Cheakamus Project Water Use Plan

Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey

Implementation Year 6

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Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey 2001-2013

Study Period: 2012

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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. In 2012, groundwater assessments were not conducted but previous years evaluations have revealed that in areas where large numbers of chum salmon spawn in the mainstem the majority of spawners appear to select areas of groundwater upwelling. In years 7-10, further assessments of spawner habitat selection will be evaluated.

During the sixth year (2012) of the chum adult escapement monitoring, fecundity, age and pre-spawn mortality were assessed to provide more confidence in the egg deposition rates used for egg-to-fry survival calculations. The results of this initial year of surveys revealed that the average fecundity of female chum salmon in the Cheakamus River in 2012 was 3,436 eggs/female, higher than the previously used literature value. There was a weak relationship between fecundity and fork length as fork length only accounted for 22.5% of the observed variability in fecundity. Throughout the run a decreasing trend was observed in both fecundity and age. The relationship between fecundity, age and size will be further analyzed over the next four years and could potentially be used to re-estimate egg deposition rates for Years 1-5.

There was a significant difference observed between egg retention in moribund or dead spawners in the mainstem verses egg retention in side channel habitats. In the mainstem habitat 89.0% of female chum were spawned out, 9.1% were partially spawned and 1.8% were unspawned. In the side channel habitat 82.9% of female chum were spawned out, 16.9% were partially spawned and 0.1% were unspawned. Average egg deposition rates for the mainstem and side channel habitats were calculated to be 86.7% and 84.4%, respectively. Area specific egg deposition rates were used to calculate egg-to-fry survival rates.

The 2012 chum salmon escapement was the highest recorded over the study period (2007 to 2012). The whole river estimate was 327,804 chum salmon and the upper river estimate was 138,485 chum salmon. The aging results revealed that the majority of female chum salmon were 5 years of age, offspring of the previously high 2007 return. Higher densities of spawners typically result in larger numbers of spawners moving upstream and entering the upstream monitoring areas, including BC Rail side channel and Tenderfoot Creek.

A habitat restoration project was complete prior to the 2012 chum return which improved access to Tenderfoot Creek and large numbers of chum were counted in Tenderfoot Creek. Access to the BC Rail side channel was also affected by the restoration project and low number of spawners were observed utilizing the channel in 2012.

A comparison of the variation in fry production before and after the implementation of the water use plan (WUP) indicates that annual variation between years of chum fry production has been higher post-WUP (CV=0.62) than pre-WUP (CV=0.29). Despite this higher variability, an increase of 33% in average

annual fry production has been observed post-WUP. The key goal of this study 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.

In 2013, 10,795,444 chum fry were estimated to have left the upper river area, the highest recorded in the study period, 2001-2013. Escapement monitoring in Tenderfoot Creek was initiated for the first time in 2013 and revealed that Tenderfoot Creek was a large contributor to this fry production. The yield from natural spawners in Tenderfoot Creek was estimated to be 26% of the total fry production in the upper river.

Egg-to-fry survival rates for the mainstem in 2012/13 was estimated at 3.1% (not accounting for pre-spawn mortality), which is in the lower range of egg-to-fry survival rates reported by other studies. Density dependent factors may be affecting egg-to-fry survival in 2012 given the relatively high escapement and the habitat area utilized. Egg-to-fry survival in side channel habitats was in comparison much higher. Egg-to-fry survival in the North Vancouver Outdoor School (NVOS) side channel was 19.9% (not accounting for pre-spawn mortality) which is in the upper and mid ranges of egg-to-fry survival rates reported by other studies. The highest egg-to-fry survival rates were seen in the groundwater fed spawning habitats. Egg-to-fry survival (not accounting for pre-spawn mortality) was 49.0% in the BC Rail side channel and 45.5% in Tenderfoot Creek. There appears to be high variability in egg-to-fry survival among habitat types. Ongoing research will establish the temporal and spatial trends in these data and explore how they may be affected by discharge.

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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 river 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. To reduce this uncertainty, one 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 13 years (see Melville and McCubbing 2000-2012) and monitoring of outmigration is ongoing (see CMSMON 01A, Melville and McCubbing 2012). Chum salmon spawner escapement in the Cheakamus watershed commenced in 2007 (see Troffe and McCubbing 2008, Troffe et al. 2008-2010, McCubbing et al. 2011-2012). 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.

Another 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, resulting in relatively greater effective spawning area. This finding and the modeling approach in general, was uncertain because chum spawning habitat selection can also be driven primarily by groundwater upwelling, and not the surface flow characteristics of water depth/velocity and spawning gravel suitability. It was suggested by some committee members 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, and 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 observed that may affect fry emergence timing. Additional data on site specific spawning at a greater range of escapement (particularly high escapement) is required to assess if 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 (BCHydro 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 (BCHydro 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?" (BCHydro 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 will commence during the 2013 chum spawning season.

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 size and environmental conditions which make traditional mark-recapture surveys difficult. 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 visual mark-recapture escapement 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 logging equipment.

In this study we used one marking location in 2007 and two marking locations from 2008-2012 (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 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 2012, radio tags were implanted in a portion of fish tagged in the upper river to evaluate movement upstream.

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 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 this report for sections 2.1.4 to 2.1.7 which were added into this study after the 5 year review process. The additional research that was implemented in 2012 includes evaluating the age and fecundity of female spawners and examining pre-spawn mortality rates. These amendments were all undertaken to focus on developing more accurate egg deposition rates for the Cheakamus River chum salmon population.

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): 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 spanned 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 were 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 accounted for (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 were conducted from October 15 through to December 15.

2.1.2 Escapement Analysis

A population estimate for the whole 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). 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).

2.1.3 Radio Telemetry

In 2012, to evaluate the spawner distribution of female chum salmon tagged at the upper river site, 23 fresh condition females were radio tagged between October 25 and November 16. A directional fixed station radio receiver was set up 50 m downstream of the Bailey bridge (RK 7). Mobile tracking was conducted weekly to evaluate the movement of the female spawners. Mobile tracking efforts were focused on the area between the upper river tagging site and the Bailey bridge but telemetry floats were also conducted from roads end (RK 16.5) to the confluence of the Cheakamus and Cheekye Rivers (RK 3.2).

2.1.4 Fecundity

Methodologies for fecundity sampling was based on the methodology used by Schroder and Ames (2004). Working with DFO staff, the fecundity of female chum salmon caught at the Tenderfoot Creek fence were sampled throughout the run. The brood stock are selected for the Salmonid Enhancement Program proportional to their abundance to ensure natural run times are maintained. Sampling was conducted at Tenderfoot Hatchery on females used for their enhancement program. Adult spawners caught at the fence on Tenderfoot Creek are held in holding tanks at the hatchery until they are ready to spawn.

When the females are ready to spawn, they are killed and their eggs and ovarian fluid are collected. Before the milt from the males was combined with the eggs to complete fertilization, fecundity was estimated. 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).

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 estimates conducted at Tenderfoot Hatchery, scale samples were collected for 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 4).

2.1.6 Pre-spawn mortality

Pre-spawn mortality surveys were conducted from mid October to the end of November to evaluate the egg retention and egg deposition in deceased females. Mainstem spawning habitats were surveyed by raft or by foot. 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 were surveyed by foot. The network of channels annually monitored for outmigrating juvenile salmonids (NVOS and BC Rail) were assessed for pre-spawn mortality. Additionally, BC Rail mile 49 (BC49) channel (located immediately upstream of the upper river tagging site on river left) and the lower reach of Mykiss channel (Lower Mykiss) (Figure 2) were assessed for pre-spawn mortality.

During the pre-spawn mortality surveys, the body cavities of deceased female chum were cut open to determine the number of eggs retained. Since fecundity sampling revealed high variability in the number of eggs per female and a weak relationship between fish size and fecundity, egg retention was classified into broad groups.

Spawners were classified as follows:

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

To determine if females had more or less than 500 eggs, eggs were counted in the field. Once people were familiarity with what 500 eggs looked like (Figure 5), visual estimates were then made. 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 Retention and Egg Deposition

Using the mean fecundity value of 3,436 eggs/female determined by sampling females at Tenderfoot Hatchery in 2012 (Results Section 3.1.4), egg retention and deposition were calculated. Females with zero to 500 eggs were classified as spawned out; this is between 0% and 14% retention or 100% and 86% deposition. Using the mid-point of these percentages, spawned out females were assumed to have 7% egg retention or 93% egg deposition. Females classified as partial spawners retained 15% to 99% of their eggs, depositing 1% to 85% of their eggs. Using the mid-point of these percentages, partial spawners were assumed to have 57% egg retention or 43% egg deposition. Females with intact skeins were classified as unspawned and assumed to have 100% egg retention or 0% egg deposition.

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

% Egg Retention =

$$\left(\frac{(0.07C) + (0.57P) + U}{S}\right) \times 100$$

% Eggs Deposited =

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

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

In 2013, 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) and in Tenderfoot Creek. Tenderfoot Creek enumeration was added in 2013 as data from the DFO trap suggested that the fry production from Tenderfoot Creek may significantly contribute to the abundance of fry observed at the RST site. In the mainstem, outmigrating juveniles are captured using RSTs. A maximum of 2,500 chum at each site are marked and then released upstream of the traps to be recaptured. In the side channel, an upstream fyke net is used to capture chum to apply marks and the downstream fyke net is used to recapture marked fish as well as count the number of unmarked chum migrating downstream. In Tenderfoot Creek, an upstream marking fyke net was used and two downstream recapture fyke nets were set up to evaluate the abundance of fish outmigrating at two different locations in the Creek. One downstream trap was set up at the fish fence where adult enumeration is conducted and hatchery brood stock are collected and another downstream fyke net was set up near the confluence of Tenderfoot Creek and the Cheakamus River to evaluate the total population of chum outmigrating from Tenderfoot Creek (Figures 1 and 2).

2.2.2 Outmigration Estimate

Outmigration estimates were calculated using a Bayesian spline model developed by 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 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)

A primary goal 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 (Nt)
2) Estimate female spawner ratio as a% (Ntf)
3) Calculate egg deposition based on the numbers of eggs per female (Nepf)
4) Calculate egg deposition rates as a% (Ned)
5) Estimate fry production (Ntfry)
6) Evaluate H' by dividing the fry outmigration estimates by the egg deposition rates

Thus,

$$H' = (Nt*Ntf*Nepf*Ned)/Ntfry$$

In 2012, egg-to-fry survival was determined using the sex ratio of females caught at the Tenderfoot trap (Results Section 3.1.3). The fecundity of females was determined by sampling at Tenderfoot Creek Hatchery in 2012 (Results Section 3.1.7). Egg deposition rates were determined from pre-spawn mortality surveys conducted during chum spawning in 2012 (Results Section 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.

3.0 RESULTS

3.1 Adult Spawners

3.1.1 Mark-Recapture

In 2012, 1,517 chum salmon were tagged with PIT and Petersen disk tags (Table 1). Over the past six years of this study (2007-2012) a total of 3,984 PIT tags have been applied at the lower river marking site (range 391-970 per year) and 2,920 at the upper tagging site (range 75-920 per year).

3.1.2 Length and Condition

The mean fork length of adult chum salmon tagged on the Cheakamus River has varied annually during the sample period of 2007 to 2012 (Table 2). In 2011, chum salmon were smallest. Females were 700mm in the lower river and males were 727mm. In 2007, the largest chum salmon were observed at the lower river tagging site. Mean fork length of female chum salmon was 743 mm and 801 mm for males. But, due to the fact that fish were tagged at different upper river location in 2007 than other years, fork length for chum salmon in the upper river was not representative for comparison. Excluding the 2007 data, the largest female chum salmon were observed in 2010 at both sampling locations. In comparison and again excluding 2007 data, the largest male chum salmon were observed in 2012 at both locations. Mean fork length of males was recorded as 778 mm in the lower river and 784 mm in the upper river. Among years, similar patterns of size variability are observed between sexes and locations: the average fork length appeared smaller at the lower river tagging site than at the upper river tagging site and consistent with other studies on chum salmon on the Pacific west coast, males were typically larger than females (Salo 1991).

Over the past six years, the visual condition of chum salmon tagged at the lower river site has generally been higher than those tagged at the upper river, due largely to the fact that the fish in the lower river were earlier in their in-river spawning migration. During tagging efforts the majority of the lower river fish were in acceptable condition for tagging. For example in 2012, 742 of 766 fish caught at the lower tagging site were tagged (84.1% condition 1 and 12.8% condition 2). At the upper tagging site more selection of fish was required as fish were observed spawning and then holding in the area. For example in 2012, 1,370 chum salmon were captured at the upper river site and 802 chum salmon, 58.6%, were tagged (29.4% condition 1 and 29.2% condition 2). Typically about equal numbers of condition 1 and condition 2 fish were tagged in each study year. Visual condition of chum salmon caught declined over the course of the sampling period in all years.

3.1.3 Sex Ratio

In the five-year review (2007 to 2011) upper river site capture data was utilized for evaluating the proportion of female spawners in the upper river and off-channel escapements (McCubbing et al. 2012) used to assess egg deposition targets. In previous years, with the exception of 2007 (small sample size) the percentage of female chum spawners that were tagged at the upper river tagging site has been similar to the percentage of females captured at the Tenderfoot Creek trap (Table 3) although the percentage of female spawners captured at Tenderfoot Creek fish fence was on average 4% higher (range 0-8%) than the percentage of females tagged (at the upper river tagging site). The greatest differences between samples were observed in 2009 and 2012 when high abundances of chum salmon spawned in the upper river but the data may also be influenced by the capture methods used at each location due to sampling bias. The 6 inch mesh of the gill nets used to capture chum salmon for tagging appears to be partially selective for males and large females. Male chum salmon are usually tangled in the net by the teeth on their mandible or maxilla, while females are most often captured after becoming wedged in the mesh. Smaller females, and other smaller non target species, are more able to swim through the 6 inch mesh (field observations). Additionally, due to the high abundance of chum salmon in 2012, shorter shallower nets were often utilized compared to the longer deeper nets used in other years. This may have allowed a greater proportion of female fish to hit the net and then swim around it, avoiding capture. In previous years when a lower abundance of chum returned, capture nets were often stretched across the entire width of the river, providing less opportunity for fish to avoid capture. The sex ratio of chum salmon captured at the Tenderfoot Creek trap is therefore a more likely unbiased representation of the sex ratio of the chum salmon spawners in the upper river of the Cheakamus. For these reasons the egg-to-fry survival calculation in 2013 utilizes the male to female sex ratio (1:0.67) of chum salmon captured at the Tenderfoot Creek fence in 2012.

3.1.4 Radio Telemetry and Spawner Distribution

In 2012, none of the 23 fish implanted with radio tags were detected upstream of the Bailey bridge (RK 7) during mobile tracks and no radio tags were detected on the directional fixed station 50m below the Bailey bridge. However, during the telemetry floats chum salmon were visually observed spawning upstream of the Bailey bridge and all the way to roads end (RK16.5). Due to the limited number of radio tags applied in a year when the escapement estimate was very high, and the lack of recoveries above the upper fixed station receiver, it was not possible to use this information to quantify the abundance of chum salmon that utilized the area upstream of the Bailey bridge in 2012.

3.1.5 Technical Malfunctions and Corrective Solutions

Due to PIT reader malfunctions at the NVOS and BC Rail side channels during the 2012 field season (from November 7th at 1500hrs until November 10th at 1100hrs), some PIT tagged fish were likely missed entering the channels over the three day period. The voltages on the internal batteries in the PIT readers were too low to detect tags and during the cold nights the PIT readers shutdown. To evaluate the potential for missed tags, seasonal PIT tag recapture rates were evaluated across years. Because each individual fish is implanted with a unique PIT tag, it is possible to determine the percent of fish recaptured from a specific tagging day. Fish tagged in the upper river generally arrive at the recapture sites (NVOS and BC Rail) between zero and seven days after tagging. Fish tagged in the lower river generally arrive at the recapture sites between two and nine days after tagging. Using these typical movement patterns of chum salmon in the Cheakamus, recapture rates of fish that could have potentially missed detection were evaluated. After comparing recapture rates in 2012 to recapture rates in 2010 and 2011, it became evident that using the average recapture rate of PIT tags in the calendar week before the 2012 malfunction and the week after the 2012 malfunction were relatively similar to the recapture rates during the time the readers malfunctioned (Table 4). Thus, to create an estimate of the number of PIT tags potentially missed during the PIT reader malfunction, the average recapture rates of the adjacent weeks in 2012 was multiplied by the marked fish that could have been detected during that time period.

In 2012, a power surge caused the resistivity counter to malfunction at NVOS site from November 21st to November 23rd. During this malfunction, a similar method was used as for PIT tags to estimate the number of fish missed. The average number of up counts from the day before the malfunction and the day after the malfunction likely gives a good representation of the number of fish missed when averaged and multiplied by the time the counter was not working. The run timing of chum salmon typically follows a normal distribution curve and this estimate takes into account the average number of fish moving the day before and after the event.

3.1.6 Distribution of PIT Tagged Chum Spawners

The lowest proportion (10.7%) of upper river tagged chum salmon that spawned in the monitored side channel habitat occurred in 2012 while in 2008, the greatest proportion (32.4%) of these fish spawned in the monitored side channel habitats (Table 5). In comparison, in 2009 the greatest proportion (11.8%) of lower river tagged chum salmon spawned in the monitored side channel habitat while the lowest proportion (2.5%) of these fish spawned in the monitored side channel habitat occurred in both 2007 and 2010 (Table 5). The proportion of tagged fish that spawn in side channels is likely a function of the number of fish tagged, total escapement as well as river discharge (additional distribution data results in Section 3.2.1.2). Also, the number of tagged fish that enter side channels may be affected by the number of fishing days lost due to high water events.

3.1.7 Fecundity

The mean fecundity of all the female chum salmon sampled during the 6 sampling events in 2012 was 3,436 eggs/female with a standard deviation of 578 eggs/female. Fecundity ranged from 2,255 to 5,144 eggs/female. The relationship between fork length and fecundity was statistically significant ($F=70.7$, $p<0.001$), but fork length only accounted for 22.5% of the variability in fecundity (Figure 6). The mean fecundity of female chum salmon sampled in the earlier part of run (November 5th-7th) was significantly higher (F-Test: two-sample for variances, $F=1.08$, $p=0.34$; t-Test: equal variances, $df=244$, $p=0.001$) than the mean fecundity of female chum salmon sampled in the later part of the run (November 13th-21st) (Figure 7). The mean fecundity of female chum sampled in the earlier part of the run (3,525 ± 575 eggs/female) was 240 eggs higher than the mean fecundity of female chum sampled in the latter part of the run (3,285 ± 552 eggs/female). Using the length-fecundity regression (Figure 6), a change in fecundity of 240 egg relates to a change in length of 35mm. There was, however, no significant difference in fork length observed between fish sampled in the earlier part of the run and the later part of the run.

3.1.8 Age

The age of 93 female chum salmon was determined through scale reading in 2012. The majority, 65% (n =60) of female chum salmon were aged five years, with 24% (n=22) aged four years and 12% (n=11) aged three years. There were no significant relationships between either age and fecundity, or age and fork length. Throughout the run a decreasing trend in average age (0.8 years) was observed (Figure 8). The mean age of the female chum salmon sampled in the earlier three sampling sessions (4.65 years old) was 0.35 years higher than the mean age of the female chum sampled in the later three sampling sessions (4.30 years). Later females appear to be younger and less fecund than earlier migrant females.

3.1.9 Pre-Spawn Mortality

Pre-spawn mortality surveys assess percentage of fish that die without spawning or only partially spawn and the percentage that completely spawn out were conducted on the mainstem and side channel habitats of the Cheakamus River. The results indicate that on average 85.6% of female chum were spawned out, 13.5% were partially spawned and 0.9% were unspawned. There was a significant difference in egg retention between habitat types (χ^2=27.9, p <0.001). In the mainstem habitat 89.0% of female chum were spawned out, 9.1% were partially spawned and 1.8% were unspawned. In the side channel habitat 82.9% of female chum were spawned out, 17.0% were partially spawned and 0.1% were unspawned (Table 6). There was no significant difference in egg retention among the seven reaches (Reach 3 to 9) assessed on the Cheakamus River.

Females at BC Rail had a significantly higher egg retention than at the NVOS side channel complex, BC49 and Lower Mykiss (Chi-Squared Tests: χ^2=47.0, p<0.001; χ^2=26.2, p<0.001; χ^2=8.9, p=0.003; respectively). In BC Rail side channel, 45.0% of female chum assessed were spawned out and 55.0% of were partially spawners (Table 7). However, only one pre-spawn mortality survey was conducted in BC Rail side channel in 2012. In future years, pre-spawn mortality surveys will be conducted multiple times in each area throughout the run to allow for further evaluations of these observed differences.

Within the NVOS complex of side channels, only 77.2% of female chum salmon in Kisutch channel were spawned out and 22.7% were categorized as partial spawners (Table 8). In the Upper Paradise channels and Sues channel, over 90% of females were spawned out. When Kisutch channel was compared to Upper Paradise channel and Upper Upper Paradise channel, significant differences were also observed (χ^2=8.4, p =0.004 and χ^2=10.7, p =0.001, respectively).

3.1.10 Egg Retention and Egg Deposition

For the 2012 egg-to-fry survival calculations, area specific egg deposition rates were calculated. The proportion of eggs retained by female chum salmon was calculated to be 14.6% for all habitat types or conversely the proportion of eggs deposited by female chum salmon was calculated to be 85.4% for all habitat types (Table 9). Significantly different egg retention rates were observed between mainstem and side channel habitats. For the mainstem habitat only above the RST site, egg deposition rate was calculated to be 86.7% while for side channel habitat only, egg deposition rates were calculated to be 84.4%. For the NVOS side channel complex, the egg deposition rate was calculated to be 86.2%. In Tenderfoot Creek where pre-spawn mortality was not analyzed and for BC Rail side channel where only one pre-spawn mortality survey was conducted, the average egg deposition rate of all side channel habitats was used for the area specific egg-to-fry survival calculation.

In both the mainstem and side channel habitats, egg deposition per female was significantly higher in the earlier part of the run than the later part of the run (Chi-Squared Tests: χ^2=32.42, p<0.001; : χ^2=7.46, p<0.01, respectively). In all side channel habitats, the total change in egg deposition rates was a decrease of 6.0% (Table 10). The largest significant difference in egg deposition were observed in two groundwater fed side channels Kisutch channel, part of the NVOS channel complex and BC 49 side channel (Chi-Squared Tests: χ^2=8.77, p<0.01; χ^2=10.97, p<0.001, respectively). A decrease in egg deposition of 11.2% was observed in Kisutch channel and a decrease of 9.8% in BC 49 side channel.

Sues side channel, a surface fed channel, was the only channel where an increase in egg deposition (an increase of 7.1%) was observed over time. In Sues channel low numbers of spawners were assessed. In mainstem habitats, a decrease in egg deposition of 7.3% was observed as spawning progressed through the season (Table 11). A recent study on sockeye salmon revealed that patterns in egg retention did not differ throughout the sockeye run (Hruska 2011). With additional years of egg retention rates, the relationships between egg retention and environmental variables, such as river discharge will continue to be assessed.

3.1.11 Kelt Behaviour

Kelting behaviour was assessed in 2012, as in all other years (McCubbing et al 2012). 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. 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 which likely assists the flushing out of kelts and the greater area for fish passage in a downstream direction. In 2012, the proportion of PIT tagged spawners that kelted was similar to those observed in 2011. Over all the years that kelting behaviour has be analyzed (2009 to 2012), the majority of fish that have been observed to kelt were males. At NVOS channel 61 out of 71 kelts were males (86%) and at BC Rail channel 9 out of 13 kelts were males (69%) (Table 12). These values decreases the risk of a miss-interpretation of egg deposition rates.

3.1.12 Validation of Counters and Discharge Correction

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 2012, counter efficiency at BC Rail was 80% for up counts and 71% for down counts (Table 13) but at NVOS, average counter efficiency for up counts was 49%, lower than in previous years, with a range from 24% to 80%. Average counter efficiency for down counts was 75%, ranging from 50% to 200%. There were no substantial high water events that were corrected for in 2012, but it was evident that debris loads and backwatering events did cause flows over the counter to be uneven affecting fish behaviour and thus counter efficiency.

3.2 Escapement Estimates

3.2.1 Adult Spawners

3.2.1.1 Whole River Estimate

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 2012, a high escapement of chum salmon returned to the Cheakamus River. For the whole river, an estimate of 327,804 chum salmon spawners was derived from the mark-recapture study. This was the highest escapement estimates recorded in the survey period from 2007 to 2012. A large escapement of chum salmon spawners also returned to the Cheakamus River in 2007 when a whole river estimate of 267,574 fish was derived (Table 14 & Figure 9). In 2010 and 2011, chum returns to the Cheakamus River were the weakest of the 6 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 14 & Figure 9).

3.2.1.2 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 2012, the upper river estimate of chum spawners in the Cheakamus River of 138,485 chum salmon was the highest estimate over the past 6 years (Table 14 and Figure 9). Notably in 2009, a large upper river spawner abundance of 105,540 chum salmon was observed (Table 14 and Figure 10) but was the result of a change in the distribution of spawners not of a particularly high chum salmon return. A higher than average percentage, 65%, of total spawners utilized the upper river habitat in 2009 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 backwatered area was previously 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.

In 2012, the proportion of total river spawners that utilized the upper river habitat areas was 42% which was similar to that observed in 2011. In 2011, low number of spawners returned to the Cheakamus River but 40% of spawners utilized the upper river spawning habitat. 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. In 2008 when a moderate return was estimated in the whole river, 24,059 chum salmon, 20% of spawners used the upper river habitat. In 2007 when high returns of chum salmon were observed in the whole river, 42,011 chum salmon, 16% of chum spawners used the upper river habitat (Table 14 and Figure 10).

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. BC Rail and Tenderfoot Creek are both groundwater fed channels as are the most popular areas for chum spawning within the NVOS side channel complex (as opposed to surface fed side channels). The distribution of upper river spawners in these monitored side channel (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 11). In 2007 and 2008, higher proportions of upper river spawners were observed spawning in both the NVOS side channel complex and Tenderfoot Creek than in the BC Rail side channel (Figure 12). The proportion of upper river spawners that utilized the NVOS side channels and Tenderfoot Creek were similar within years (e.g., in 2008 both channels had 14% of upper river spawners), but has varied among years (NVOS side channel ranged from 6-14% and Tenderfoot Creek ranged from 4-14%). From 2009 to 2011 the majority of side channel spawners utilized the NVOS side channel complex (range 6-16%) and small proportions of chum salmon were observed spawning in both BC Rail side channel and Tenderfoot Creek (range 2-3%). This distribution changed again in 2012, with higher proportions of spawners in NVOS side channel and Tenderfoot Creek than in BC Rail side channel (Figure 12). The confluence of Tenderfoot Creek and BC Rail side channel with the Cheakamus River was realigned as part of a habitat restoration project by DFO in 2012.

The highest proportion (33%) of upper river chum salmon that utilized side channel habitat for spawning occurred in 2008 (Figure 11). Average daily discharge during peak spawning (November 1 to November 15) in 2008 was higher than in any of the other study years (from 2007 to 2012, Table 15). During peak spawning times in 2008, maximum flows were 118 m^3/s and average flows were 53 m^3/s. Elevated river discharges were also observed in 2010 with maximum flows during peak spawning recorded at 101 m^3/s and an average flows of 46 m^3/s. A higher proportion (21%) of chum salmon were also observed spawning in side-channel habitat in 2010. In 2010, the NVOS side channel habitat had the highest proportion of spawners at 16% of upper river spawners and in 2008, 14% of upper river spawners were observed in the NVOS side channel habitat (Figure 12). Additionally, in 2008, the proportion of upper river spawners that utilized Tenderfoot Creek (14%) was substantially higher than any other year (Figure 12).

When high escapement of spawners was estimated in the upper river in 2009 and 2012, the greatest numbers of chum spawners utilized the monitored side channel habitats, 15,603 and 14,961 chum salmon, respectively (Table 16). The majority of these side channel spawners utilized the NVOS side channel complex (9,357 spawners in 2009 and 8,859 spawners in 2012), but large numbers were also found in Tenderfoot Creek (3,003 spawners in 2009 and 5,419 spawners in 2012). In 2010, the lowest escapement of spawners was observed in the upper river and although a large proportion of spawners utilized side channel habitats, the lowest number of spawner utilized the monitored side channel habitats (2,708 chum salmon). When 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) and greater numbers were observed farther upstream in the mainstem (field observations).

In 2012, low numbers of spawners (683 chum salmon) were found in the BC Rail side channel, despite high escapement of spawners returning to the upper river and other side channel habitats (Table 16). The number of spawners found in Tenderfoot Creek were 8 times higher than the number found in BC Rail side channel. From 2009 to 2011, similar numbers of spawners were found in Tenderfoot Creek and BC Rail side channel and although higher numbers of spawners were observed in Tenderfoot than in BC Rail side channel in 2007 and 2008, the number of spawners in Tenderfoot Creek were only 3.0 and 2.6 times higher than BC Rail side channel, respectively. Prior to the chum salmon run in 2012, a habitat restoration project had been undertaken to improve access to Tenderfoot Creek which has also altered access to the BC Rail side channel.

3.2.2 Outmigrant Fry

Since 2001, chum fry production has been monitored on the Cheakamus River at the RST site (RK 5.5). In 2013, chum fry outmigration timing was similar to those observed from 2001-2012. Outmigration is generally either just commencing or has not yet started when sampling commences on February 15th. On average only 10% of the total yield has typically migrated by the fourth weekly stratum. The peak of migration for chum fry generally occurs between April 4th and May 2nd (weekly strata 8-11; McCubbing et al. 2012). In Year 1 to 6, chum fry migration is concurrent with an increase in river temperature (from 4.5 to 8^{o}C) but not necessarily discharge (Appendix A Figures 1A-13A) (McCubbing et al 2012). It is likely spawner timing in conjunction with water temperature during incubation and emergence are the primary factors regulating migration timing of chum fry (McCubbing et al. 2012).

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 13 and Table 17). The average annual fry production pre-WUP (2001-2006) was 3,705,110 chum fry/year. The average annual fry production post-WUP (2007-2013) was 5,053,871 chum fry/year. An increase in average annual fry production of 33% has been observed since the introduction of the WUP, although, in three of the seven 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 0.62.

Estimates of chum fry production have been derived annually from 2007 through 2013 from BC Rail and NVOS side channels. In the NVOS side channels 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. 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 18). Fry production from NVOS and BC Rail combined has represented between 27% and 43% of the total production annually above the RST site (Figure 14).

In 2013, the largest number of chum fry were estimated to have outmigrated from the upper river since the monitor was initiated. The 2013 estimate was 2.6 fold higher than the average post-WUP estimate prior to 2013 and 1.5 fold higher than the next highest estimate derived in the upper river mainstem (2010). The yield from NVOS and BC Rail side channels (2,887,817 chum fry) was estimated to be 27% of the total chum fry production upstream of the RSTs in 2013 (Figure 14). NVOS produced 2,428,254 chum fry, 22% of the total chum fry and BC Rail produced 459,562 chum fry, 4% of the total chum fry. Tenderfoot Creek was a large contributor to fry production in 2013: 2,656,729 chum fry, or 26% of the total fry production in the upper river (Table 18 and Figure 14). In comparison the yield from the mainstem and smaller unmonitored side channels was 47% of total chum fry production (Figure 14).

3.3 Juvenile Outmigrant Bio-sampling

Mean fork length of juvenile chum fry from 2001 to 2013 was 39 mm (Table 19). An analysis of variance of the fork length of juvenile chum fry from 2001 to 2013 revealed that there was a significant difference among years (ANOVA: $F=61.17$, $p<0.001$). The size of juvenile chum was significantly larger pre-WUP (39 mm) than post-WUP (38 mm) (F-Test: two-sample for variances, $F=1.72$, $p=0.28$; t-Test: equal variances, $df=10$, $p=0.028$).

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 RST site (upstream of RK 5.5), egg-to-fry survival in 2012 and fry emerging in 2013 were calculated to be 6.6% or 5.7% without accounting for pre-spawn mortality (Table 20). Egg-to-fry survival, H' in the mainstem and unmonitored side channels above the RST site only, was calculated to be 3.6% or 3.1% without accounting for pre-spawn mortality (Table 20).

Egg-to-fry survival, H' was also calculated independently for the NVOS channel complex, the BC Rail channel complex and Tenderfoot Creek upstream of the fish fence. In the NVOS side channel complex, egg-to-fry survival was 23.1% or 19.9% without accounting for pre-spawn mortality (Table 20). In the BC Rail side channel complex, egg-to-fry survival was 58.0% or 49.0% without accounting for pre-spawn mortality. In Tenderfoot Creek upstream of the fish trap, egg-to-fry survival was 53.9% or 45.5% without accounting for pre-spawn mortality (Table 20).

4.0 DISCUSSION

One of the goals 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) and egg-to-fry survival 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. To achieve these goals it is important that enumeration data (by trap and counter), fish marking and tag recovery data are accurate and as free as possible from sampling bias. To evaluate the methodology used in this study, a number of validation checks were conducted in Years 1 to 5 to confirm data assumptions. These validations revealed that the methodologies used in this study are robust (McCubbing et al. 2012). In Year 6, validation of counter data by video records of observed fish movement was continued to enhance accuracy of counter data and the analysis of kelting behaviour continued to be conducted to assess the portion of up counts at counter sites that are for fish which ultimately spawned upstream of the counters. In the uncommon event of a technical malfunction of electronic equipment, estimates were made to fill in gaps (in counter and PIT reader data) by understanding the run timing patterns and by using previous data as a model.

Chum spawning can be broken down in the Cheakamus River 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. To this end, two years full river data, 2007 and 2012, indicate high escapement years, two years indicate low escapement (2010 and 2011) and the other years (2008 and 2009) are in between.

As chum escapement increases on this river, higher densities of fish are typically observed in the upper river, in the monitored side channels and in Tenderfoot Creek. Chum salmon spawning also appears to occur farther upstream on the mainstem in years with high escapement. At lower escapements, much fewer chum salmon have been estimated to spawn in BC Rail side channel and Tenderfoot Creek. One exception to these observations is the low numbers of chum salmon that were estimated to have spawned in BC Rail side channel in 2012 when the highest densities of chum spawners were estimated to have spawned in the upper river. In this case, construction to enhance access to Tenderfoot Creek was undertaken in 2012, immediately prior to the chum salmon returns. This construction changed the access route to both BC Rail and Tenderfoot Creek and at least based on 2012 data, seems to have affected the distribution of chum spawners between the two locations. In 2012, the largest number of chum salmon during the study period (5,419) was enumerated at the Tenderfoot Creek fence.

The highest proportion of upper river chum salmon that utilized side channel habitat for spawning was observed in 2008 (33%) and 2010 (21%), respectively, when average discharge during peak spawning was high. In these years, the greatest proportion of upper river spawners utilized the NVOS side channel habitat 14% and 16%, respectively. As the NVOS channel is partly "flow through" and fed by mainstem water through an intake, it is possible that higher flows during peak spawning enticed more spawners to enter the channel, but more data are required to confirm this hypothesis.

In 2012, additional research was conducted to better address the issues of egg deposition of chum salmon in the areas upstream of the RSTs. The evaluation of fecundity, age, pre-spawn mortality and egg retention/deposition rates provided for the development of a more relevant average egg deposition rate for the upper river of the Cheakamus in 2012. The first year of the methodology has allowed the development of a non-biased sampling regime. Fecundity of females sampled earlier in the run was significantly higher than the fecundity of females sampled later in the run. To get an accurate estimate of average fecundity, it is important that female chum salmon be sampled throughout the run and in a proportion representative of spawner abundance. Pre-spawn mortality surveys revealed that egg retention was significantly higher in the later part of the run than in the earlier part of the run. Pre-spawn mortality rates will continue to be sampled in the mainstem and side channel habitats multiple times throughout the run in order to detect changes in egg deposition rates.

In 2012 the number of eggs recorded per female was higher than the literature value used in previous years to calculate egg-to-fry survival. Although no statistically significant relationships between fecundity and age were observed, both age and fecundity decreased throughout the run. Mean age of chum measured on the Fraser River was also observed to decline throughout the run (Beacham and Starr 1982). Other rivers in BC (Beacham 1984), central Alaska (Helle 1979) and southeastern Alaska (Clark and Weller 1986) all reported a decline in mean age during spawner migrations, with five year old chum returning earlier, four year old chum returning throughout and three year old chum returning later in the sampling period. A more recent study by Volobuev (2000) indicates that length, weight and fecundity increase when abundances of chum salmon are low and there is an inverse relationship between age at maturity and run abundance. Further evaluations of fecundity during Years 7-10 will aid and strengthen the understanding of any relationships between fish age, fish size and fecundity. These relationship may also be linked to run size (Volobuev 2000). If appropriate, analysis of archived scales from Years 1-5 could assist in developing fecundity estimates where field data on egg numbers were not collected. Additionally, the assessment of pre-spawn mortality rates in Years 6-10 could 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.

It is evident from the 2012 pre-spawn mortality and fecundity studies that egg deposition was likely higher than the 2500 previously reported in McCubbing et al. (2012). The mean fecundity of female chum salmon sampled at Tenderfoot Creek in 2012 was 3436 eggs/female and at an egg deposition rate of 85.6%, on average 2,941 eggs were deposited per female. Data from 2013 will be assessed and if similar all previous egg to fry survival rates will be recalculated.

Significant differences in egg retention were detected between mainstem and side channel habitats as well as among some of the side channel habitats. Two side channels where higher egg retention rates were observed were Kisutch channel (in the NVOS side channel complex) and BC Rail side channel. 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, low water conditions (Wild Fish Conservancy 2008) and stress from angling pressure (Troffe and Ladell 2007). In the BC Rail side channel, beaver activity prevents access to some of the potential spawning areas and could be affecting pre-spawn mortality rates while at Kisutch channel signs of predation by bears is always visible perhaps causing stress to spawning fish.

Chum fry outmigration estimates calculated since 2001 on the mainstem indicate that chum fry production has varied greatly on an annual basis. Including 2013, comparisons of variation pre-WUP (CV=0.29) and post-WUP (CV=0.62) 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 washout in 2009). Despite the high variability, an increase of 33% in average annual fry production has been observed post-WUP. The key 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 size of juvenile chum was significantly larger pre-WUP (39 mm) than post-WUP (38 mm). 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.

The improvements to the chum adult study focusing on the number of eggs being deposited (fecundity estimates and pre-spawn mortality surveys) has provided more confident 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 estimates of 3.1% in 2012/13 (Table 20; not accounting for pre-spawn mortality) was in the lower range of those observed by Parker (1962). Parker observed a broad range of survivorship, 1-22% from 14 years of sample data on Hooknose Creek, BC. This mainstem estimate is also lower than the 7% to 9% average egg-to-fry survival reported by Bradford (1995) who looked at multiple rivers along the Pacific west coast and the 6% to 35% range observed by Beacham and Starr (1982) from 19 years of research on the Fraser River, BC. Density dependent factors may be affecting egg-to-fry survival in 2012 given the relatively high escapement. Much higher egg-to-fry survival rates were seen within side channel habitats. The NVOS side channel egg-to-fry survival estimate of 19.9% (not accounting for pre-spawn mortality) was in the upper range of the average reported by Parker (1962) and in the mid-range of the range reported by Beacham and Starr (1982). The highest egg-to-fry survival rates were seen in the groundwater fed side channel habitats of BC Rail side channel and Tenderfoot Creek, 49.0% and 45.5%, respectively. When pre-spawn mortality was included, egg-to-fry survival in BC Rail side channel was 58.0% and in Tenderfoot Creek was 53.9%. 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.

5.0 Recommendations

5.1 Reinstate Radio Telemetry

Spawner distribution may affect fry production if there is a high variance in egg-to-fry survival between different locations in the river above the RST sampling site (mainstem, flow through and groundwater channels) or if distribution varies annually above and below the fry sampling location. An assessment of the annual distribution of chum salmon spawners was achieved in this study through the use of both radio tags and PIT tags. Understanding these spawner distribution variances provides insight into spawner habitat selection and the influences discharge may have on salmon migration. For example, in 2009, changes in the habitat conditions on the mainstem of the Cheakamus River substantially increased the proportion of spawners that utilized the upper river spawning areas following a summer storm event which resulted in the backwatering of a substantial area of spawning habitat (1.5km) above the Cheekye confluence. Currently, a new channel restoration project occurring between the RST site and the Cheekye/Cheakamus confluence may affect the distribution and habitat use of chum salmon as they migrate upstream. Assessing the annual variance in distribution of chum spawners throughout the river can be best addressed by radio telemetry. In Years 7 to 10, radio tagging will be re-conducted to determine the distribution of spawners throughout the Cheakamus and further evaluate the relationship between redd selection and mainstem groundwater upwelling areas.

5.2 Install additional Channel (PIT Antenna and Resistivity Counter) at the NVOS Counter Site

Counter efficiency was highly variable for both up and down counts in 2012 and average counter efficiency for up counts at the NVOS counter site was lower than in previous years. During storm events, large debris loads clog up the gates at the site and create a backwatering effect resulting in an uneven flow of water over the counters which appears to affect fish behaviour and thus counter efficiency. A way to address the efficiency of this counter would be to provide more area for water to flow through the counter site at NVOS. This could be done by adding an additional channel at NVOS. This would prevent so much water from backing up above the counter site, which appears to affect counter efficiency.

5.3 Seed a Fixed Number of Chum Spawners in BC Rail Channel Annually

BC Rail side channel could be seeded with a fixed number of chum adults annually to remove density dependent effects and evaluate the linkages between river discharge and egg to fry survival. Using the existing stock-recruit data, carrying capacity could be estimated and the channel could be seeded to an estimated carrying capacity annually. If in-season estimates predicted that escapement into the channel (from Years 1-6 counter data) would not meet carrying capacity, the channel could be augmented from fish collected at Tenderfoot Creek trap. By undertaking this experiment annually for 4 years, the potential effects of flow variations in the mainstem could be evaluated in a groundwater off channel habitat without the complicating factor of varied spawner density.

6.0 TABLES

Table 1. Numbers and distribution of PIT tags applied to chum salmon adults on the Cheakamus River, 2007-2012.

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	1890		970	766	204	21%		920	763	157	17%
2012	1517		722	379	343	48%		795	587	208	26%

Table 2. Mean fork length ± standard deviation (mm) of sampled adult chum salmon during tagging operations, Cheakamus River 2007-2012.

Year		Lower River			Upper River	
		Female	Male		Female	Male
2007		743 ± 34	801 ± 20		-	-
2008		718 ± 42	765 ± 50		719 ± 43	763 ± 51
2009		722 ± 31	769 ± 44		734 ± 26	760 ± 46
2010		737 ± 46	769 ± 49		748 ± 52	764 ± 52
2011		700 ± 35	727 ± 45		708 ± 33	730 ± 46
2012		726 ± 37	778 ± 52		739 ± 43	784 ± 49

Table 3. Percentages of females captured by tangle netting at the upper river tagging site (number captured in parenthesis) on the Cheakamus River and at the Tenderfoot Creek fish fence (DFO) from 2007-2012.

Year	% Females	
	Upper River	Tenderfoot
2007	40% (30)*	23% (358)
2008	34% (130)	36% (1191)
2009	30% (110)	38% (1141)
2010	23% (85)	23% (67)
2011	17% (157)	21% (150)
2012	26% (208)	40% (2168)

*based on small sample size

Table 4. Average recapture rates in 2010, 2011 and 2012 for the time period when fish potentially missed detection due to a PIT reader malfunction in 2012 and average recapture rates of the week prior and the week after.

	Recapture Rates					
	2010		2011		2012	
Upper River Fish	**NVOS**	**BC Rail**	**NVOS**	**BC Rail**	**NVOS**	**BC Rail**
Oct 31 – Nov 9 (2012 PIT reader malfunction)	18.49%	6.16%	10.07%	2.29%	Estimated to be 5.65%	Estimated to be 1.61%
Oct 24 – Oct 30 & Nov 10 – Nov 16	23.94%	5.16%	10.07%	2.61%	5.65%	1.61%
Lower River Fish	**NVOS**	**BC Rail**	**NVOS**	**BC Rail**	**NVOS**	**BC Rail**
Oct 28 – Nov 7 (2012 PIT reader malfunction)	11.50%	2.65%	4.58%	1.96%	Estimated to be 2.94%	Estimated to be 0.25%
Oct 21 – Oct 27 & Nov 8 – Nov 17	2.88%	0.00%	4.01%	1.53%	2.94%	0.25%

Table 5. Proportion (%) of recaptured chum spawners in the side channels from the upper and lower river tagging sites.

Location	**Year**					
BC Rail	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Upper River	1.3%	7.3%	3.5%	3.2%	2.7%	*1.9%
Lower River	0.6%	2.3%	3.1%	0.5%	1.4%	0.7%
NVOS						
Upper River	9.3%	17.2%	9.4%	11.1%	10.3%	*6.3%
Lower River	1.6%	2.8%	5.9%	1.8%	3.6%	*2.5%
Tenderfoot						
Upper River	4.0%	7.9%	1.9%	3.1%	1.9%	2.5%
Lower River	0.3%	1.4%	2.8%	0.2%	0.8%	1.2%
All Side channels						
Upper River	14.6%	32.4%	14.8%	17.4%	14.9%	10.7%
Lower River	2.5%	6.5%	11.8%	2.5%	5.8%	4.4%

*recaptures adjusted due to PIT reader malfunction (see Results Section 3.1.5 and Table 4)

Table 6. Proportion (%) of female chum salmon per spawner category on the Cheakamus River by habitat type in 2012

Habitat Type	N	Spawner Category Spawned Out	 Partially Spawned	 Unspawned
Mainstem Habitat	602	89.0%	9.1%	1.8%
Side channel Habitat	773	82.9%	17.0%	0.1%
All Habitats Types	**1375**	**85.6%**	**13.5%**	**0.9%**

Table 7. Proportion (%) of female chum salmon assigned to each spawner category and number (N) of females assessed for pre-spawn mortality in each side channel on the Cheakamus River in 2012

Side channel	N	Spawner Category Spawned Out	 Partially Spawned	 Unspawned
Lower Mykiss	13	92.3%	7.7%	0.0%
BC Rail	40	45.0%	55.0%	0.0%
NVOS	458	86.7%	13.1%	0.2%
BC49	262	81.7%	18.3%	0.0%
All Surveyed Side channels	**773**	**82.9%**	**17.0%**	**0.1%**

Table 8. Percentage of female chum salmon per spawner category and number (N) of females assessed for pre-spawn mortality in the NVOS Side channel complex in 2012

NVOS Side channel	N	Spawner Category Spawned Out	 Partially Spawned	 Unspawned
Baby Gorb	41	82.9%	14.6%	2.4%
Kisutch	123	77.2%	22.8%	0.0%
Sues	41	90.2%	9.8%	0.0%
Upper Paradise	151	90.1%	9.9%	0.0%
Upper Upper Paradise	102	93.1%	6.9%	0.0%
All NVOS Side channels	**458**	**86.7%**	**13.1%**	**0.2%**

Table 9. Proportion (%) of eggs retained and eggs deposited by female chum salmon in the Cheakamus River in 2012

Habitat Types	% Eggs Retained	% Eggs Deposited
Mainstem Habitat	13.3%	86.7%
Side channel Habitats	15.6%	84.4%
NVOS side channels	13.8%	86.2%
BC Rail side channel*	34.5%	65.5%
All Habitats Types	**14.6%**	**85.4%**

* one sampling period, not representative of entire run

Table 10. Egg deposition rates in side channel habitats upstream of the RSTs on the Cheakamus River in 2012

Side channel	25-Oct	1-Nov	14-Nov	21-Nov	27-Nov	Total Change Over Time
BC49	88.7%	78.7%	87.6%		78.9%	-9.8%
Upper Upper Paradise	93.0%	88.0%	90.2%		89.1%	-4.0%
Upper Paradise		89.4%	91.5%		84.4%	-5.0%
Kisutch			87.3%		76.1%	-11.2%
Sues			85.9%		93.0%	7.1%
BC Rail				65.5%		
Lower Mykiss Channel					89.2%	
Baby Gorb					83.4%	
All side channels	**90.9%**	**85.4%**	**88.5%**	**65.5%**	**84.9%**	**-6.0%**

Table 11. Egg deposition rates in the mainstem habitat on the Cheakamus River in 2012

Mainstem Habitat	
Date	**Deposition Rates**
25-Oct	93.0%
8-Nov	92.1%
14-Nov	87.6%
16-Nov	86.3%
21-Nov	85.0%
27-Nov	85.7%
Total Change Over Time	**-7.3%**

Table 12. 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

NVOS	% Kelts	Total	PIT Tagged Kelts			BC Rail	% Kelts	Total	PIT Tagged Kelts	
			Males	Females					Males	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
PIT Tagged Kelt Total (71)			66	5		PIT Tagged Kelt Total (13)			9	4

*averaged from 2008-2011

Table 13. Resistivity fish counter efficiency (%) based on video validation, range in parenthesis

NVOS	Up	Down		BC Rail	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 (24-80)	75 (50-200)		2012	80	71

*at normal flows

Table 14. Pooled Petersen Estimates of chum salmon spawner abundance for the Cheakamus River upstream of the RST site and for the full river, 2007-2011 with 95% confidence limits.

	Estimate Upper River	95% CL LCL	95% CL UCL	Estimate Total River	95% CL LCL	95% CL UCL
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

Table 15. Average daily discharge (m^3/s) during peak chum spawning on the Cheakamus River (November 1 to November 15) from 2007 to 2012.

Date	2007	2008	2009	2010	2011	2012
1-Nov	20.4	31.1	49.1	57.9	23.3	54.9
2-Nov	18.6	67.4	23.0	49.3	17.6	42.3
3-Nov	18.7	92.1	19.0	33.2	16.7	79.9
4-Nov	24.1	28.9	20.1	30.1	16.0	80.9
5-Nov	20.7	25.5	31.2	48.5	15.9	70.9
6-Nov	19.0	25.2	43.0	96.5	16.5	32.4
7-Nov	19.4	24.6	32.2	101.0	16.8	21.2
8-Nov	19.3	70.5	27.5	74.7	16.3	17.9
9-Nov	38.9	118.0	44.9	44.8	16.5	16.6
10-Nov	46.7	91.7	34.2	28.9	21.4	17.3
11-Nov	35.2	33.8	28.6	27.4	22.3	17.3
12-Nov	71.5	56.1	22.2	26.2	19.7	16.9
13-Nov	39.8	67.2	29.3	25.2	17.0	16.5
14-Nov	28.6	36.6	71.2	24.3	16.1	16.1
15-Nov	38.1	26.0	50.3	25.1	16.4	16.1
Average	**30.6**	**53.0**	**35.1**	**46.2**	**17.9**	**34.5**
Minimum	**18.6**	**24.6**	**19.0**	**24.3**	**15.9**	**16.1**
Maximum	**71.5**	**118.0**	**71.2**	**101.0**	**23.3**	**80.9**

Table 16. Estimates of chum salmon spawner numbers at NVOS and BC Rail spawning channels and Tenderfoot Creek, 2007-2012.

	Year					
Location	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
NVOS	2,170	3,263	9,357	2,048	2,915	8,859
Tenderfoot	1,555	3,309	3,003	293	713	5,419
BC Rail	522	1,279	3,243	367	754	683
Total Channels	4,247	7,851	15,603	2,708	4,382	14,961

Table 17. Number of juvenile chum caught, marked and recaptured at the rotary screw trap on the Cheakamus River from 2001-2013 and Bayesian Time-Stratified Population Analysis System population estimates with upper and lower confidence limits, standard deviation and coefficient of variation. Bold = post-WUP estimates

Coefficient of Variation > 0.3 = Poor precision.

Year	Total Caught	Total Marked	Total Recap	BTSPAS Estimate	95% Upper CL	95% Lower CL	SD	CV
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**

Table 18. Chum Fry Production on the Cheakamus River upstream of the RST site 2008-2013

Year	NVOS		BC Rail		Tenderfoot		Side channel Yield	Mainstem & TF Yield	Mainstem Yield
	Mean	CV	Mean	CV	Mean	CV			
2008	965,069	0.04	156,740	0.02			1,121,836	2,684,494	
2009	924,726	0.03	391,018	0.12			1,315,744	1,709,022	
2010	1,986,853	0.02	268,755	0.02			2,255,608	5,008,836	
2011	557,908	0.02	23,022	1.05			580,930	1,301,759	
2012	668,231	0.02	98,153	0.05			766,366	1,994,304	
2013	2,428,254	0.02	459,562	0.01	2,854,058	0.42	5,741,874		5,053,570

Table 19. Summary of mean chum fry lengths (mm) 2001-2012 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**

Table 20. Egg-to-fry Survival by Habitat Area

Location	Egg-to-fry Survival	Egg-to-fry Survival -not accounting for pre-spawn mortality
All area above RST	6.6%	5.7%
Mainstem above RST	3.6%	3.1%
NVOS side channel complex	23.1%	19.9%
BC Rail side channel	58.0%	49.0%
Tenderfoot Creek Natural Spawners	53.9%	45.5%

7.0 FIGURES

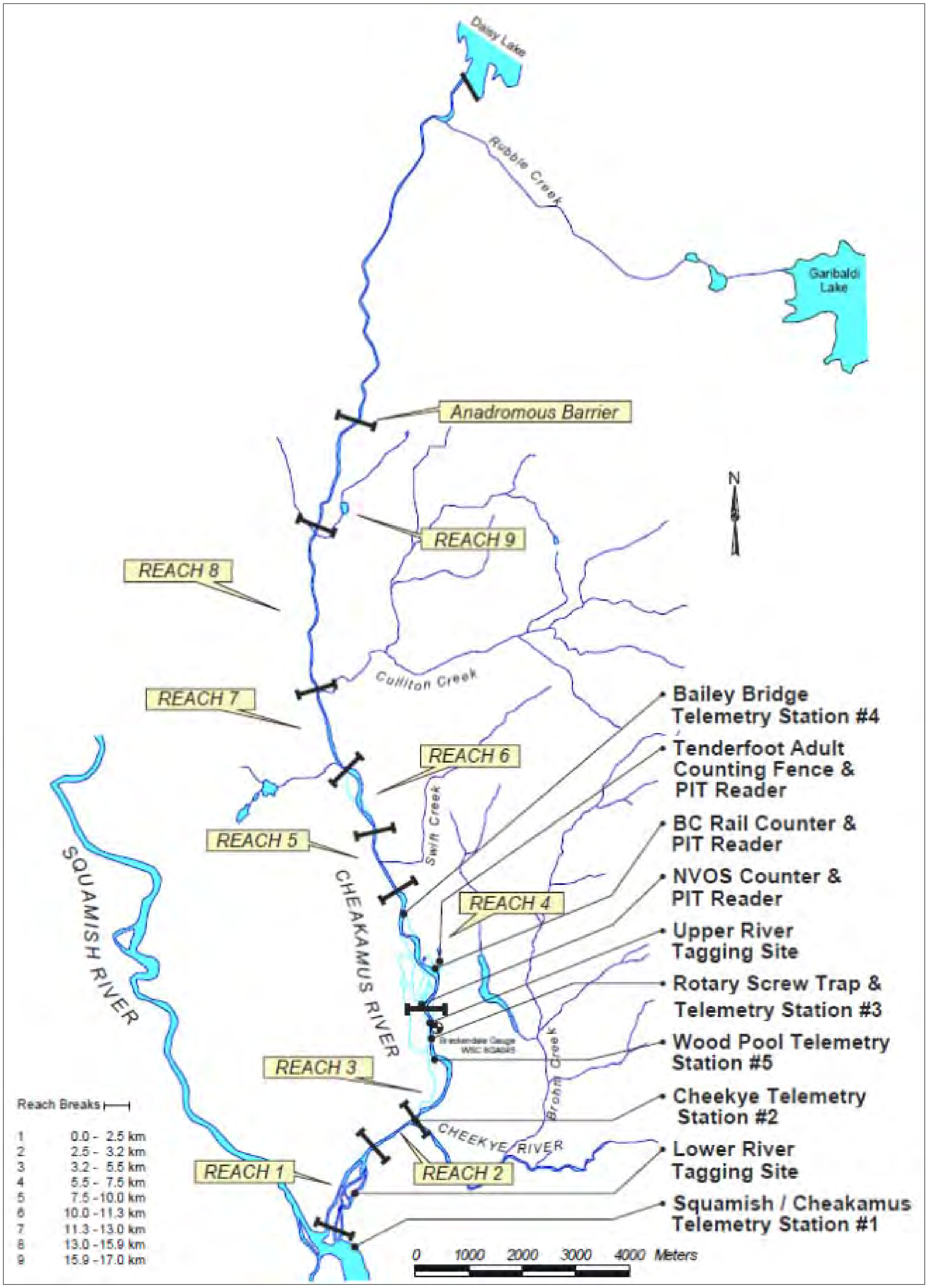

Figure 1: Study area for Cheakamus River chum salmon escapement monitoring (River KM 0.5- 8.0)

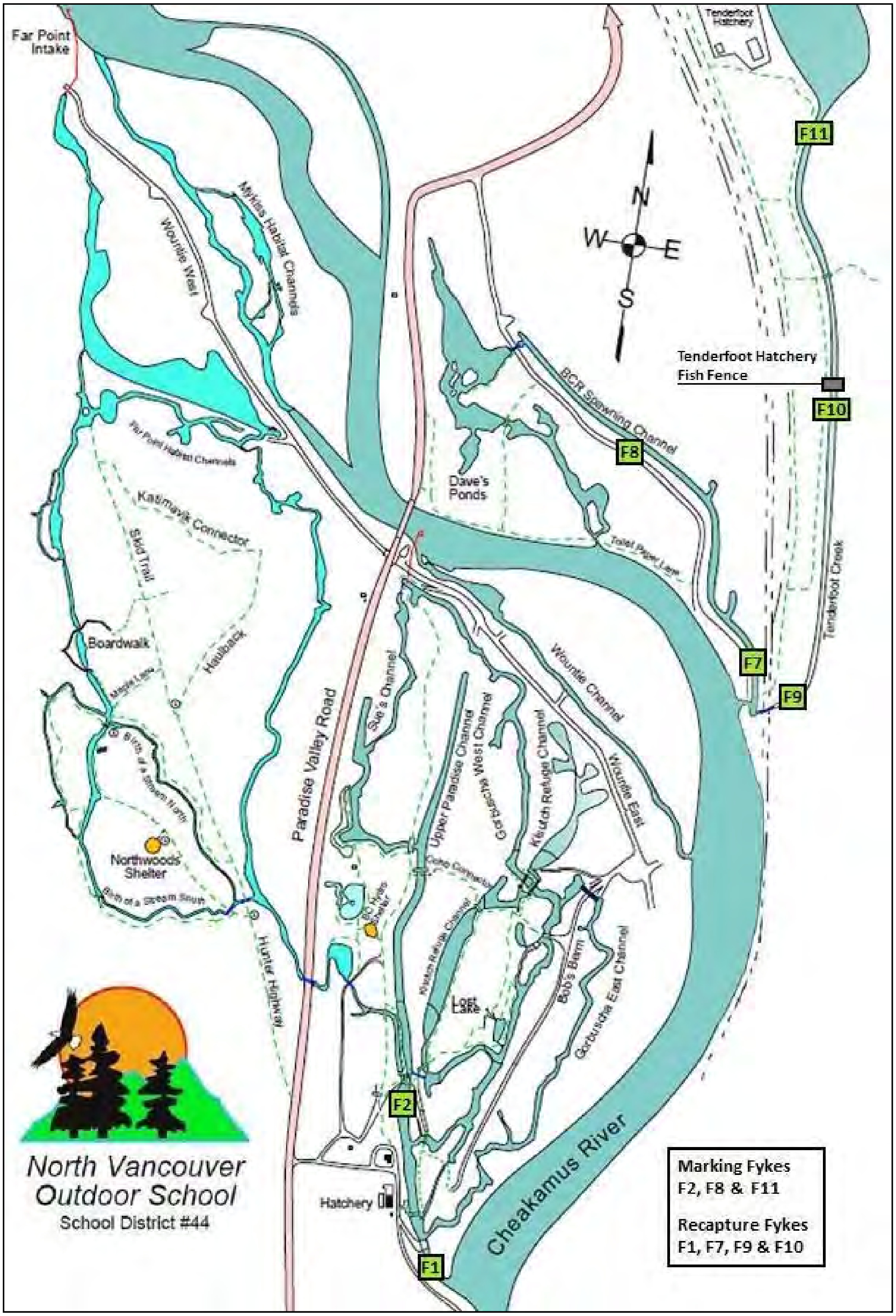

Figure 2. Site map showing fyke trap locations and network of side channels upstream of the RST site (Figure 1)

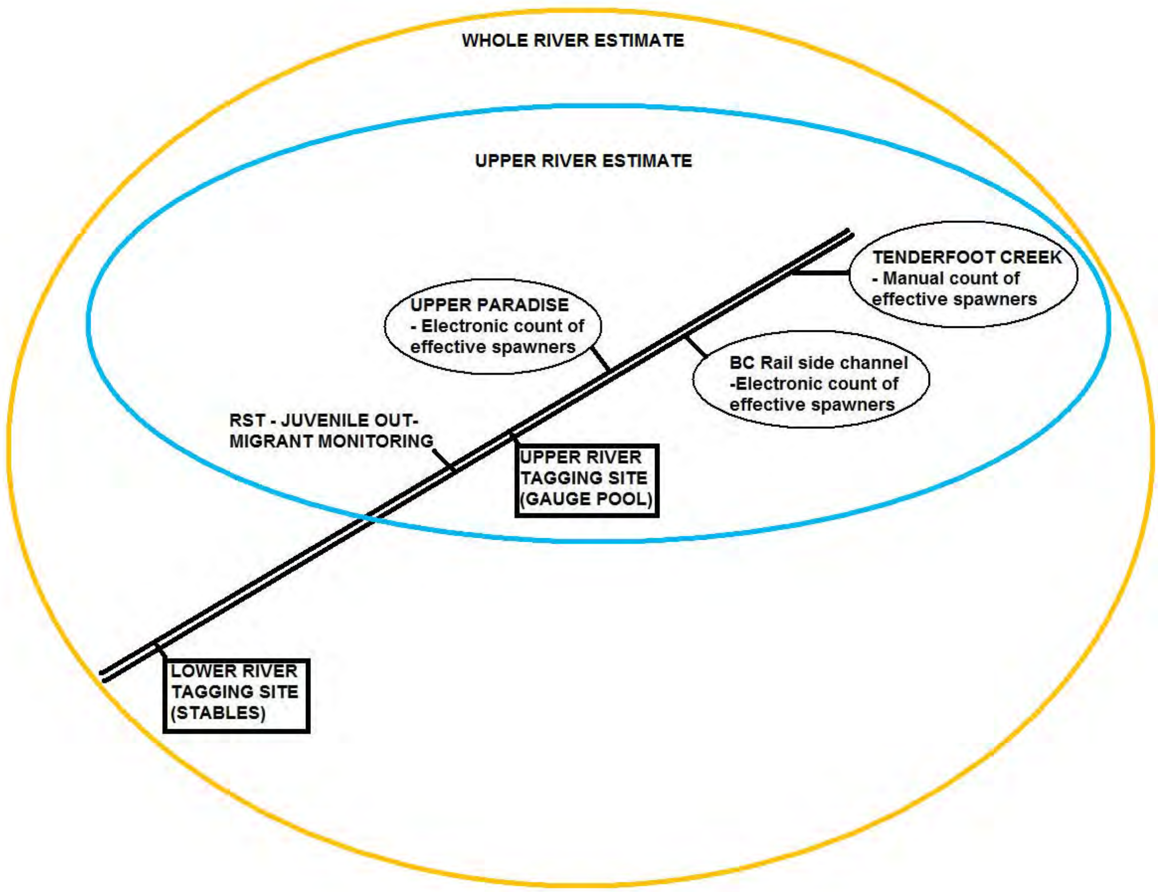

Figure 3. Conceptual diagram of the Cheakamus River chum salmon spawner enumeration monitor illustrating the spatial relationship of tagging and monitoring locations. Whole river (yellow ellipse), Upper river (blue ellipse), and individual side channel (black ellipses) spawner estimates are highlighted.

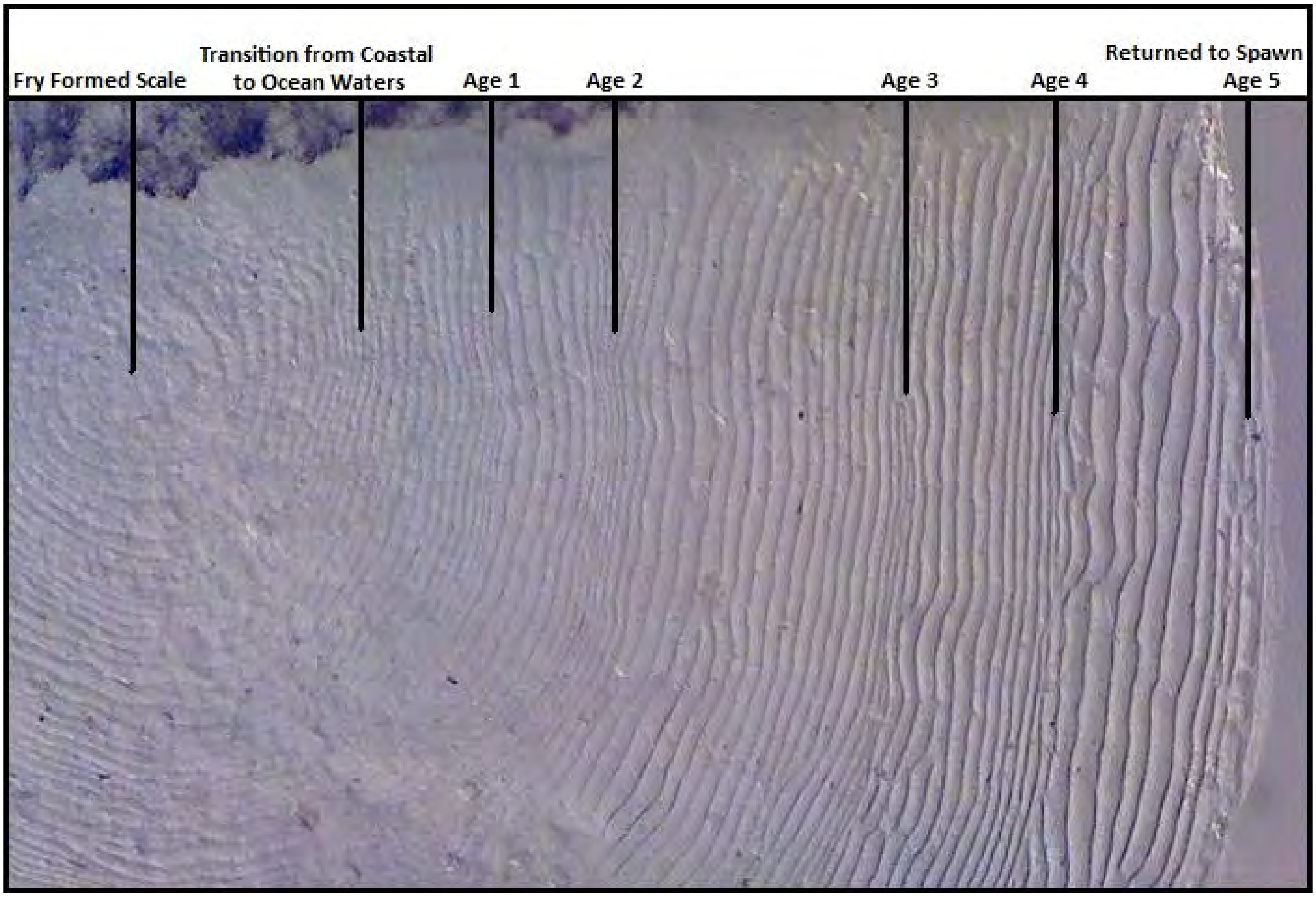

Figure 4. Magnified chum scale (200x) showing periods of slowed growth during the transition from coastal to ocean waters and winter periods at age 1,2,3,4, and returning to spawn at age 5

Figure 5. 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

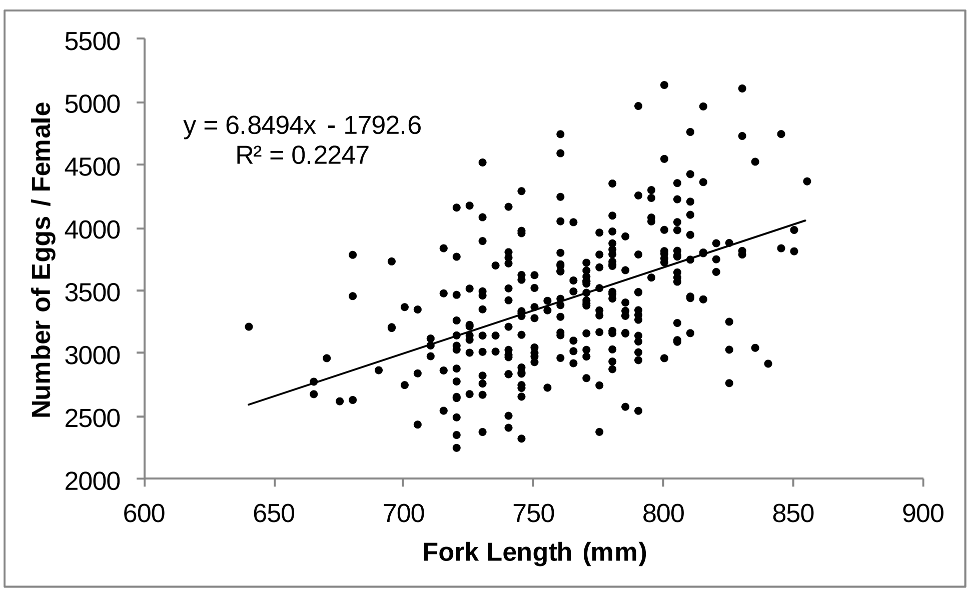

Figure 6. Fecundity (number of eggs/female) vs. fork length (mm); female chum salmon from Tenderfoot Creek, 2012

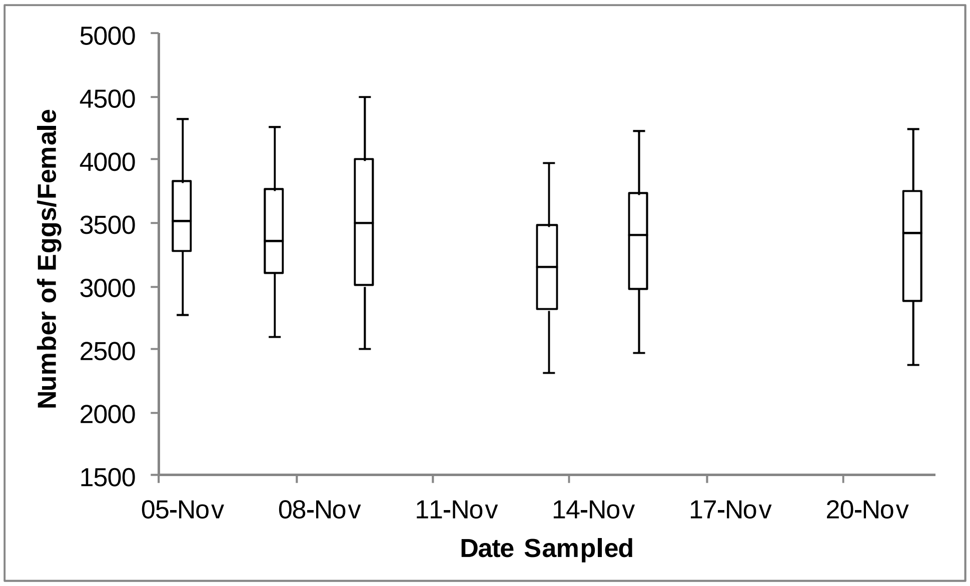

Figure 7. Box plots showing the variation (min and max), 1st to 3rd quartile (box) and median (line in box) in fecundity of female chum salmon sampled at Tenderfoot Creek throughout the chum run in 2012

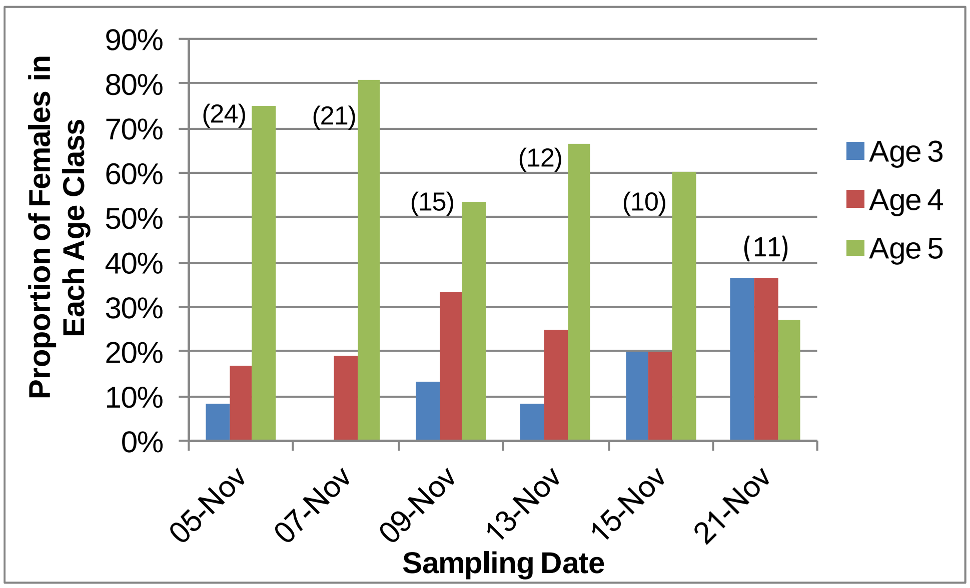

Figure 8. Proportion of female chum salmon in each age class (number aged in parenthesis) during each sampling session at Tenderfoot Creek, 2012

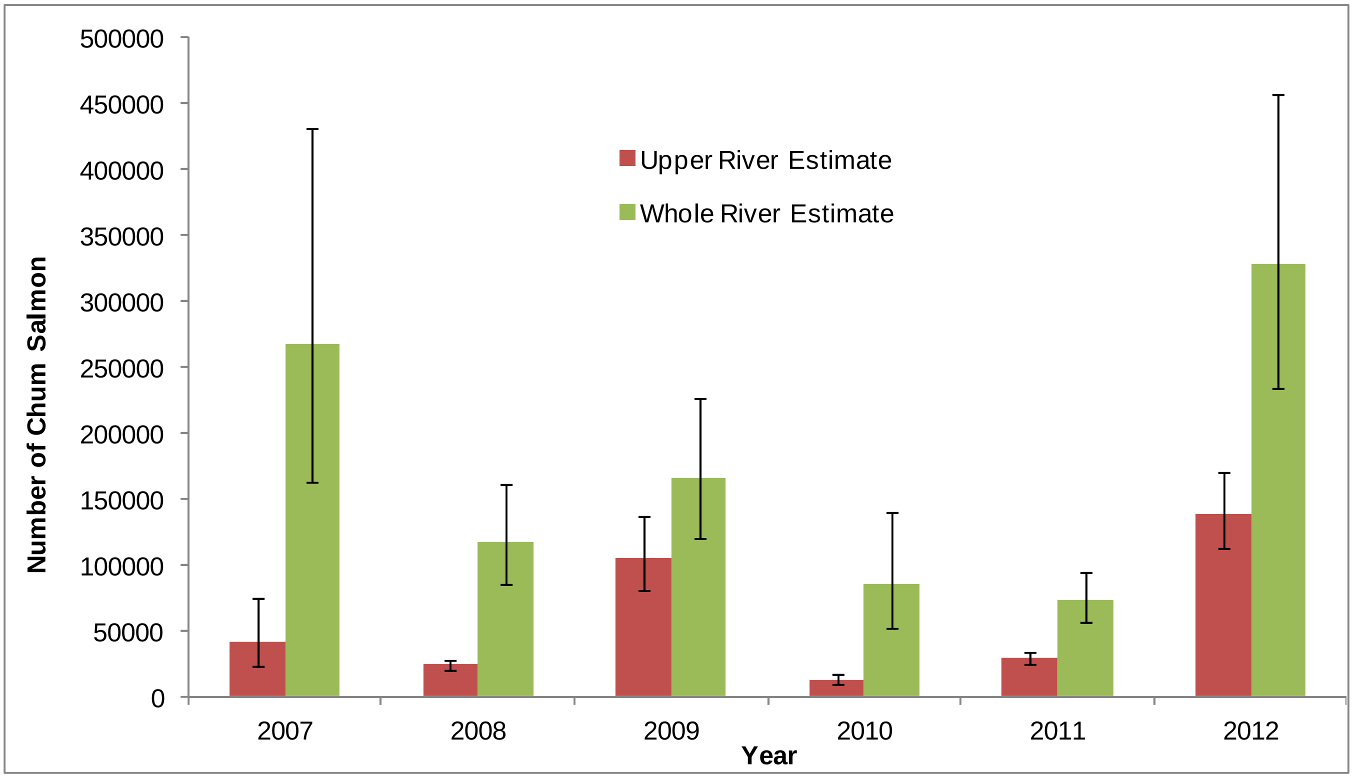

Figure 9. Pooled Petersen Estimate of chum spawner escapement in the upper portion of the Cheakamus River and whole river estimate with 95% confidence limits from 2007-2012

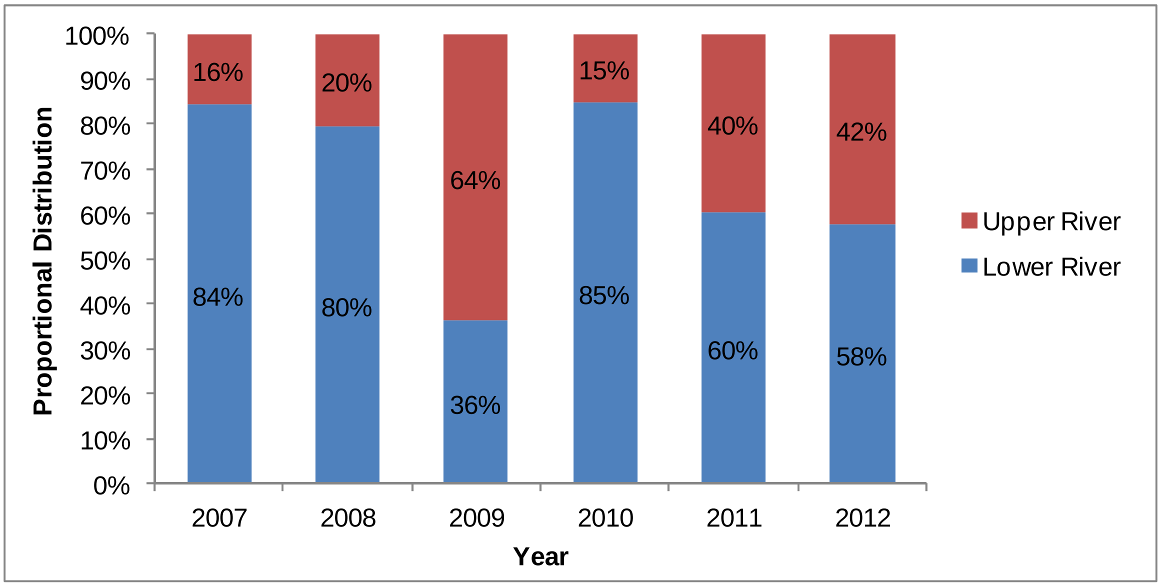

Figure 10. Distribution of chum spawners in the upper and lower river habitat areas from 2007 to 2012

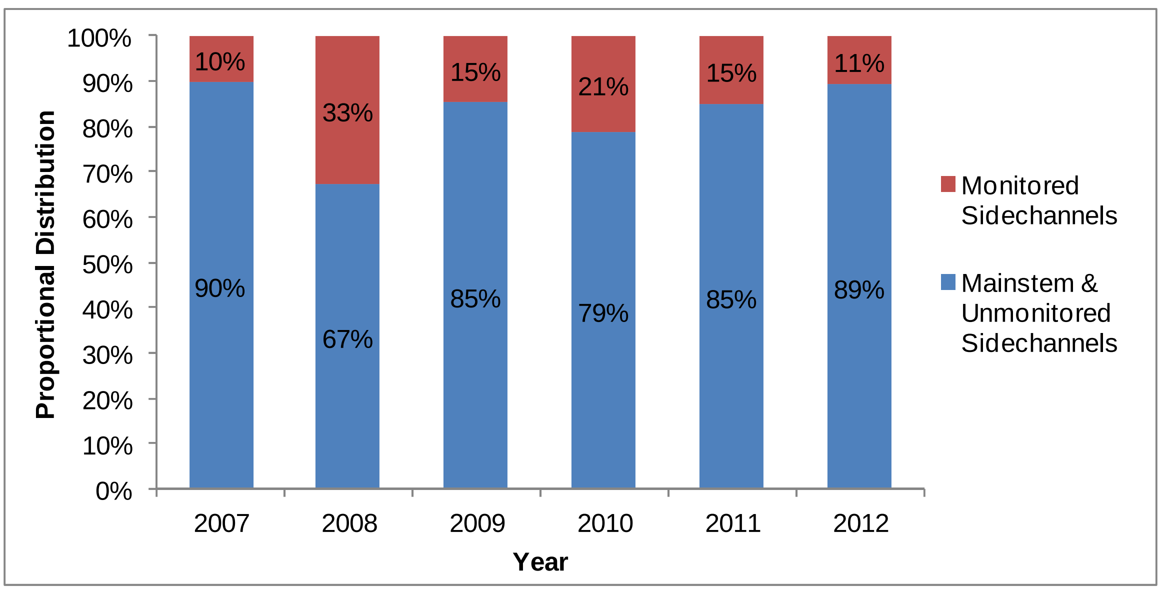

Figure 11. Proportion of upper river chum spawners utilizing monitored side channel habitats and those utilizing the mainstem and unmonitored side channel habitats from 2007 to 2012

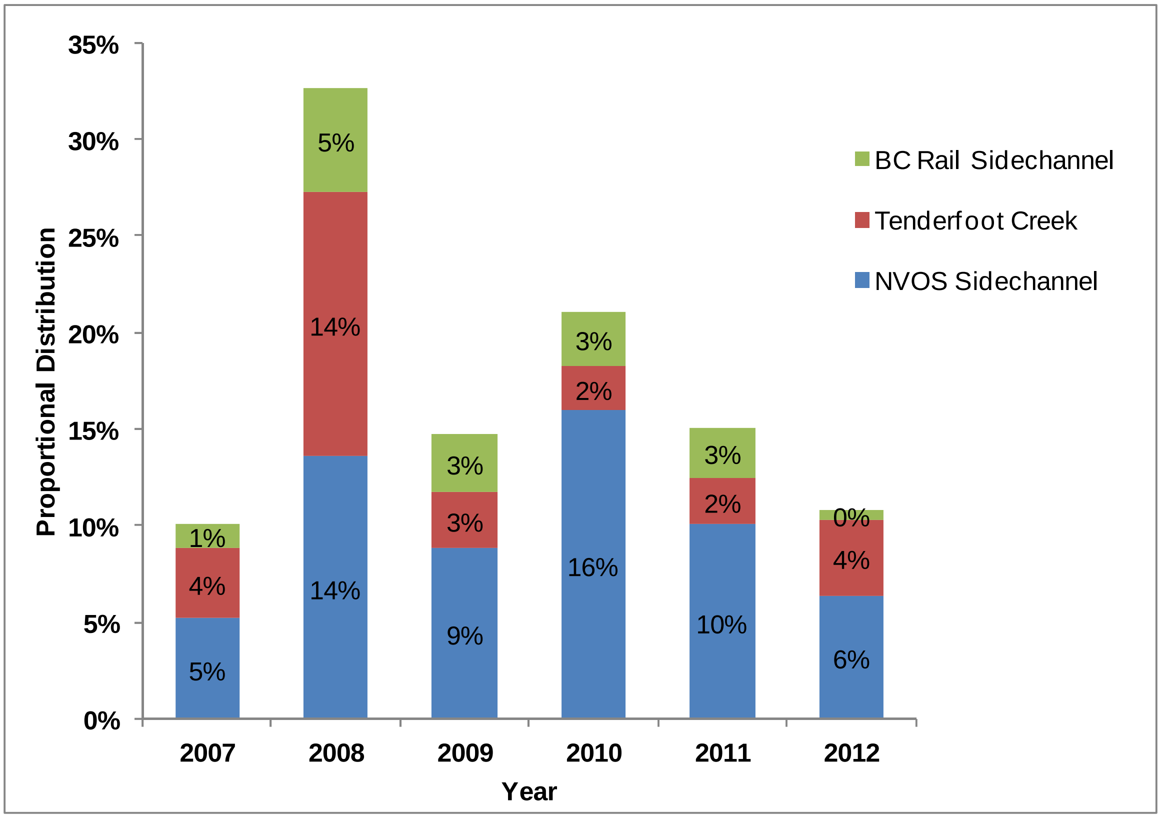

Figure 12. Proportion of upper river chum spawners utilizing the side channel habitats from 2007 to 2012. Side channels proportions derived from resistivity counts for NVOS and BC Rail side channels and manual counts for Tenderfoot Creek

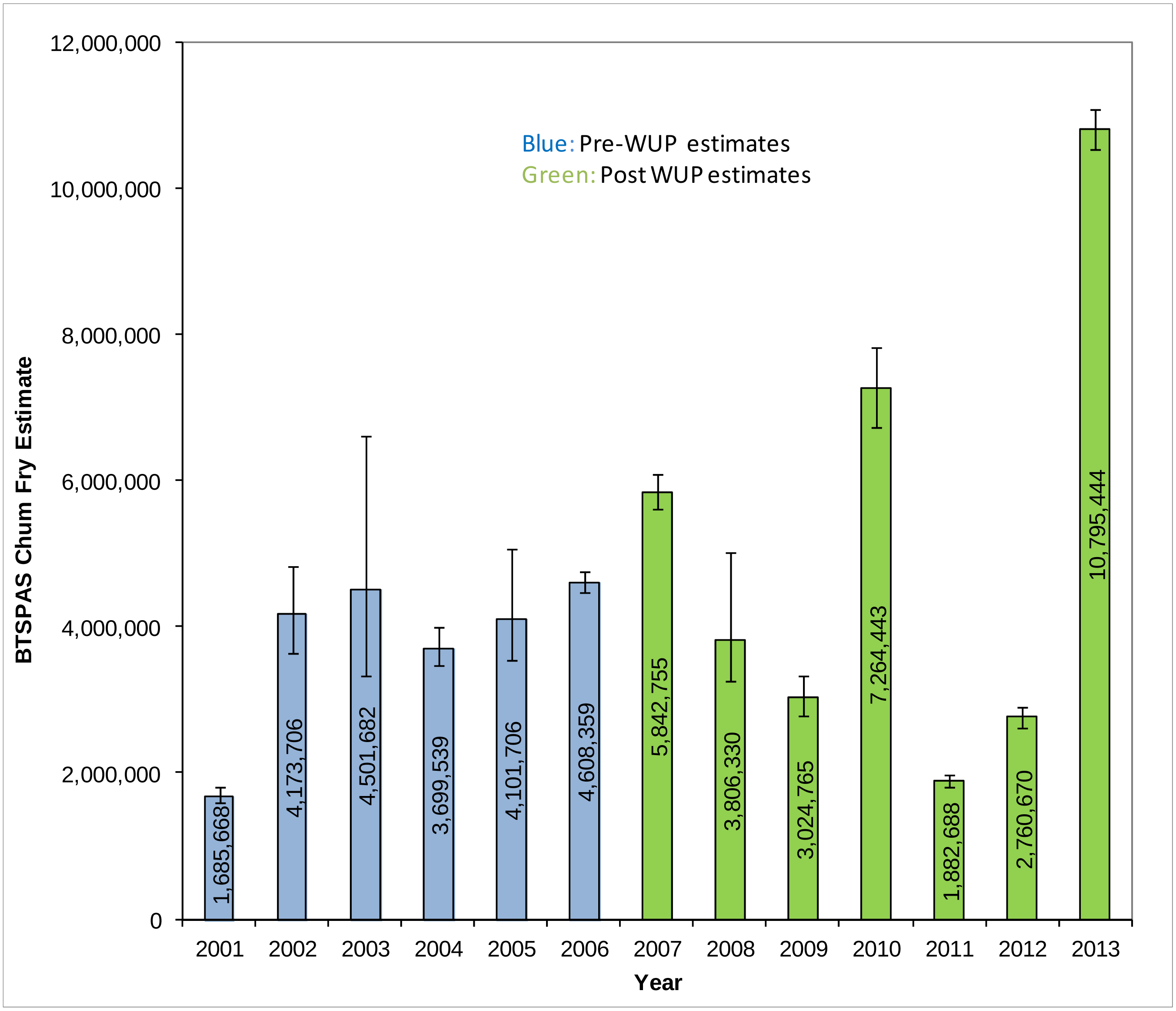

Figure 13. Bayesian Time-Stratified Population Analysis System (BTSPAS) Estimate of chum fry outmigrating from upstream of the Rotary Screw Traps on the Cheakamus River from 2001-2013 including 95% confidence limits

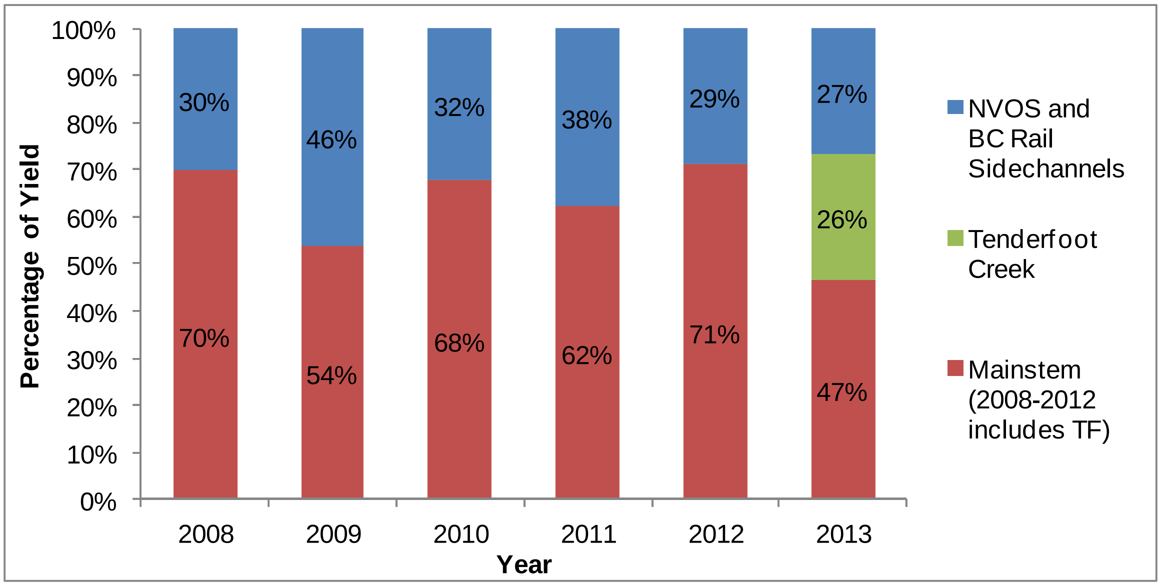

Figure 14. Yield of chum fry from the mainstem habitat, NVOS and BC Rail side channels and Tenderfoot Creek (2013) in the Cheakamus River 2008-2013

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APPENDIX A. Supplemental Data

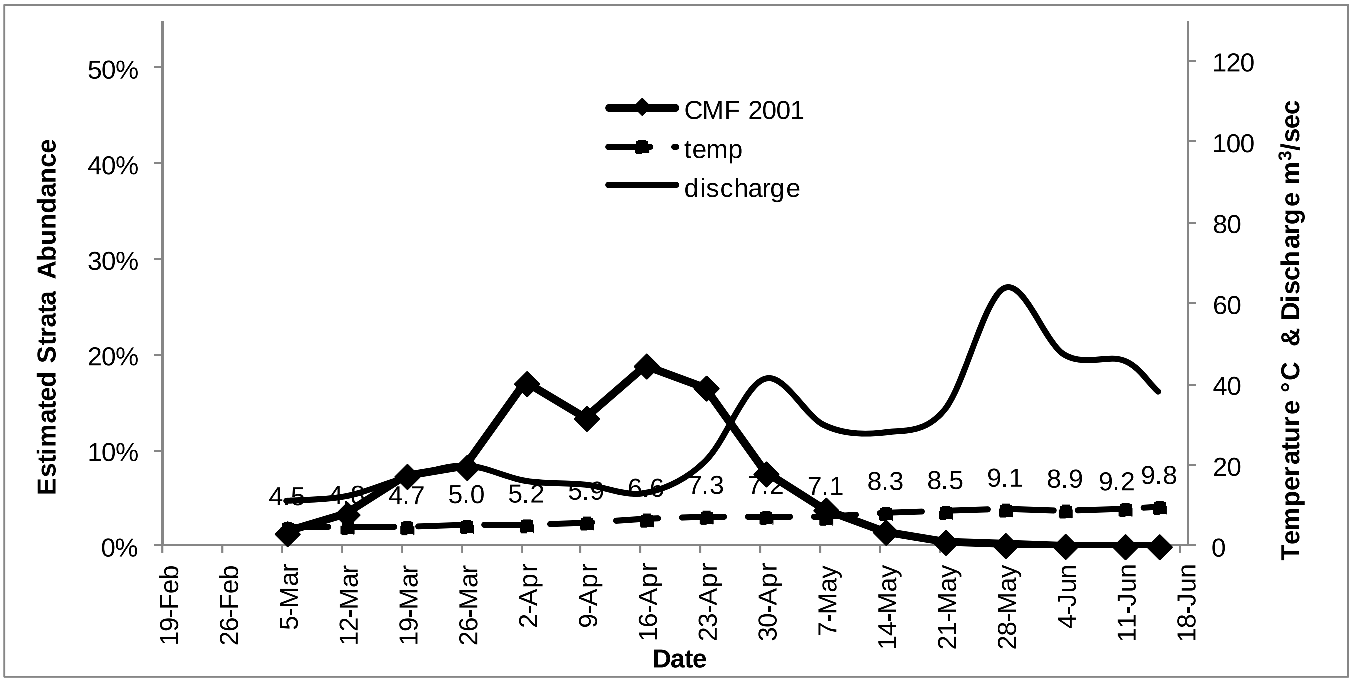


Figure 1A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2001 (Pre-WUP)

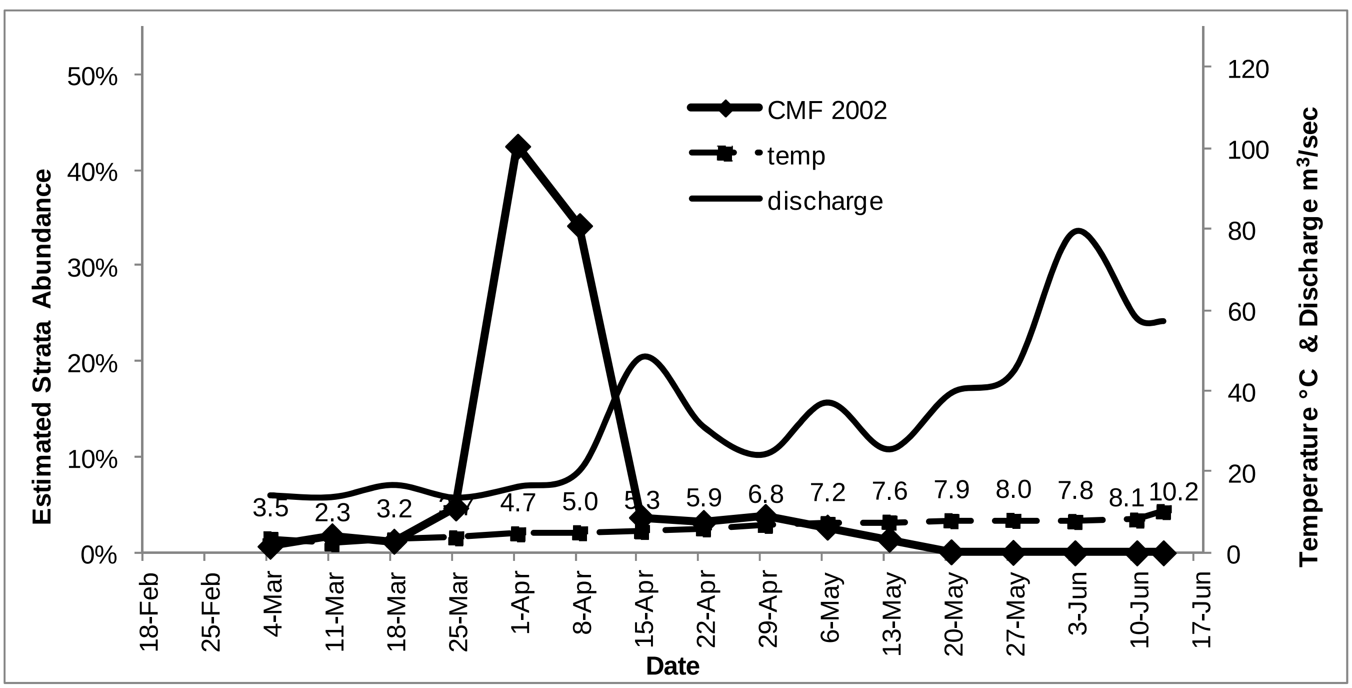


Figure 2A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2002 (Pre-WUP)

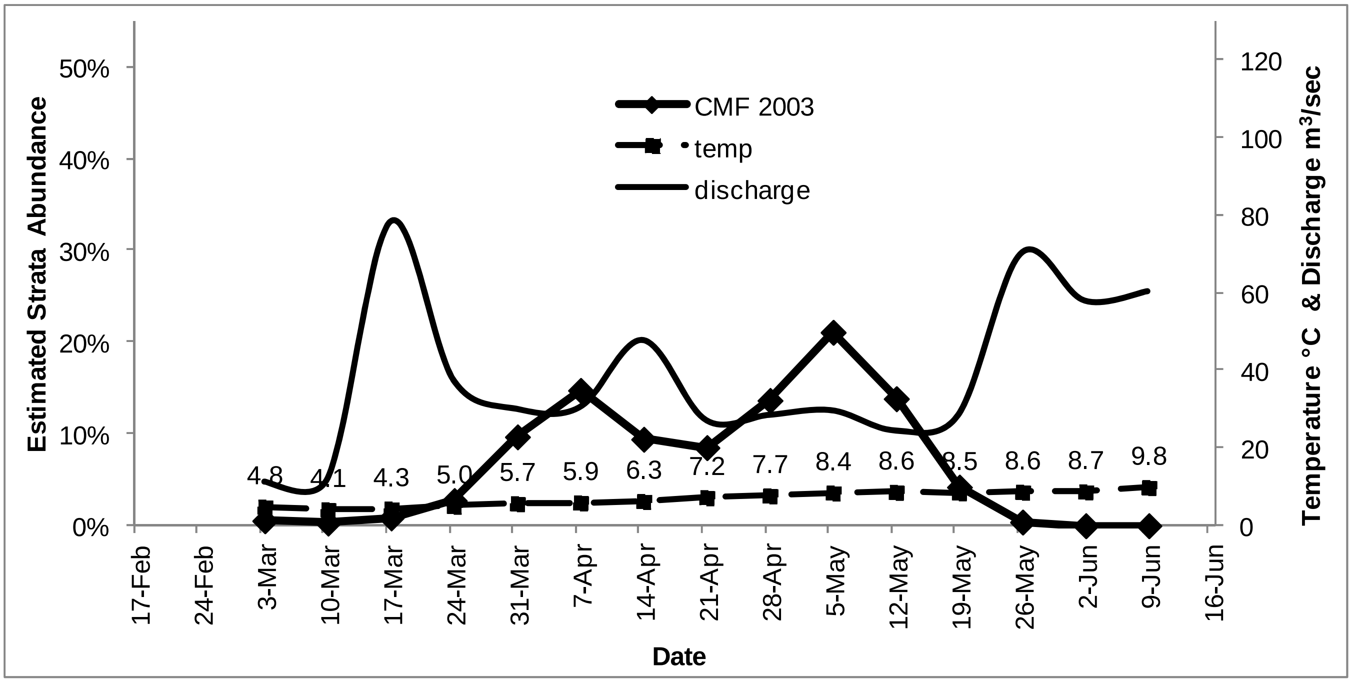


Figure 3A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2003 (Pre-WUP)

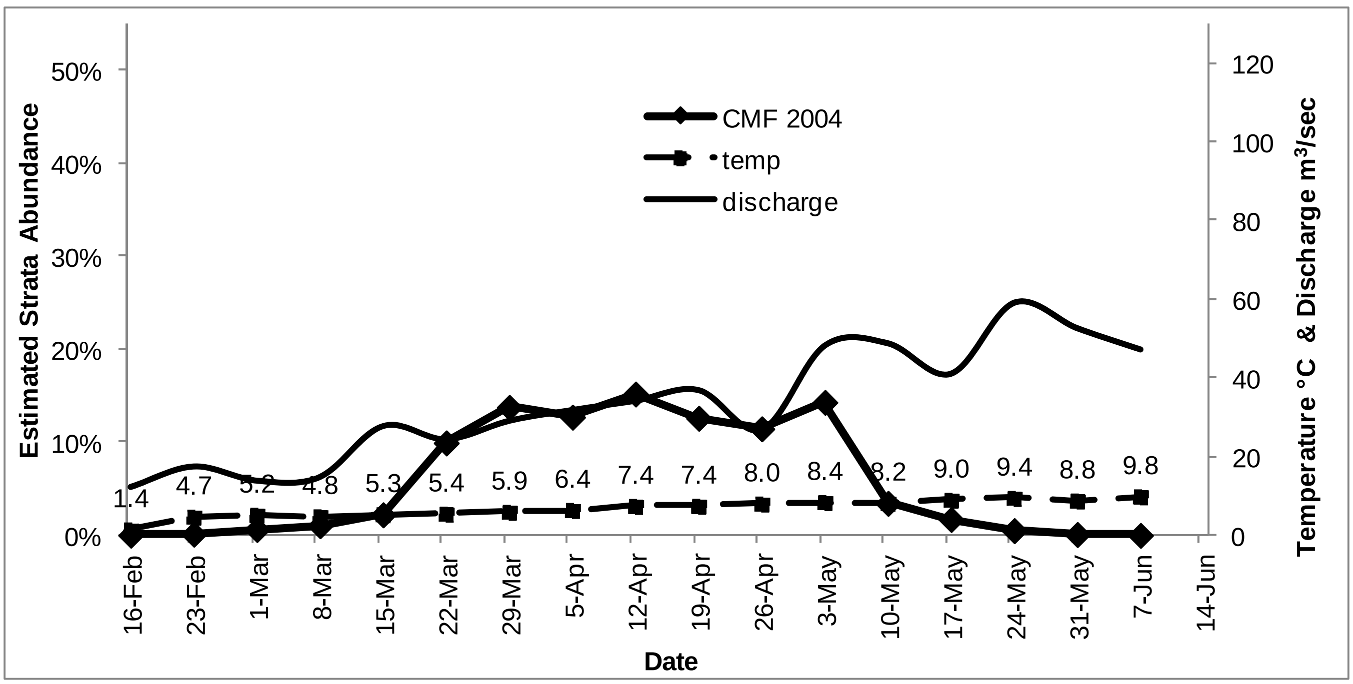


Figure 4A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2004 (Pre-WUP)

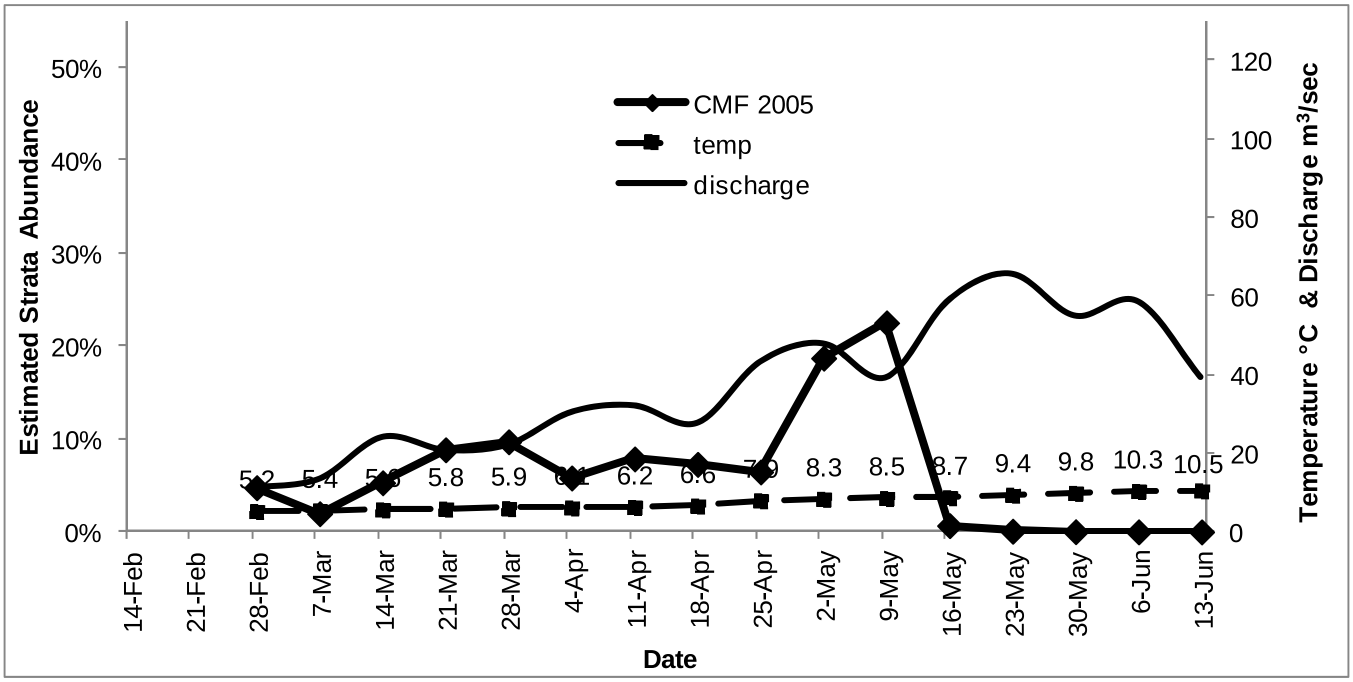


Figure 5A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2005 (Pre-WUP)

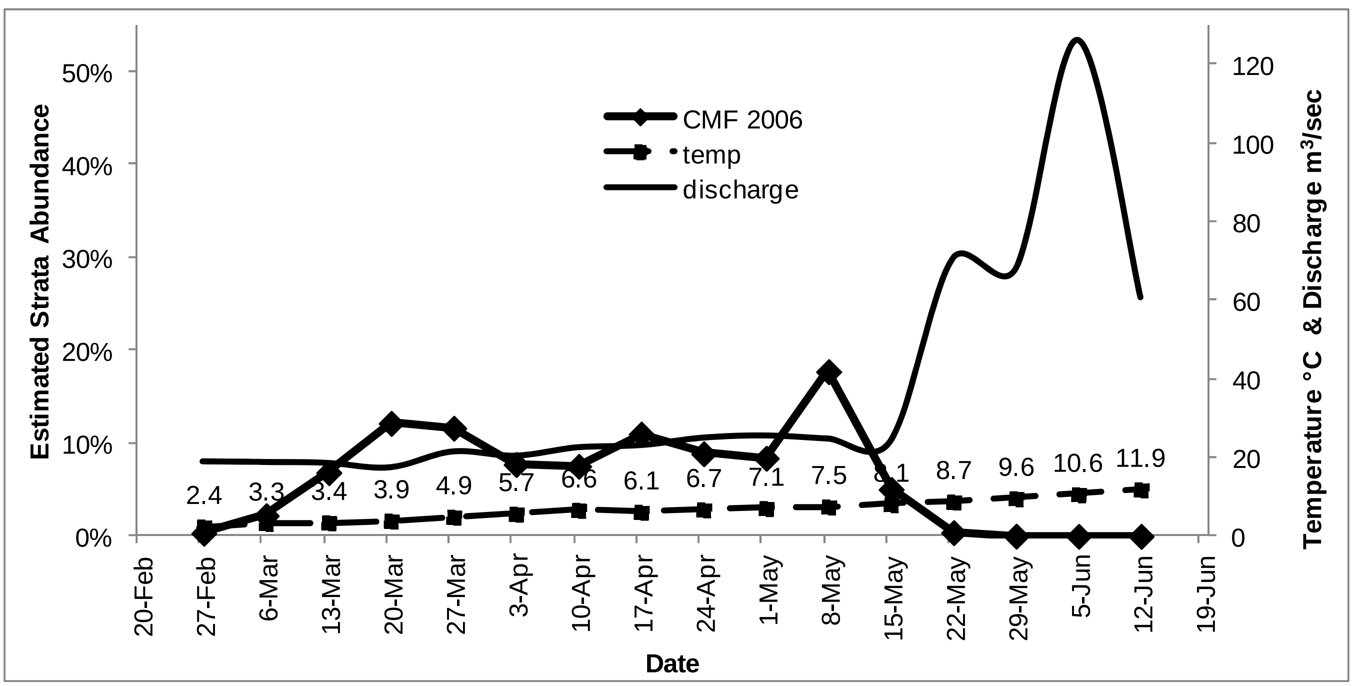


Figure 6A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2006 (Post-WUP)

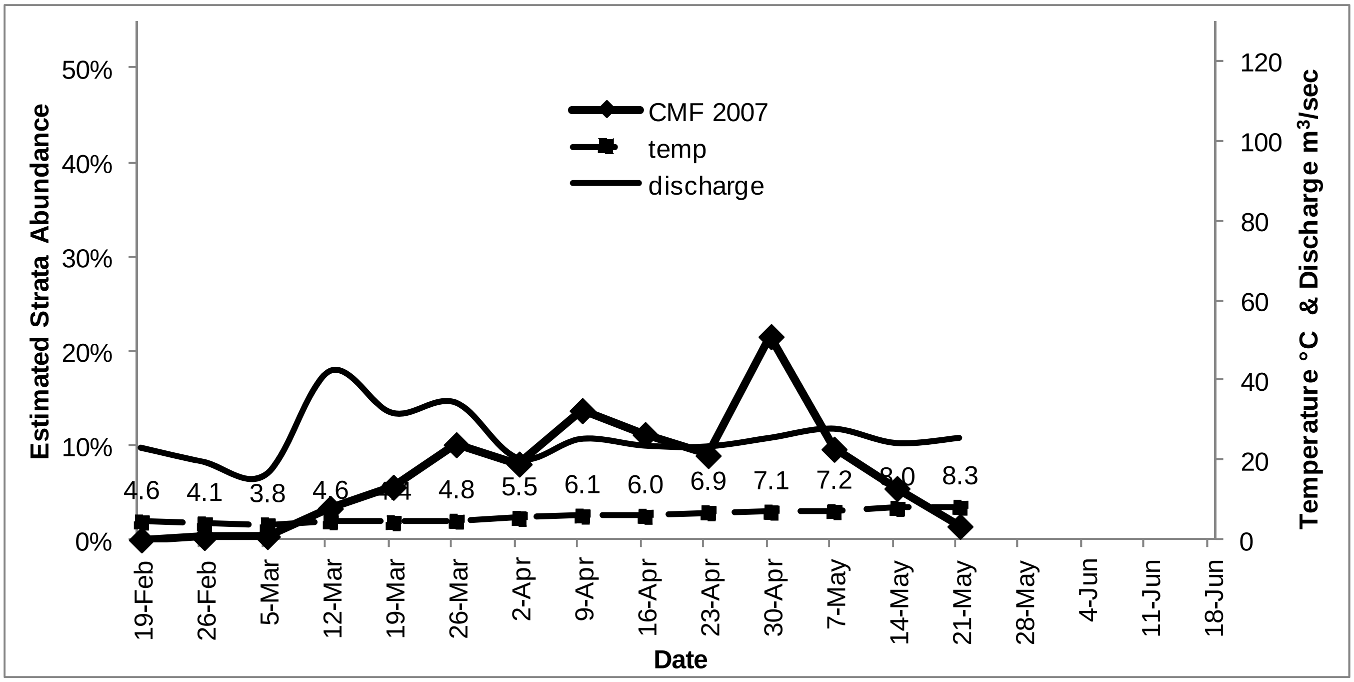


Figure 7A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2007 (Post-WUP)

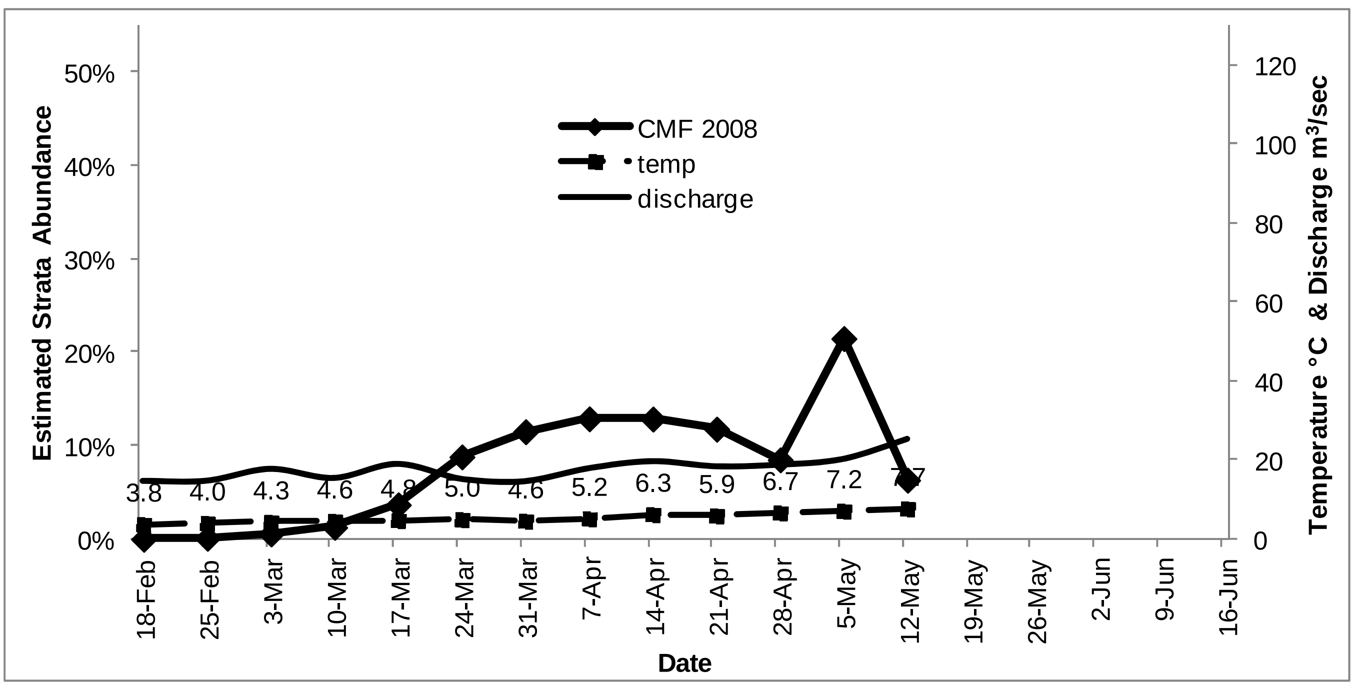


Figure 8A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2008 (Post-WUP)

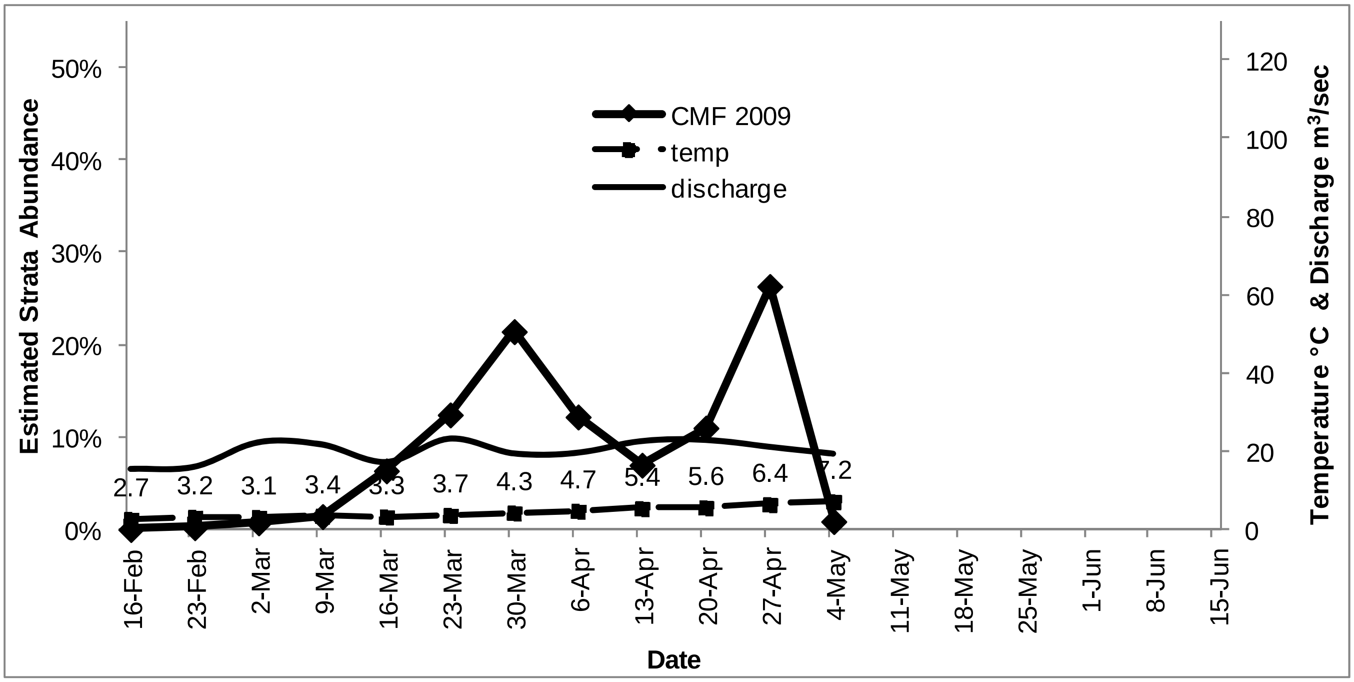


Figure 9A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2009 (Post-WUP)

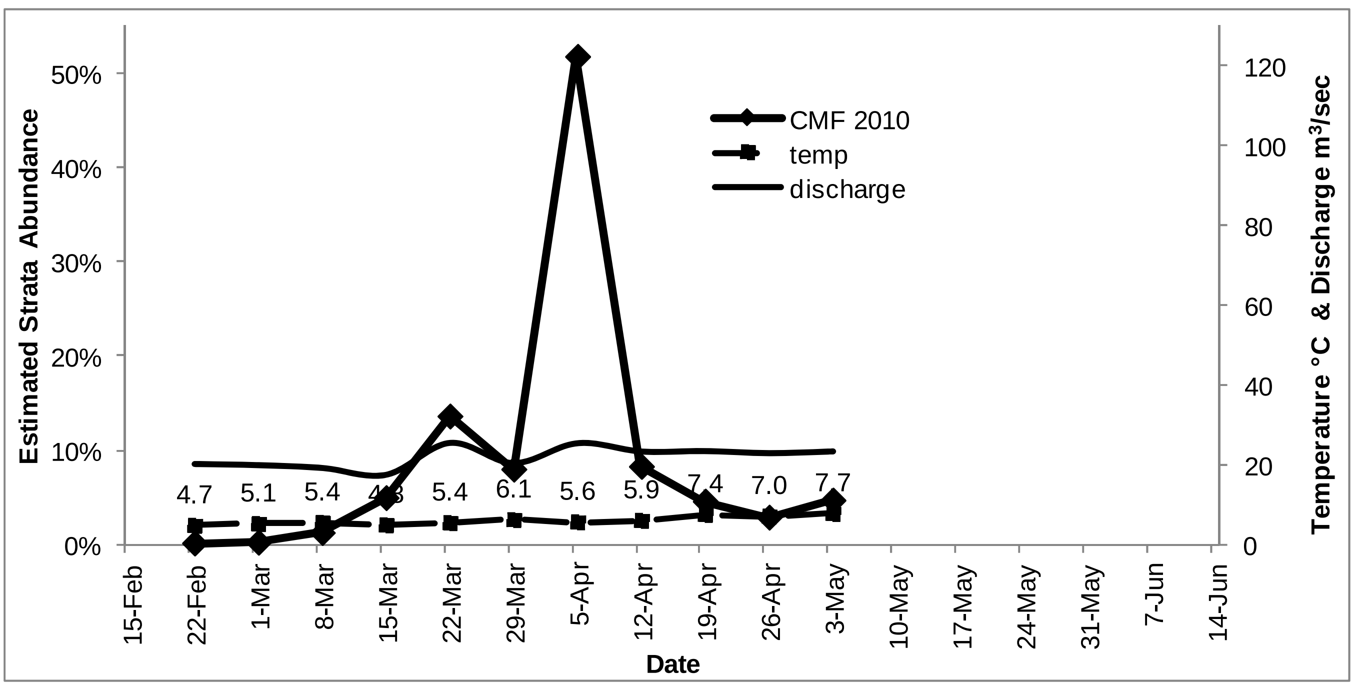
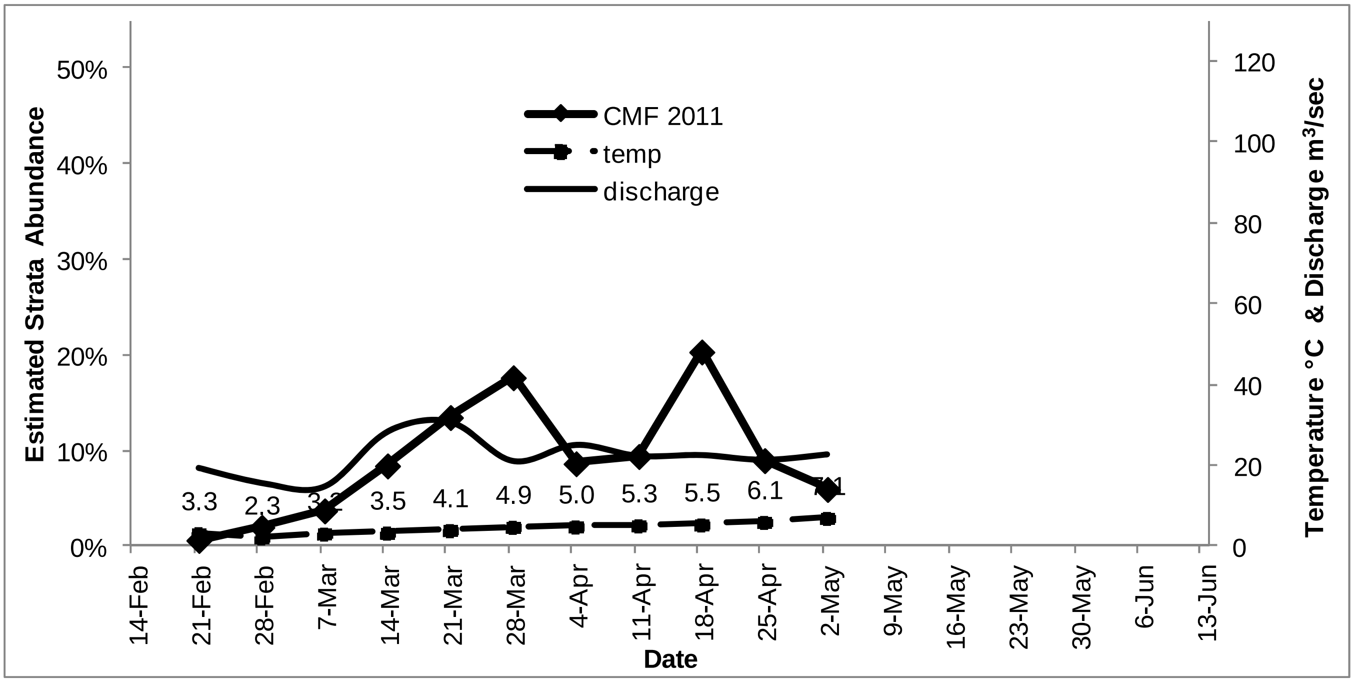


Figure 10A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2010 (Post-WUP)



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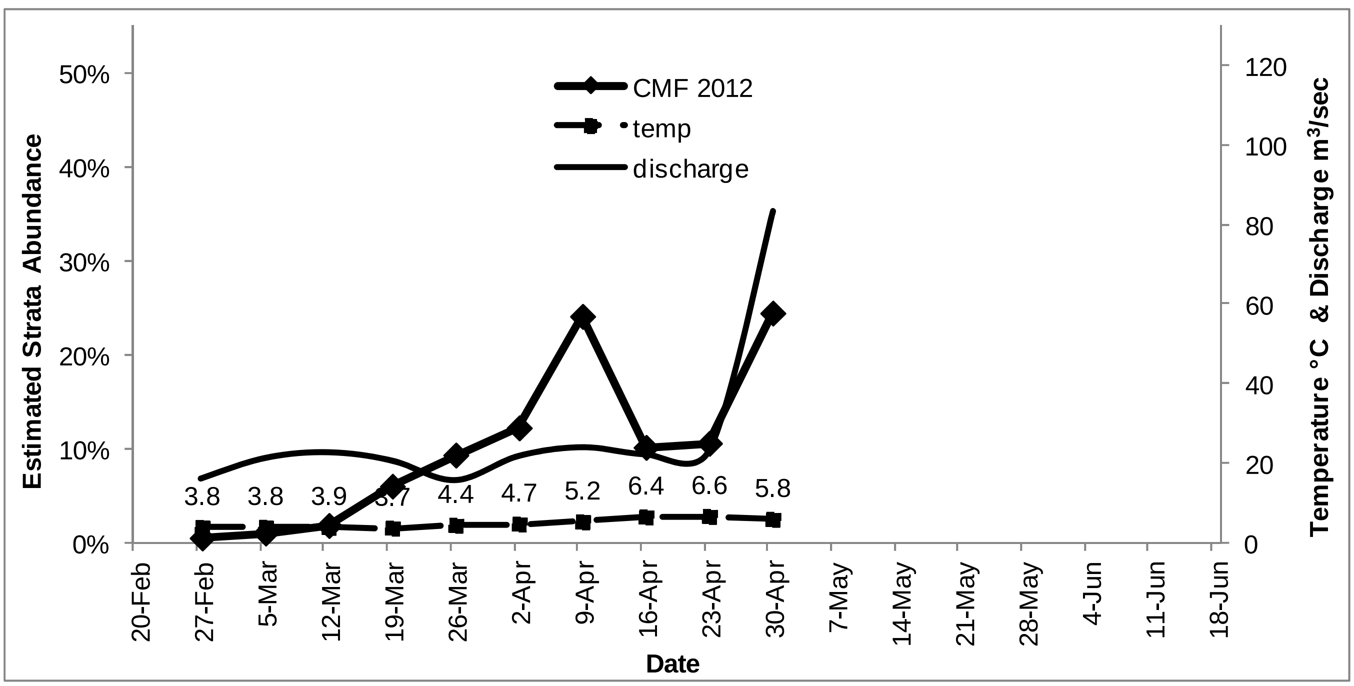

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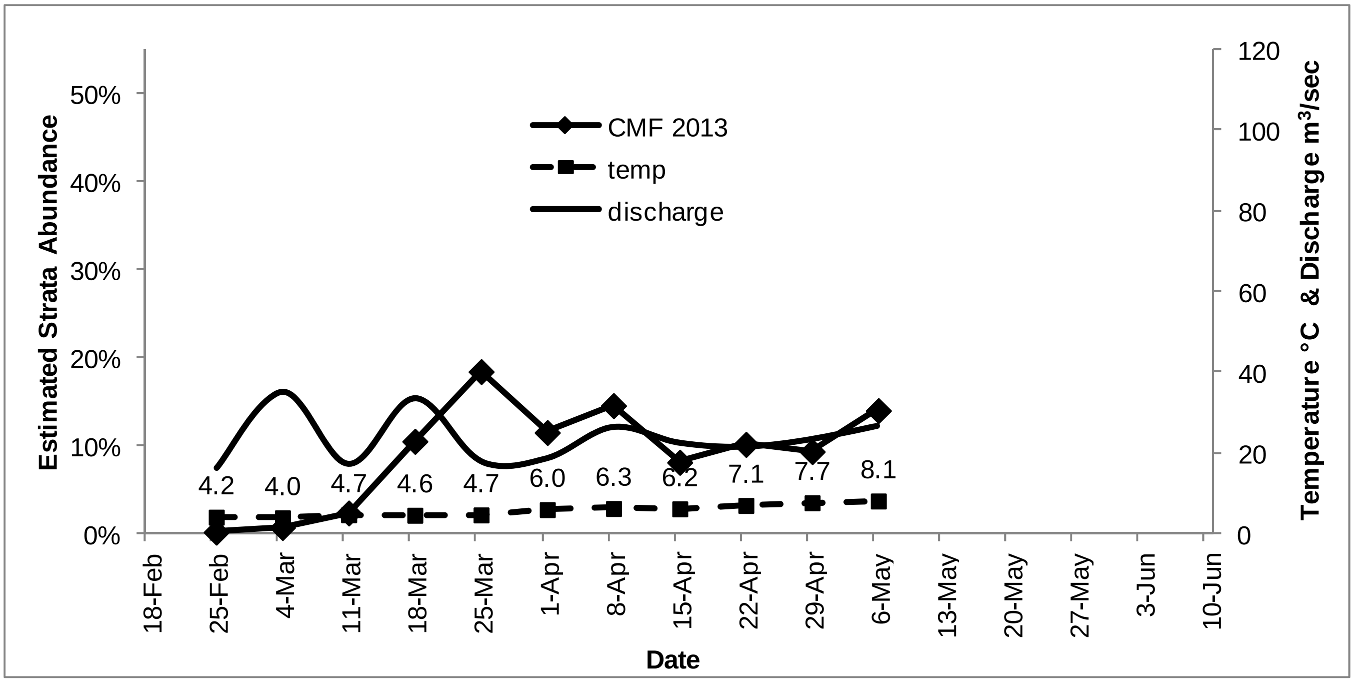

Figure 13A. Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in °C (broken line, squares) and discharge (solid line) from the Cheakamus River in 2013 (Post-WUP)