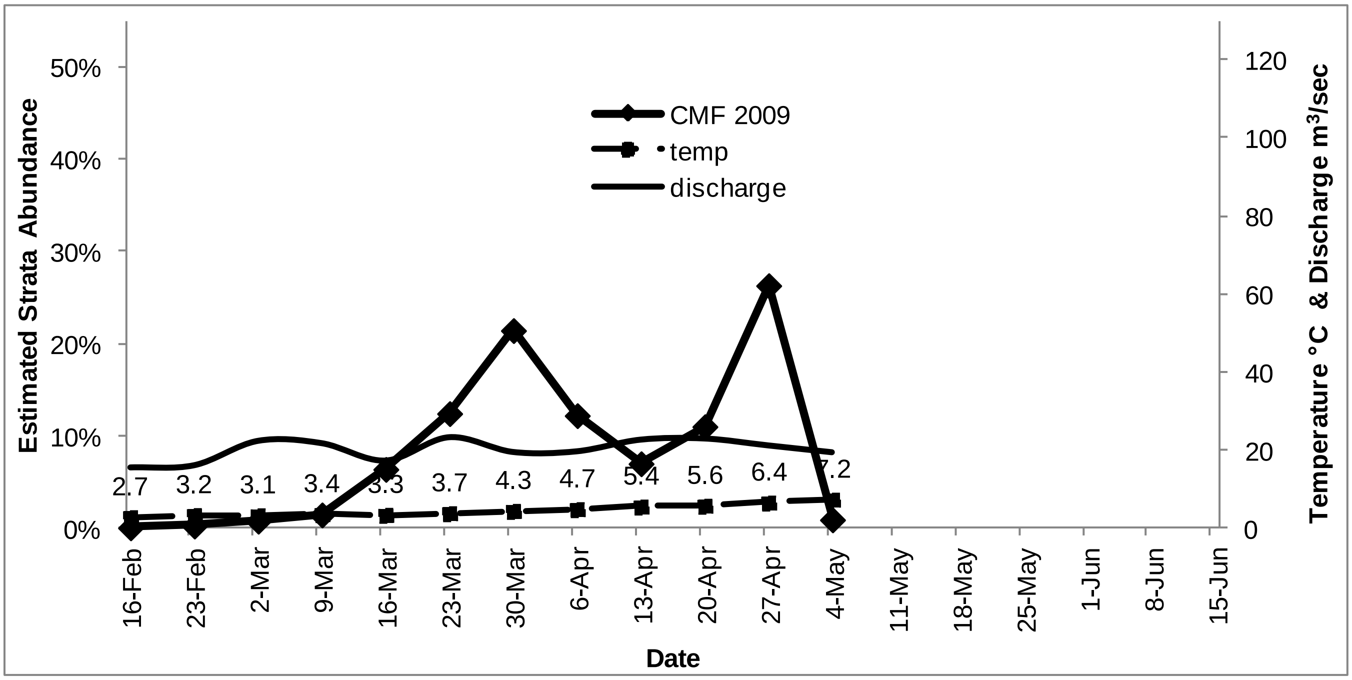

Figure 9A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2009 (Post-WUP)

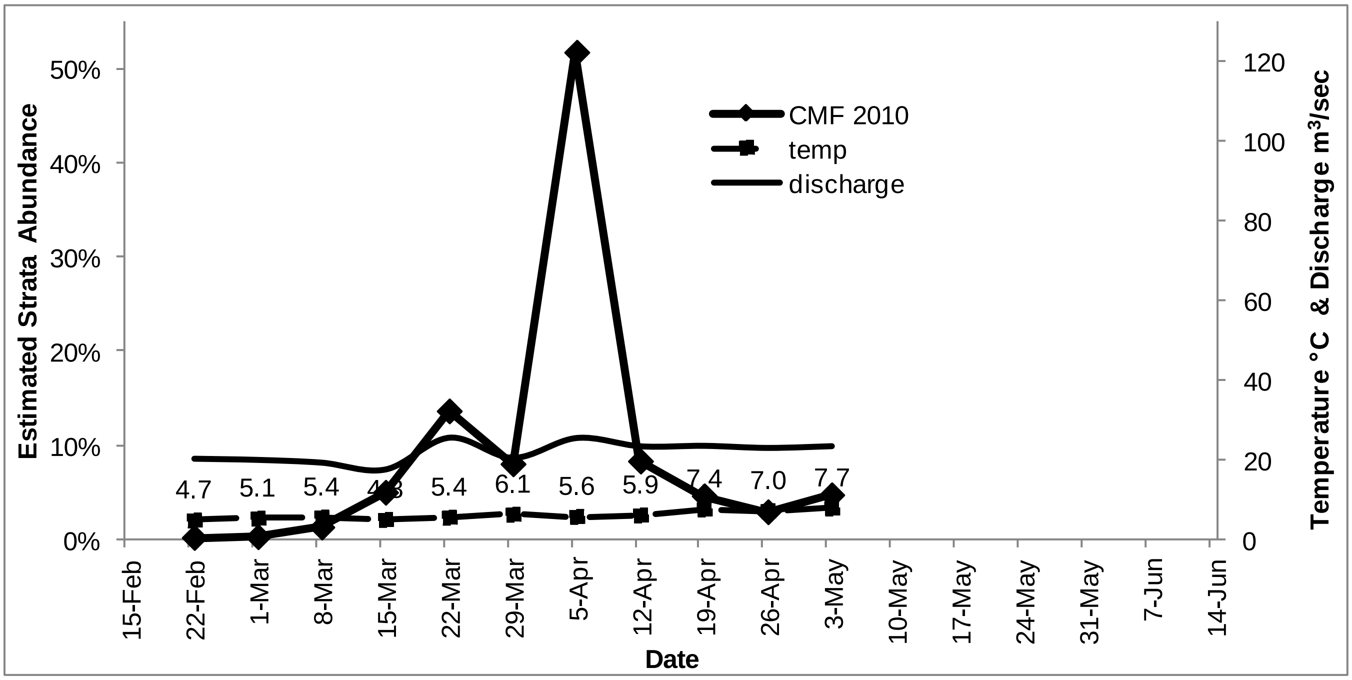

Figure 10A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2010 (Post-WUP)

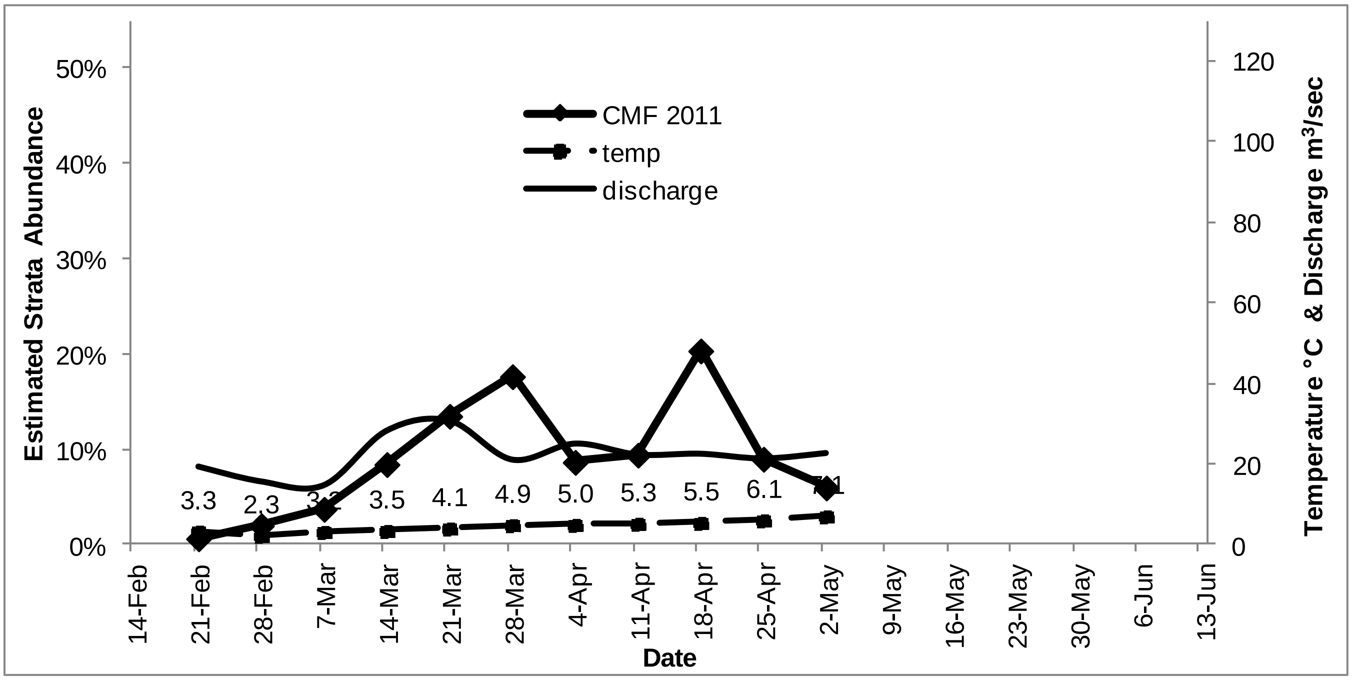

Figure 11A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2011 (Post-WUP)

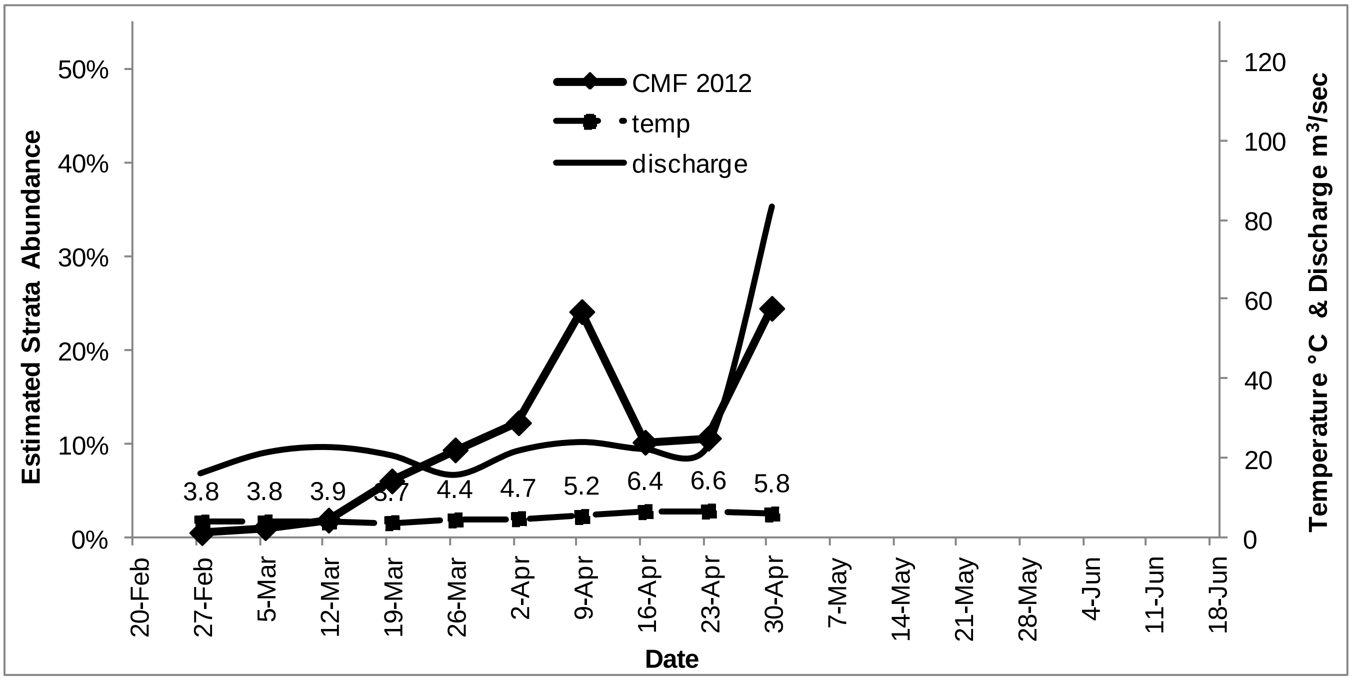

Figure 12A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2012 (Post-WUP)

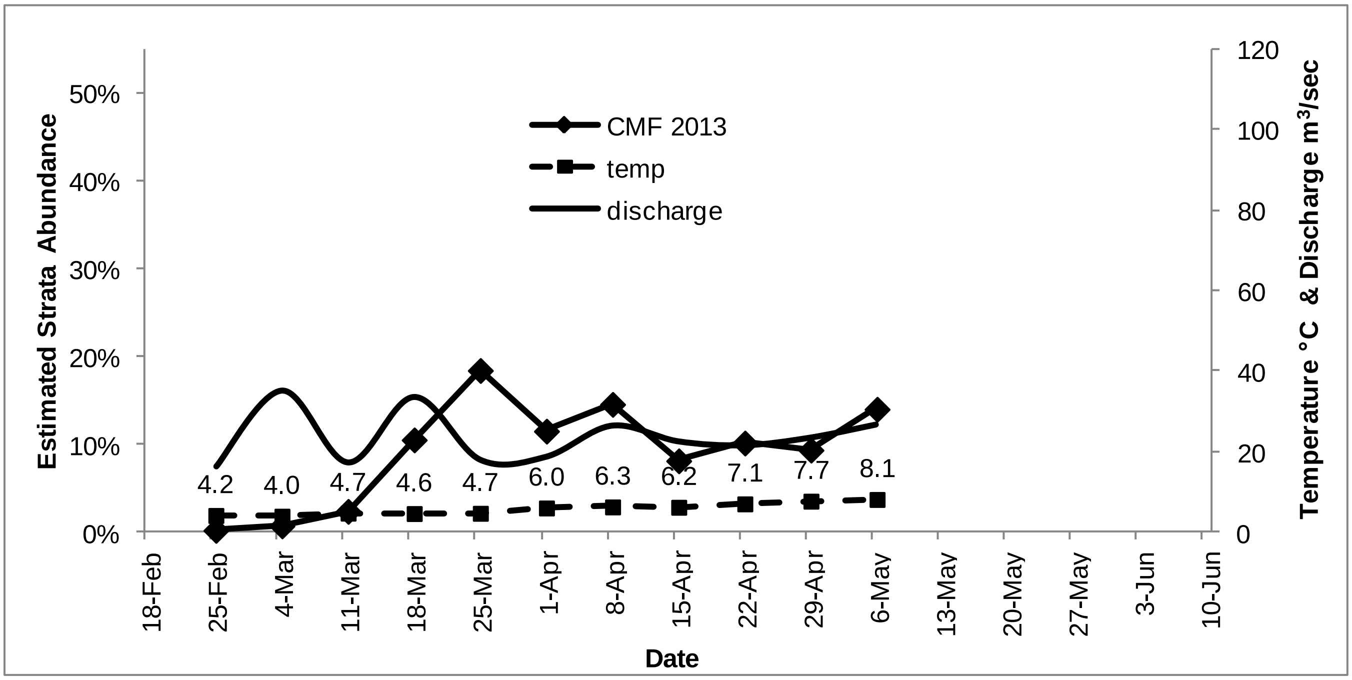

Figure 13A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2013 (Post-WUP)

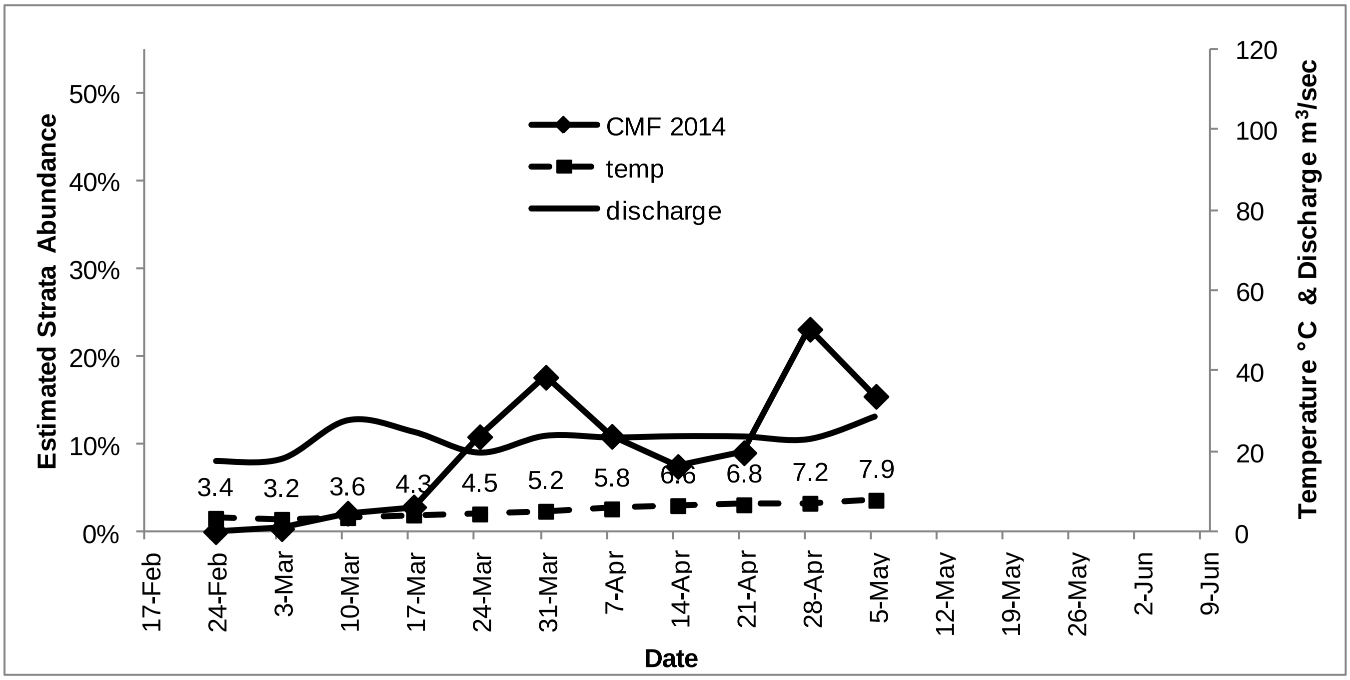

Figure 14A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2014 (Post-WUP)

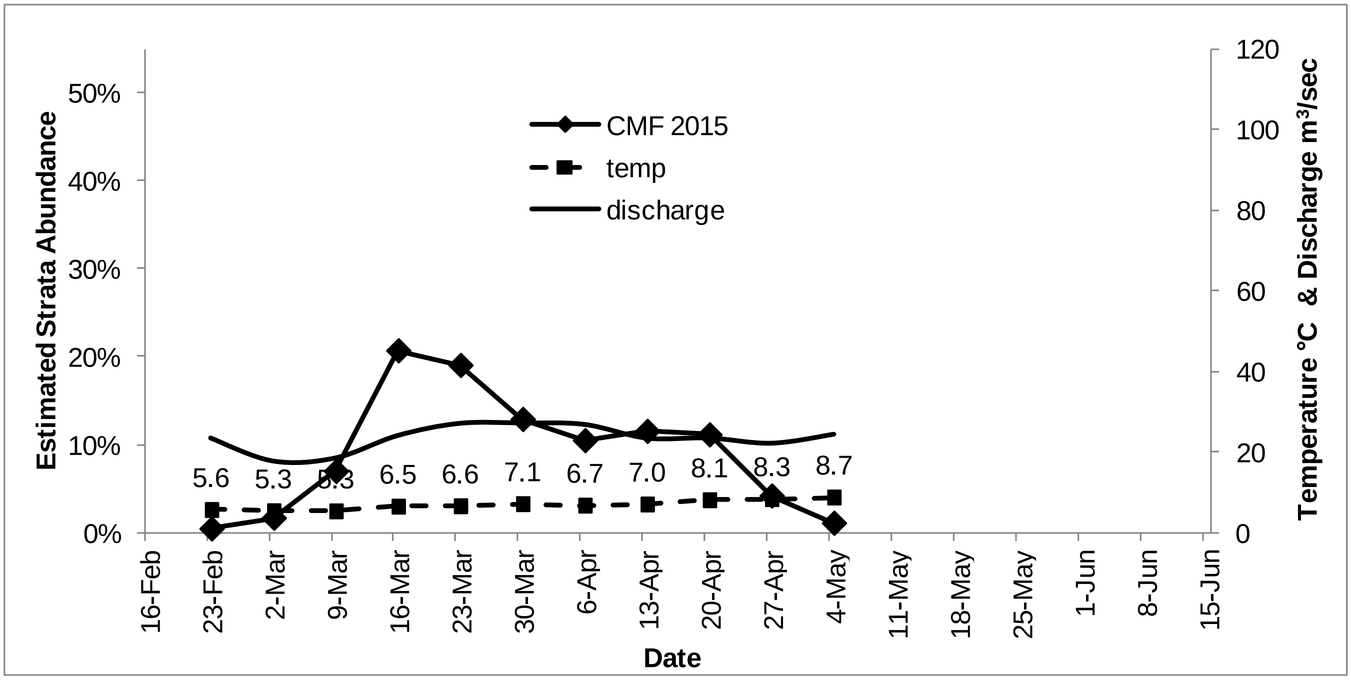

Figure 15A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2015 (Post-WUP)