Cheakamus River Project Water Use Plan

Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey

Implementation Year 5

Reference: CMSMON-1B

Cheakamus River Chum Salmon Salmon Adult Spawner and Fry Yield Monitoring

Study Period: Spring 2001 to Summer 2012

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InStream Fisheries Research Inc.

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Cheakamus River Chum Salmon Adult Spawner
And Fry Yield Monitoring
Project Review – 2001-2012

Submitted by:

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EXECUTIVE SUMMARY

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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 designed to balance environmental, social and economic values. One of the fundamental objectives of the Cheakamus River WUP was to operate under the new flow regime without any loss in fish production compared to the previous Interim Flow Agreement (IFA). In addition the WUP recommended an operating alternative and associated river flow regime based in part on expected benefits to some wild fish populations. A large part of these perceived benefits was a significant modeled increase (by 75%, Marmorek and Parnell 2002) in the availability of chum salmon spawning habitat. However, the perceived benefits to chum populations from the new river flows were not certain because they were modeled based on uncertain relationships between fish habitat and flow, and assumed relationships between fish habitat and fish production (Parnell et al. 2003). To reduce this uncertainty, the Cheakamus WUP Consultative Committee (CC) recommended a number of environmental monitoring programs one of whose interim results are reported here.

The Cheakamus River chum salmon population was identified during the consultative process as a key-stone indicator species important for overall river health, 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 with juvenile out migration 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). In this modeling work a power analysis was undertaken utilizing a meta analysis of published chum spawner-recruit data with a sensitivity analysis of between -25% for members of the CC who felt it was important to establish there was no reduction on chum production following WUP implementation, through to an increase in production of 75% the potential improvement in production relating to modeled increases in spawner habitat. A target of high statistical power was required (80%) in the power analysis to be sure that the benefits observed were real and not related to observer error. Simulations indicted that at best a power of 0.68 was likely to be achieved for a 12/12 year before/after (BA) WUP implementation experiment utilizing H’ and that this was reduced to 0.61 for an 8/8 year experiment.

BC Hydro has monitored Cheakamus River juvenile chum fry out-migration on the mainstem since 2000 with various side-channel productions being evaluated since 2007. Chum adult escapement has only been evaluated in detail since the 2007 brood year, again in the mainstem and in selected spawning channels. As the WUP was implemented in the spring of 2006, the 2006 adult spawner and 2007 outmigrant fry populations were the first years to spawn and rear in the altered flow regime. Juvenile data collected in

2000 are removed from our analysis because they were temporally incomplete as the study started in mid-March. Thus the data presented in this report relate to a 6/6 year BA study of fry production and a 0/5 study of spawner/fry production (H').

Another important uncertainty during the consultative process was the relation 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 tend to overestimate the area of spawning habitat relative to empirical measures (Parnell et al. 2003). The model does not predict the precise location of spawning. Thus, the model is useful for comparing alternative flows, but 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 Agreement) would provide a larger area suitable for spawning that would also remain wetted during incubation, resulting in relatively greater effective spawning area. These findings 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 (Marmorek and Parnell 2002). 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 over-estimated suitable spawning area under low flows.

Based on the CC's concerns the key management questions for this monitor are:

1) What is the relation between discharge and chum salmon spawning and incubation?
2) Do the models used to calculate effective spawning area provide an accurate representation of chum salmon spawning site selection, and the availability of spawning habitat?

To best answer the management questions the monitor was developed to examine the effects of the WUP flow regime on chum salmon spawning in the mainstem of the Cheakamus River and major side channels and includes three components:

1) Estimating annual escapement of adult chum salmon in the Cheakamus River, and distribution within the mainstem and in key off channel habitats.

2) Estimating the mainstem and sidechannel fry rearing production in relationship to river discharge by H where applicable and by fry production when H is unavailable.
3) Examining the relationship between discharge, groundwater upwelling, and the selection of spawning habitat by chum salmon in the mainstem.

Data from this study will also be used to develop stock-recruitment relationships that are critical for separating effects of spawning escapement from flow-related changes in survival during incubation.

The primary null hypotheses associated with these management questions are:

H_{1a}: Discharge during the chum salmon spawning and incubation period does not affect productivity, measured as the number of fry produced in the mainstem.

H_{1b}: Discharge during the chum salmon spawning and incubation period does not affect productivity, measured as the number of fry produced per spawner in the mainstem

H_2: Discharge during the chum salmon spawning and incubation period does not affect productivity, measured as the number of fry per spawner in the key side-channels.

H_3: Spawning chum salmon do not select areas of upwelling groundwater for spawning in the mainstem.

The key water use decision that would potentially be affected by the results of the monitoring is the seasonal flow release from the Daisy Dam, in particular, releases during the chum spawning and incubation period. Such changes would affect power generation and other social and environmental values in the Cheakamus River.

This report summarizes results from 2001 through 2006 (fry abundance only) and 2007-2011, fry and spawner abundance.

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. Observations of considerable downstream movement of spawned-out moribund fish among mainstem spawners combined with restricted water visibility and poor access to some river/channel reaches when river discharges are high (*see*: Melville and McCubbing 2000; Korman et al. 2002) create challenges for traditional visual tag mark recapture approaches that are commonly employed in smaller coastal systems.

Traditional visual mark-recapture escapement surveys involve tagging salmon with external tags followed by detailed manual 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 PIT (Passive Integrated Transponder) scanning tag readers to scan for tags on all fish at these locations. PIT tags are small sealed electronic modules with unique identification codes that can be implanted in, or externally attached to juvenile and adult fish. Fixed station in-river pass-through antennas monitor movements of fish with tags and record data with logging equipment.

PIT technology has many advantages over externally mounted visual tag techniques and has been extensively used as an adult and juvenile salmonid monitoring tool since the mid-1980s in the Columbia River basin (e.g. Zydlewski et al. 2006; Prentice et al. 1986; Prentice et al. 1990; McCutcheon et al. 1994; Downing et al. 2001; Matter and Stanford 2003) and is currently used in a wide variety of aquatic and terrestrial monitoring programs worldwide (see: biomark.com for a bibliography and Thorsteinsson (2002) for additional references).

In this study we used one marking location in 2007 and two different marking locations from 2008-2011 (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 (RST) monitoring site. 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 behavior that may affect estimates, provide information on spawner distribution to assist with mainstem ground water/spawner evaluations, as well as assisting in evaluating spawner residence time during the initial four years of the monitor.

The addition of the second marking site in 2008 immediately above the mainstem juvenile monitoring site adds significantly more marks to those fish most likely to spawn and produce progeny above the juvenile assessment location increasing the precision of the estimates and analytical power of the study. In an effort to assess the likelihood of marked fish dropping out of the assessment zone and skewing the upper river estimate high, a portion of the radio tags applied were used at the upper river tagging site in 2010, a departure in method from previous study years.

1.2.2 Juvenile Outmigration

Prior to the implementation of the new flow order (WUP) in 2006 the Juvenile Outmigration Monitor 1a 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 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 study includes detailed assessment of juvenile salmonid outmigration using estimated counts from mark-recapture (Cheakamus Water Use Plan Monitoring Program Terms of Reference, Feb 2007).

2.0 METHODS

2.1 Adult Spawners

2.1.1 Capture - Upper and Lower Sites

Fish capture methods, effort and timing in each year generally followed the same pattern, except for the re-distribution of capture effort to the upper-site post 2007, as described in section 1.2. Fishing effort directed at the capture of chum salmon for tag application was conducted during daylight hours from mid-October through late November. The lower river tagging site was located upstream of the Cheakamus/Squamish River confluence at RK 1.5, and is commonly known as the 'stables pool' (10U 0487823:5515191, Figure 1). Fish capture was also undertaken in two pools one approximately 200m upstream and one a similar distance downstream of this location commencing in 2010 as pool topography at the stables site had changed and less fish were being captured per unit effort. Suitable spawning/incubation habitat downstream of this area has previously been visually assessed as limited and of poor quality, (Troffe et al 2009) suffering from high bed-load movement and siltation from the Cheekye River.

The upper river tagging location was located at RK 5.5, approximately 250 m upstream of the RST juvenile out-migrant monitoring location at a pool commonly known as the 'gauge pool' (10U 0489186:5518291; Figure 1). To ensure that all fish had an equal probability of being tagged, we endeavored to allocate tagging effort at the upper and lower tag application sites in proportion to fish abundance throughout the migration period. Chum salmon were captured using 18 x 4.5m or 13.5 x 3.6m tangle type floating gill net hung with 15cm stretched length ‘Alaska twist’ tangle mesh or a 30 x 6m beach seine net hung with 6cm seine mesh. As often as river conditions were appropriate (discharges < 45 $m^{3/}s$ at Brackendale WSC gauge 08GA043), a two person crew deployed and drifted a tethered net from a small pontoon raft at the upstream section of the fishing area, while a separate shore based two person crew walked the tethered line through the 50-120 m of pool to a bank side landing location. All captured chum salmon were quickly placed into floating fish tubes for holding prior to processing, while other fish species, as well as any re-captured chum that had been previously tagged, were recorded and placed in holding for later release. Fishing effort was recorded as the number of fish captured during each standardized net set.

Prior to tag application fish were removed from holding tubes and sex and fork length were recorded. To increase likelihood of tagging pre-spawners destined for upstream migration, body condition was assessed according to a five point scale (descriptions below) and tags were applied only to 0 through 2 condition spawners.

Condition 0 and 1: fish were ‘silver’ un-coloured pre-spawners, which appeared to have entered the river recently, Condition 0 fish displayed sea lice on their body.

Condition 2: fish exhibited some spawning colouration, but were in fresh condition and free body decay.

Condition 3: fish clearly display spawning colouration and are showing early signs of body decay.

Condition 4: fish are heavily coloured, have some body deterioration, and may show signs of previous spawning activity.

2.1.2 Tagging and Release

All high condition chum salmon were placed in a portable tagging cradle with the dorsal surface exposed and tagged through the leading edge of the dorsal fin with a uniquely numbered one inch Petersen Disk tag (Floy Ltd., Seattle WA), with site and sex specific tag colours. In addition to the visual Petersen Disk tag, each fish was implanted with a 20 mm 1420 SST Destron-Fearing 134.2 kHZ full-duplex glass encapsulated PIT tag which was placed into muscle tissue on the lateral surface just below the dorsal fin. For pre-spawners at the lower "stables site" in 2007 through 2010 approximately every fifth tagged fish was also gastrically implanted with a 90 day life span Lotek radio tag (model MCFT-3A) in a methodology similar to Brown and Eiler (2005). In 2010 radio tags were also applied to every fifth tagged fish at the upper "gauge pool" site. Tagging time, from holding tube removal through tag application to placement in the recovery pen was usually less than one minute. Tagged fish were held in two 2.5 x 2.5 m recovery pens and released once the day's fishing and tagging sessions were complete. Tagged pre-spawners remained vigorous after tagging and no recovery/mortality problems were observed during the tagging portion of this survey.

2.1.3 Spawner Enumeration, PIT Tag Detection and Recovery

Briefly, the enumeration technique involved the use of full spanning fish fences at the lower reaches of two side channel sites (NVOS and BC Rail, Figure 1) each fitted with fish counters and PIT antenna arrays at the upstream and downstream openings in the fences. The fish counters continuously monitor and log the number of tagged and untagged pre-spawners entering or leaving each side channel while the PIT receivers continuously monitor for PIT tagged individuals. At Tenderfoot Creek DFO annually operate a fence to capture coho and chum salmon brood stock and at this site pre-spawners were enumerated manually in place of a fish counter.

2.1.4 Radio Telemetry - Mobile and Fixed Sites

A total of five directional fixed station Lotek W31 radio receivers and one mobile Lotek radio tracking unit were used to survey the side channels and mainstem habitats to determine spawner distribution and to assist in evaluating spawner residence time data. As in previous years four fixed station receivers were utilized, located near the Cheakamus/Squamish River confluence (10U 0488781:5513505, at the confluence of the Cheakamus and Cheekye rivers (10U 0488781:5516404), at the juvenile monitoring RST site (10U 0489127:5518052), and 50 m downstream of the Bailey bridge (10U 0488983:5519335), Figure 1. During 2010, one additional fixed location receiver was installed at the 'wood'pool' on the Cheakamus River approximately 200 m downstream of the RST site (10U 0489151:5517710).

Mobile tracking was performed by foot and raft one to two times per week from 200 m upstream of the Bailey bridge (RK 7.0) downstream to the Cheakamus River confluence (River KM 0.0) to assess spawner movements between fixed telemetry stations. In addition two mobile tracks were undertaken from ‘road end’ (RK 13) to the confluence. Evaluation of spawner location was undertaken combining mobile tracking and fixed station records. The upper location of a fishes likely spawning migration was estimated from mobile tracking to be the area in which a fish was found resident for at least two consecutive surveys (>48hours). Due to the frequency of the mobile tracks, this assessment method may have under estimated the total number of spawners above a particular location. For example, if a fish makes an upstream movement after a survey, is resident in the new location for >48hours but moves downstream post spawning to a location at or below that previously observed prior to the next survey then its spawning location may be misclassified. Fixed station records will detect such movement but are generally unable to accurately detect spatial locations of fish to a range of better than 400m. To evaluate fine scale behavior of radio tagged fish around the RST site, we installed the additional receiver at the ‘wood pool’ (RK 5) and mobile tracked fish in the area from the ‘gauge pool to the ‘wood pool’ every other day at minimum. .

2.1.5 Channel Walks - Enumeration and PIT Tag Recovery

To verify enumeration timing, spawning distribution, and tag retention channel walks were conducted by a three to four person field crew twice a week during the October 15 through December 15 survey period. The intent of the channel walks was to visually estimate and tally the total number of live, dead, and tagged chum spawners in all assessable portions of spawning habitat upstream of the fish counter and PIT tag detection sites. The areas surveyed include:

- NVOS: channel upstream from fish counter site to Sue’s Channel, Kisutch Channel, and the Gorbuscha Channels.
- BC Rail: channel upstream from Tenderfoot Creek outlet culvert through to Dave’s Pond.

2.1.6 PIT Tag Detection

To detect PIT tags applied to upstream migrant pre-spawners, full-duplex PIT tag detection and logging equipment comprised of Destron-Fearing FS2001 134.2 kHZ readers/loggers and 0.5 X 0.5 m (Biomark Inc.) pass-through river antennas. In a gated type design, two pass through antennae were deployed concurrently with each fish counter channel such that upstream and downstream migrant spawners would be monitored by both PIT antennas and the fish counter. As for the Logie fish counters the PIT array and loggers were operated continuously through the monitoring period. Each PIT antenna and receiver was individually tuned to reduce any background signals and periodically tested by floating a drone tag taped to a 3m piece of twine up and down through the detection field to confirm a 0.3-0.5 m tag detection range.

2.1.7 Spawning Channel– Fish Enumeration

Tag detections through PIT tag logging as well as spawner detection through resistivity counter monitoring/ trap operations were conducted from October 15 through to December 15 each year in the lower reaches of side channels including: NVOS spawning channels, BC Rail channel, and Tenderfoot Creek (DFO trap).

- NVOS counter (~100m from mainstem): 10U 0488967:5518642
- BC Rail counter (~200m from mainstem): 10U 0489287:5519288
- Tenderfoot Creek trap (~350m from mainstem): 10U 0489141:5518035

2.1.8 Fish Counters, Traps and Video Validation

The primary method for evaluating the numbers of pre-spawning salmon entering the BC Rail and NVOS side channels was by means of a resistivity fish counter. A resistivity fish counter operates by detecting the change in resistance caused by a fish as it passes a fixed point and close to sensors submerged in water. The change in resistance observed occurs because the fish is more conductive than the water it is displacing and therefore allows a slight increase in conductance while present between a pair of electrodes. The electrode sensors in any resistivity counter are designed to encourage migrating fish to pass close enough to the sensors to be detected and in a uniform manner, such that each fish passage can be recorded consistently.

The Logie 2100C fish counter uses these changes of electrical resistance between electrodes pairs caused by fish passage to provide counts. The date, time, conductivity, channel, direction of movement (up or down) and peak signal size (PSS) are recorded by the counter when a change in electrical resistance above threshold setting is encountered. If a change of resistance occurs which is not interpreted as a fish count by the counter's fish algorithm, the direction of count is substituted with the character 'E' which denotes an unclassified event. Such events may be fish which have been miss-classified, or failed to pass completely over the counter as well as debris flow, and air entrainment noise (Aprahamian et al. 1995). To each change of resistance the counter assigns a peak signal size which relates to the maximum deviation from baseline resistance observed during the event. PSS is a function of the fish size, counter gain setting (electrode sensitivity), river conductivity conditions and of the sensors bulk resistance (a measure of the instantaneous background resistance created by water flowing over the electrodes). To avoid collecting a multitude of events with low PSS due to background 'noise' a threshold PSS is selected for each sensor and each type of counter record. The counter is then able to evaluate records which are at least 0.5 seconds apart and can enumerate fish passing over all enabled sensors simultaneously. The Logie counter is designed to re-calibrate every 30 minutes for changes in bulk resistance and conductivity. These calibrations alter the gain (sensitivity) setting so that a fish of a standard size will be attributed a similar PSS, under a wide range of environmental conditions. Data are stored on the fish counter memory and were downloaded weekly by laptop computer.

Site Specific Design and Settings:
Briefly, the NVOS spawning channel counter consisted of two counter chutes affixed to a sill constructed across the channel bed approximately 100m upstream of the mainstem/channel confluence. Into the chutes in a high density polyethylene (HDPE) sheet were set three stainless steel electrodes (12 by 4mm) at 30 cm spacing. These electrodes were connected to the Logie 2100C counter unit by copper wire.

At the BC Rail channel resistivity counter electrodes were placed on the base of a 60 cm wide, 2.0 m long flume fixed to two fence wings approximately 200m upstream of the mainstem/channel confluence. The sensor unit was placed flush with the base of the flume and consisted of electrodes set in HDPE as in NVOS channel.

Pre-spawners were visually enumerated at Tenderfoot Creek through capture with an aluminum vee-type slot trap near Tenderfoot Hatchery. Each day the number, sex and presence of any Petersen disk tagged chum spawners were visually assessed by DFO hatchery staff and recorded before the fish were released through an upstream trap gate to spawning habitat located in the groundwater fed Tenderfoot Lake. During 2010 a PIT antenna and logger unit monitored the entrance to the Tenderfoot Creek fish trap and this data was used to confirm the visual assessment of tagged spawners.

Fish counter conductivity calibration was not required at any site as conductivity was expected to vary little and was low (circa 50 µs), resulting in the counter generating large peak signal sizes for chum salmon passage while utilizing a predetermined fixed ‘gain’ setting of 100. In this study, although each sites electrode arrays were of different designs a minimum threshold PSS of 30 (on a scale of 1-127) was selected for both upstream and downstream counts and events. This threshold was visually observed to minimize background noise triggers while evaluating all fish passage. Lower threshold levels while allowing for the potential enumeration of smaller fish (*i.e.*< 0.5 kg), tend to pick up resistance noise created by water turbulence and entrained air bubbles so are best avoided. As our target species were adult chum salmon with weights in excess of 3.5 kg all fish created PSS well in excess of this threshold as observed visually and by remote video.

Video Validation:
Counter data obtained at NVOS and BC Rail enumeration sites were analysed in relation to video footage recorded using digital video recorders (Capture DVMS 400 and HD Mini DVR MDVR25) linked with

infra-red micro-cameras, as described in Aprahamian et al. (1995). Similar studies in the United Kingdom and British Columbia (Fewings 1987; Welton et al. 1987; Dunkley 1991) have demonstrated the utility of this video validation methodology. Counter efficiencies were based on the number of fish viewed passing completely over the counter in relationship to the number correctly assigned as upstream or downstream counts by the electronic counter. Time-lapse video records were used to provide observations of fish that might have passed by the counter without creating counter events. These video records were then compared with counter records to establish counter efficiencies unique to each enumeration location in each year and stratified across the migration period.

Discharge and Counter Efficiency:

In an extension of the video validation river discharge at the Brackendale gauge (WSC 08GA043) which is representative of stream discharge in the sidechannels due to backwatering was used to help identify temporary periods when the fish counters were subjected to high water events which can result in temporary changes to counter detection efficiency. Corroborating the video validation and counter data to relative stream stage allowed us to parse correction efficiencies to ‘high’ and ‘normal’ flow periods if required.

Counter Efficiency and Daily Counts:

By design, the resistivity counter allows fish to move freely upstream and downstream over the directional counter electrodes. Based on the literature for chum salmon spawning behaviour, originally, we expected fish to undertake one directional upstream migration ‘through’ a counter channel and one set of directional PIT tag readers. Once in the channel the fish was expected to spawn and die, with the carcasses remaining in the channel, as observed with a large accumulation of mortalities in the various preferred spawning locations. In this simple case for fish moving in a single direction upriver to spawn, the spawning escapement is the sum of all the UP counts at one counter site. However, during the inaugural enumeration season in 2007, we observed that a proportion of fish, termed as kelts, moved downstream past the counter/PIT tag station after spawning as did some pre-spawn individuals. It was also suspected that a small proportion of fish may move up and down past the fish counters on several occasions (i.e. recycling) prior to spawning. This was observed as multiple through passage events on the PIT tag arrays in both directions separated by a limited time period, minutes through several hours. As the fish counters cannot identify specific individuals to determine whether a fish is a kelt or an unspawned adult an additional calculation is required to generate spawner numbers. The time marked directional PIT antennae arrays can be used to identify tagged spawner movement patterns and these data after evaluation were extrapolated and used as a surrogate to correct for side channel specific ‘kelting and recycling behaviour' for those fish that exhibited downstream movements. To assist with interpretation of these behaviours we offer the following definitions:

- Spawning escapement: total number of male and female chum spawners estimated to have spawned upstream of the monitoring site during the monitoring period.
- Simple spawner behaviour: a fish which moves upstream past the detection sites and is not detected again during the monitoring period (one net up count and zero down counts are recorded).
- Recycling/pre-spawn migration behaviour: spawners which move upstream and downstream over the counter array in a period of less than 48 hours. These fish may make multiple passage events in each direction and may or may not make a final directed movement upstream.
- Kelted spawner behaviour: spawners that move upstream into the side channels, but at a later date (>48hrs), after spawning make a directed downstream movement past the counter array. A spawner was considered a kelt if it was resident above the detection array for at least 48 hours, which is considered the minimum time required for female spawning (Salo 1991, Troffe 2008).

Allowing for recycling of pre-spawners but assuming no downstream movement of kelts, the total net upstream spawner escapement for each side channel monitored by a fish counter can be derived from the sum of the daily number of up counts minus down counts or equation 1. This calculation does not take into account the efficiency of the fish counter in detecting fish passage:

$$E_{sp} = \Sigma_{daily}\ [U - D]$$

Where,

E_{sp} = total side channel spawning escapement
U = the number of daily up counts
D = the number of daily down counts

As it was observed through video validation that the counters are not 100% efficient (i.e. not every fish that fully passes over the sensor units in the counter channel is correctly enumerated as an up or down count), these data require correction for daily counter efficiency.

$$E_{sp} = \Sigma_{daily}\ [U(1/Q_U) - (D(1/Q_D)]$$

Where,

Q_U = efficiency of up counts at site determined through video validation
Q_D = efficiency of down counts at site determined through video validation

However as it was evaluated that a proportion of down counts are created by outmigrant kelts and not just recycling fish, we must take this into account or our estimate will be bias low. To this affect the total daily escapement can be calculated as the total number of up counts minus the total number of down counts corrected for the total number of kelted fish, using the following equation:

$$E_{sp} = \Sigma_{daily} [U(1/Q_U) - \{(D(1/Q_D) - D(1/Q_D)K\}]$$

Where,

K= side channel specific proportion of down counts estimated to be post spawned fish exhibiting ‘kelting behaviour’. Here, calculation from PIT detections over the entire season, side-channel specific.

e.g. - During a single 24 hr period the counter records 100 up counts and 25 down counts. Video validation shows upstream and downstream efficiency of the fish counter is 90% and 95% respectively, and 10% of down counts are estimated to be post spawned kelts. Using the equation above we can derive the daily spawner escapement:

$(100_{\text{up count}}(1/0.90_{\text{up effc.}})$

= 110 corrected up counts

↓

$(25_{\text{down count}} (1/0.95_{\text{down effic.}})-\{25_{\text{down count}} (1/0.95_{\text{down effic.}})0.1_{\text{ kelt ratio}}\}$

= 24 corrected down counts

↓

110 up counts – 24 down counts

Total spawners = 86

For the purposes of the mark-recapture analysis, the total number of fish enumerated at a counter site is equal to the total escapement estimate. The number of marked recaptures (*R)* is the number of unique PIT tag coded fish which were evaluated to have spawned in the channel. PIT tagged fish which entered the channel but left within 48 hours were excluded from the recapture total being assumed to be recycling fish which spawned in an alternative location.

$$R = \Sigma \text{ unique } PIT\ Up - PIT\ rec$$

Where,

R= total number of recaptured tags
PIT Up = the number of unique tag codes detected on the upper PIT antenna
PIT rec = the number of *PIT Up* tags identified as recycling fish, i.e. leave channel without a period of at least 48 hour residence.

2.1.9 Channel Walks - Enumeration and PIT Tag Recovery

To verify counter enumeration, run timing, spawning distribution, and tag retention channel walks were conducted by a three to four person field crew twice a week during the October 15 to December 15 survey period. The intent of the channel walks was to visually estimate and tally the total number of live, dead, and tagged chum spawners in all assessable portions of spawning habitat upstream of the fish counter and PIT tag detection sites. The areas surveyed were:

- NVOS: channel upstream from fish counter site to Sue's Channel, Kisutch Channel, and the Gorbuscha Channels.
- BC Rail: channel upstream from Tenderfoot Creek outlet culvert through to Dave's Pond.

2.1.10 Escapement Analysis

Escapement estimates of chum salmon spawners into the Cheakamus River are required for hypothesis testing at a variety of levels. Our study aims to provide three key estimates of spawner abundance which are outlined below and conceptualized in Figure 2.

1) Whole river chum salmon spawner estimate: this estimate accounts for all spawners upstream of river KM 1.5 the 'stables' tag application location, including all side channel complexes (e.g. NVOS, BC Rail, Tenderfoot Creek).

2) Upstream of RST juvenile monitoring site (RK5.5) chum salmon spawner estimate: using detection data from spawners tagged at the upper river 'gauge' pool site and/or proportional distribution of telemetry tagged lower river spawners observed above the RST site.

3) Individual channel chum salmon spawner estimates/counts: utilizing resistivity counters in NVOS and BC Rail and counts from Tenderfoot Creek trap.

To determine the actual number of chum salmon arriving back to the watershed to spawn, in a given sample time period, a known number of marked fish are released into the population downstream of the side channel enumerating locations. An unknown portion of these fish will then move upstream past the enumeration station (resistivity counter with PIT tag receiver or manual trap) effectively being recaptured (i.e. re-observed). Assuming that fish do not lose their marks before recapture, that no marks are missed during sampling, and that the chance of detecting any marked fish is equal to any unmarked fish, the efficiency of a capture trap on sampling marked fish can be calculated for a given time period (Seber 1982; AFS 2007). Combined with these data, when the total number of unmarked fish are also evaluated at the same recapture locations, it is then possible to statistically model the numbers of total fish in the study population from which the sub-sample was derived (*see:* equations below for Pooled Petersen estimator herein).

Pooled Peterson population estimates can be calculated from the basic mark-recapture equation 1 provided by Ricker (1975):

$$N = \frac{(M+1)(C+1)}{(R+1)} + (mortalities)$$

Where,

N = escapement estimate

C = total catch

R = number of marked fish detected

M = number of marks released

If random mixing of marked and unmarked individuals is assumed, then the variance of recovered marks has a binomial distribution. In these cases it is best to obtain approximate confidence intervals from a table or equations that approximate the binomial distribution using recovered marks as the key parameter. Ricker (1975) derives the confidence intervals for N in large sampling regimes (>25) as in equation 1 as approximately equal to:

$$R(V) = R + 1.92 \pm 1.96 \sqrt{(R+1)}$$

Where,

V = the variance of R

R = number of detections

By substituting the upper and lower calculated values of R (equation 2) the confidence limits for Peterson population estimates can be derived.

Mark-recapture designs can estimate the population (*N*) at either the time of tagging (N_1), or the time of recapture (N_2), and the assumptions required for each estimate differs. For this program, N_1 refers to 'returns' and N_2 is 'effective spawners'. Given the intent of this program to ultimately calculate the number of fry produced per spawner, *N* at time of recapture (approximated as the spawning escapement) would be most relevant. However, several additional assumptions are required to estimate N_2, for example pre-spawner mortality or harvest rates, (many of which cannot be rigorously evaluated with this design). We chose, therefore, to estimate N_1 (approximated as the number of the fish that pass the tagging site) since fewer assumptions are required, if we further assume that these processes affect tagged and untagged fish equally. For example; we do not need to assume many components of the closure assumption, such as no removal of fish from harvest, predation, downstream migration, or death prior to arriving at the recapture location, if we assume that these processes affect tagged and untagged fish equally. Thus the whole river estimate whilst estimating the number of returns to the marking site, may tend to overestimate the number of effective spawners. In comparison numbers derived from the fish trap on Tenderfoot Creek located close to the spawning areas are both a total count and more likely a better representation of effective spawners, while the estimates derived at the counter sites on NVOS and BC Rail are likely good indicators of effective spawners but may contain some error related to varied counter efficiency, differences in tagged to un-tagged spawner sex ratios and the assumptions of kelting and recycling behavior that are used in spawner escapement derivation.

During our analysis we assume that:

1) ***The population is closed during the survey period, mortality and emigration affect tagged and untagged fish equally, and all components of the population are vulnerable to either capture or recapture.***

   For this assumption to be valid, it is critical that marks be applied to chum salmon throughout the entire migration period, and that tagged individuals are well mixed within the population at time of recapture.

   - Spawners were tagged sufficiently downstream of recapture locations to promote equal mixing and tag application was conducted throughout migratory period except during relatively short periods when river discharges were too high for fish capture.

2) ***Tagged and untagged fish are correctly identified***.

   If tagged and/or untagged fish are not detected, the proportion of tagged fish may be over or underestimated in recapture samples, and population abundance may be biased high or low.

   - The detection efficiency of resistivity counters has been demonstrated to be >90 per cent and of low variance in several other river systems in British Columbia (McCubbing et al. 1999; McCubbing and Ignace 1999). Here, we use video validation to check counter efficiency.

- Most literature studies observed PIT tag detection efficiencies of >95 per cent (Prentice et al. 1990; McCutcheon et al. 1994; Castro-Santos et al. 1996). Here, we estimate PIT detection efficiency at > 99% by comparing PIT detections to those tagged carcasses reported during stream walks (2008/09).

3) ***No tags are lost***.

If tags are lost (due to poor application technique or aggressive behaviour during spawning), the proportion of tagged fish will be underestimated in the recapture samples, and as a result population abundance will be overestimated.

- Most salmonid studies using PIT technology to investigate long term survival through multiple life-stages indicate that PIT tag loss is low at< 2 % over the entire life-history cycle (Prentice et al. 1990; McCutcheon et al. 1994; Buzby and Deegan 1999; Dare 2003) In this, short duration, six week monitor we applied pit tags to returning adult fish through intra-muscular injection and have not observed any PIT tag loss (100% retention) during stream walks focused on tag retention (All recovered Petersen disk tagged carcasses are scanned for PIT tags).
- For visual tags, Schubert et al. (1996) found loss rates from 0 to 2.7 % from adult pink salmon. During streamwalk surveys for carcass counts (2007/08/09) we have observed some damaged Petersen disk tags on spawned-out carcasses, however, it is unclear when tag damage was incurred (*e.g.* predator or spawning activity induced).

4) ***Tagging does not change the availability of fish for detection***.

The stress of capturing, holding and marking fish could lead to behavioural changes which might affect a fishes post tagging behavior and thus result in no further upstream movement or in some cases even cause mortality. Such effects would result in an overestimate in the number of tagged fish available for recapture and would bias the population abundance estimate high.

- Visual surveys provide some inference on behaviour of both untagged and tagged spawners. Fish condition at release and radio telemetry also provides information on post-tagging behaviour.

5) ***Tagged and untagged fish have an equal probability of initial capture and subsequent detection***.

This assumption is generally violated to some extent in all mark-recapture studies (Otis et al. 1978), but can be minimized by making tag application and recovery as representative as possible, through standardized effort and the use of gear with minimal selectivity.

- PIT detection arrays and resistivity counters are passive type technologies which are, in this study, located in very close proximity to each other by design to maximize the likelihood that tagged and untagged fish are detected equally.
- Multiple marking and detection locations allow for comparisons on mixing rates

2.2. Juvenile Outmigrants

2.2.1 Study Area and Trapping/Enumeration Locations

The primary location of juvenile fish enumeration consists of two rotary screw traps (RSTs) operated adjacent to the North Vancouver Outdoor School (NVOS) property (10U 0489141:5518035) at RK 5.5. Secondary enumeration sites were operated on both river augmented and ground water side-channels at locations on the NVOS property and BC Rail channel (Figure 3).

2.2.2 JuvenileTrapping Methods

Prior to 2007 only mainstem juvenile fish production were assessed. In order to meet the objectives of the WUP monitor to partition side channel from mainstem fish production side-channel assessments were added to the study plan using various trapping methods in 2007. Two methods have been used for enumerating outmigrant chum fry in the Cheakamus River during this study:

1) *Rotary Screw Traps*

   Mainstem RST trapping methods for the Cheakamus in all years of operation have followed those outlined in Melville &McCubbing, 2001 & 2002a. Briefly, emigrating salmonid juveniles are captured in the mainstem of the Cheakamus River at RK 5.5 using two six-foot diameter rotary screw traps during the sampling period from February 15th to June 15th.

   In 2007, a change to operational procedures was placed in effect in an effort to increase trap operating efficiency in May and early June. With lengthening days and increased sunlight, conditions are typically dominated by higher discharges due to high elevation snowmelt and also by increased algal growth which clogs screens during this time period. This results in a reduced ability to operate traps with small mesh drums (Melville &McCubbing, 2006). As a result 5/32" mesh (fry) screen drums were replaced by larger 1/4" mesh in order to reduce screen surface area and thereby reduce resistance to water flow as well as minimize clogging due to algal and debris build up. Although this improved the capture of smolts, the larger mesh size does not capture chum, pink or chinook fry. Therefore, to minimize the reduction in precision of yield estimates as a result of reduced capture efficiencies for fry, the date change for drum mesh size was selected as on or after May 1st, after which, based on data collected in previous years (2001 to 2006), ≤10% of fry captures occur (Melville and McCubbing, 2008).

   A new cableway/anchoring system was installed in the spring of 2008. The old cable way system was replaced to improve safety margins and allow trap operation under higher discharges. This cableway has allowed for more consistent operation of the traps at discharges between 50-90 m^3/sec at Brackendale gauge, thus improving mark-recapture data particularly in May.

2) *Side-channel Fyke Net Traps*
Since 2007 estimates of chum fry production, from channels with only ground water sources and river augmented flow-through channels (which may or may not have groundwater influences) in the Cheakamus River, have been provided by operating fyke nets (Figure 3). The fyke nets (1/8" mesh) have openings of 1m by 1m tapering down to a 6" tube which is attached to a capture box. These fry estimates assist in the assessment of mainstem vs. side-channel production and also inform Monitor 6.

Methods for the operation of the fyke net traps are described in detail in Melville and McCubbing 2008 & 2009. In general upstream capture nets were used to obtain fish for marking. These fish were released at the site of marking with a portion being captured in downstream traps, allowing a population estimate to be derived for the area upstream of the enumerator traps using mark-recapture methods.

In 2008 estimation of chum fry production from BC Rail channel (Site F7 & F8) was added. This ground water channel was added to replace Site F5 (NVOS Ground water) as the physical geography of NVOS groundwater channel was altered after the study was designed and, as a result, the area available for groundwater production evaluation was much reduced in size (Melville and McCubbing 2009).

2.2.3 Population Estimate Methods

In 2002 the CC recognized that it is essential to address critical scientific uncertainties that could affect future decision making, and to comprehensively assess the response of the system to the operating alternative. To achieve this, the importance of refining statistical and sampling methods was identified as the highest priority within the monitoring plan (Mamaorek and Parnell, 2002). Therefore the Terms of Reference for Monitor 1a included a component to develop improved statistical models for estimating fish production (Cheakamus Water Use Plan Monitoring Program Terms of Reference, Feb 2007).

Historical population estimates (Melville and McCubbing 2001-2011) from Cheakamus outmigrant data have been calculated using unstratified Petersen and/or the temporally-stratified Darroch method as implemented in SPAS (Arnason et.al. 1996). Population estimates were derived by applying the proportion of the total marked fry recaptured to the total unmarked catch also known as the total estimated catch efficiency (ECE_T). This estimate makes a number of assumptions as outlined in Seber 2002:

1) the population is closed such that the population is constant,
2) all untagged fish during the sample period have the same probability of being captured at the rotary traps,
3) marking and clipping fish and releasing them upstream does not affect, their subsequent catchability in the rotary screw traps,
4) sampling at the rotary trap for marks is a simple random sample where each of the possible combinations of tagged and untagged fish have an equal probability of occurring,
5) fish do not lose their marks between the release site and the recapture site,
6) all marks are reported on recovery in the second sample.

As well, we assume that:

7) marked and unmarked fish have similar movement patterns from the release site to the rotary trap,
8) fish can pass the rotary trap only once and all marked smolts pass trap the traps by the end of the study, i.e., none of the fish remain above the rotary trap,
9) there is no mortality and no fish leave the system without passing trap.

A key challenge in meeting these assumptions (in particular 2 & 4) has been changing catchability as flows fluctuate during the spring. For example, the Pooled-Petersen estimator will simply pool all releases, all recaptures of marked fish, and all captures at the relevant locations and use these pooled values in the simplest capture-mark-recapture estimator (Seber, 1982). This estimator makes a crucial assumption of homogeneity of catchability (among others) and can be biased if the assumption of homogeneity is not valid. More importantly estimates of precision from the Pooled-Petersen estimator in the presence of heterogeneity of catchability, will tend to understate the actual uncertainty in the estimate i.e. the results from the Pooled-Petersen method will appear more precise than they should be (Seber, 2002).

In order to address the heterogeneity in catchability throughout the study population estimates calculated using capture efficiency estimates over shorter time periods (strata) are likely to be more accurate than population estimates calculated using average capture efficiency over the entire migration period (Seber, 1982). This requires a planned marking regime where individual strata can be differentiated based on separation of mark groups. The estimator for Stratified-Petersen studies was introduced by Darroch (1961) with further work by Seber (1982, Chapter 13), Plante et al. (1998), Schwarz and Taylor (1998), Arnason et al. (1996), and Bjorkstedt (2000). While these methods are theoretically justified, there are several practical problems that prevent their simple usage. When the data from the study are stratified, the resulting matrix of recoveries can be sparse with small counts. Consequently, the resulting estimates are often very unreliable and can often not be computed because they rely upon the inversion of this sparse recapture matrix with small counts. As well, these methods do not take into account the temporal stratification in the study where the abundance in one stratum is likely to be similar to that in adjacent strata and the movement pattern of a release group is also likely to be similar to the movement pattern in adjacent release groups. Because of sparse data, extensive pooling of strata is often required. But there is no defensible method to decide which strata to pool, and the pooling decisions are not incorporated into the estimates of uncertainty (Schwarz and Bonner, 2012).

Bonner (2008), Schwarz et al. (2009), and Bonner and Schwarz (2011) have developed an alternate method (Bayesian spline model) for calculating population estimates that has many advantages over existing methods. It takes into account the temporal stratification and shares information among neighboring strata to help alleviate problems caused by small counts. The key features of this method 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. The method is self-calibrating in the sense that if the data are sparse, the equivalent of simple-Petersen methods where the catchability is assumed to be roughly the same over the study are fit, but when the data are rich, more complex models are fit. Estimates of abundance are provided for each recapture stratum and so it is relatively simple to also estimate derived quantities such as the time at which 50% of the run has passed, or the time needed to reach a pre-specified target number of fish. In the past; 2001-2011 run-timing has been reported as actual strata catch, which is likely not always a true indication of abundance through time. The features of the model also deal with problems (such as no sampling in some strata) in a straightforward fashion – the spline curve for the run is used to “interpolate” for the missing data. These last two features are difficult to obtain from the previous methods.

Despite its complexity, the spline model is not a panacea to solve all potential problems encountered in capture-mark-recapture studies. There are number of caveats that apply to this and potentially to other stratified models (Schwarz and Bonner, 2012). These potential problems are more fully described in Schwarz and Bonner, 2012.

A detailed description of methods used for collecting the field data and calculating the Bayesian spline model (BTSPAS) population estimates for the Cheakamus are described fully in Schwarz and Bonner, 2012 and appended in Melville and McCubbing, 2012). Briefly; in 2011 all years (2001-2011) and for all species, mark-recapture data was prepared for analyses using the BTSPAS model. This analysis was completed in early 2012. In addition to calculating annual population estimates and run timing, the covariates of discharge and temperature were plotted against the estimated catchability in mainstem estimates to determine if these parameters had any observed effect on estimated catchability. This analysis was not undertaken for side channel estimates as discharge and temperature data for these locations is unavailable.

2.2.4 Bio-sampling and Age Data Collection

A sub-sample of chum salmon fry captured were sampled for lengths and weights at the RST site throughout and the study (2001-2012) methods are more fully described in Melville and McCubbing, 2011.

Chum juveniles are all 0+ when migrating from fresh to salt water and in general spend less than 2 weeks post emergence prior to migrating to saltwater.

2.3 Discharge Data Collection and Analysis

Mean daily and weekly discharge (Q) over the study period was computed from the Water Survey of Canada (WSC) hourly discharge record for the Cheakamus River at Brackendale WSC 08GA043 (10U 0489186:5518291), located 100 m upstream of the RST site (Figure 3). These readings are used for all analysis relating to discharge and fish production in this study.

2.4 Temperature Collection and Analysis

Prior to 2007 hourly temperature data was only collected during the study period (Feb 15 to June 15) using a temperature logger at the RST site (Figure 4).

As part of the expanded monitoring plan five temperature loggers have been maintained for the full calendar year and hourly data collected. Loggers are downloaded once every month and the data are archived for use in other Cheakamus WUP monitors.
The five locations are described as follows and are shown in Figure 4:

1) Downstream of Daisy Dam (upstream of Rubble Creek, RK26, 10U 0489781:5535658)
2) Upstream of Cheakamus Canyon (anadromous barrier, RK20, 10U 0489782:5535665)
3) Suspension Bridge (upstream of Culliton Cr., RK13, 10U 0486976:5525175)
4) Rotary Screw Trap site (downstream of Culliton Cr., RK5.5, 10U 0489141:5518035)
5) Downstream of Cheekye (RK2, 10U 0487911:5515362)

The temperature data recorded at the Rotary Screw Trap (Temperature Logger 4) were used for analysis in this study, unless otherwise noted.

2.5 Statistical Analysis of Data

2.5.1 Power Analysis of Juvenile Outmigrant Estimates

A power analysis based on a t-test of mainstem derived juvenile production estimates (BTSPAS) was undertaken to test the statistical power and probability of the available data to find statistical change between pre- and post-WUP periods.

Each year's estimate (2001-2012) was considered pre- or post-WUP based on life history. A post-WUP year class was identified as all freshwater life stages for the species occurring during the post-WUP flow regime. i.e. chum fry are not considered post-WUP until 2007 (even though the WUP was instituted in Feb 2006) as 2006 fry would have been spawned in the fall of 2005 and spent most of their incubation under pre-WUP flows. In addition some estimates were excluded as data used to derive estimates was weak (i.e: few fish to mark and/or few recaptures). From this initial data set the number of pre and post-WUP years, the change in abundance and the relative change in abundance was summarized. The power analysis was calculated using R and the power.t.test function which requires the standard deviation in the population estimates and a specified Type I error level, (0.05 was used). Based on these statistics three power-related statistics were computed:

1) The statistical power given the available data. That is, what is the probability of finding a significant change in post-WUP compared to pre-WUP given the sample size, variance, and difference in average abundance between pre- and post-WUP periods?

2) Relative change in abundance required to achieve a power of 0.8 given the sample size and inter-annual variance in population estimates.

3) Number of years to detect a 25, 50 and 75% change in abundance during the post-WUP period (relative to pre-WUP) given the variation in population estimates across years and a power of 0.8.

2.5.2 Evaluation of Adult Spawner Discharge

A key assumption in the WUP is that chum spawner habitat area will be increased as a result of setting the base flow at a minimum 15 m^3/sec based on preferred velocity and depth data from the 2D habitat model. This assumes that chum salmon are not heavily influenced by groundwater upwelling for spawner site selection as this data was not considered in the modeling process. To evaluate the changes in available spawning habitat we ranked the flow days from November 1st through December 1st each year as this is the time period that peak spawning has been observed (McCubbing et al 2010, Troffe and McCubbing 2008). Each day that river discharge exceeded 14 m^3s but was less than 18 m^3s was given a rank of zero, while any day where the flows were less than 14 m^3s or >18 m^3s was ranked with a score of 1. By summing the ranking we can evaluate the number of days that chum spawners had an opportunity to spawn in conditions which were less than optimal based on the 2D habitat model due to reduced habitat area (<14 m^3s) or in areas that would potentially become dewatered during the incubation period (>18 m^3s). This was undertaken from 2001 through 2012 for pre and post-WUP related discharges. We also calculated a simple mean daily discharge with standard deviation for all years during the spawning period as a general indicator of typical annual river discharge.

2.5.3 Evaluation of Incubation Discharge

A further key assumption in the WUP is that chum incubation habitat total area, while perhaps reduced compared with higher discharges, will be kept watered by setting the fall/winter base flow at a minimum 15 m^3/sec the same as the base discharge during peak spawning. To evaluate the changes in available incubation we undertook several analyses. We ranked the flow days from December 15th through April 30th each year as this is the time period that eggs and alevins have been observed to be present in the gravel (Melville and McCubbing 2010). Each day that the flows were greater than 14 m^3sec was given a rank of zero, while any day where the flows were less than 14 m^3sec was ranked with a score of 1. By summing the ranking we can evaluate the number of days incubation habitat area was likely reduced in area (<14 m^3s) during the pre-WUP (2001-2006) compared to the post-WUP (2007-2012) discharges. In an effort to compare differences in average daily discharge under the two regimes the 10th, 50th and 90th percentile mean daily flow data were also calculated and the values were compared statistically using a T-test, pre and post-WUP

2.5.4 Comparison Of Spawn/Recruit (H) To Discharge

A primary goal of this project is to assess the potential relationship between H’ the index of egg to fry survival for spawners under the varied river discharges observed. In this case H’ is calculated by 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 (Nepg)
4) Estimate fry production (Ntfry)
5) Evaluate H’ by dividing the fry outmigration estimates by the egg deposition rates

Thus

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

Each of these steps can be broken down into stages and calculated for all spawners above the RST or for each individual side channel where the numbers of adults and fry have been independently estimated. In the case of Tenderfoot Creek, while adult escapement is monitored (by DFO); fry outmigration is not currently evaluated. Thus while we can evaluate the average egg to fry survival above the RST in the mainstem independently of the BC Rail and NVOS side channel complexes, the result will contain an element of Tenderfoot Creek survival data at this time.

The method of evaluating adult and juvenile population estimates has been previously described for adult and juvenile fish. To evaluate female spawner estimates, we examined the ratio of females in all catch data (marking and recapture), during stream walks and in remote PIT and radio tag recoveries.

The number of eggs per female was taken from literature, in conjunction with discussions with DFO Tenderfoot staff and was standardized for the purposes of this report in all years as 2500 eggs per female. Recent publications have indicated that egg per female fecundity may be a derivative of both fish age (3 or 4 years) and fish length (Kaeve, 2000). In addition summer and fall migrants may have differing egg numbers (Pacific Fishes of Canada) and egg size may vary with body size (Kaeve 2000). While these facts may affect annual egg deposition estimates, no directed annual measure of fecundity or age evaluation has been undertaken on Cheakamus River chum salmon at this time. Data from scales collected in tagging efforts, (2008-2011) are archived and egg per female rates could be made available in the future through joint work with Tenderfoot Hatchery. A brief sensitivity analysis indicates these variances in egg per female values may alter the value of H’ by approximately 1-3% for mainstem and channel combined river estimates at current escapement data levels, albeit that the greater change occurs when egg survival is already high.

Data derived from the above calculations are presented as % egg to fry survival and are compared to the ranking of habitat availability and compared to spawner density, as the availability of spawning habitat and incubation habitat are the most likely limiting factors in fry production for non-stream rearing salmonids.

3.0 RESULTS

3.1 Adult Spawners

3.1.1 Capture and Tagging

Tagging effort was directed at the upper and lower tag application sites from mid October each year through late November. The best opportunities for fishing appeared related to river discharge changes. In general, more fish and higher catch per unit efforts (CPUE) were encountered when river discharges were falling after a period of recent increased discharge, especially during late October through mid-November.

A total of 3262 PIT tags were applied over five years at the lower river marking site (range 391-970 per year) and 2050 at the upper tagging site (range 75-920 per year, Table 1).

3.1.2 Length and Condition

The average fork length of female spawners tagged at the lower “stables” location has varied annually from a low of 700mm in 2011 to a high of 743 mm in 2007,. Female chum salmon captured at the upper “gauge pool” site were also smallest in 2011 averaging 708mm. Unlike the lower site the largest fish were captured in 2010 (748mm) although no sample data is available for 2007 as this site had limited capture effort in that year. Male chum salmon followed the same pattern as females at both sites with largest fish captured in 2007 (801mm) at the lower “stables” site, and in 2010 (765mm) at the upper “gauge pool” site. Smallest fish were captured at both sites in 2011 (727 and 730mm, Stable and Gauge respectively), Table 2.

The visual condition of spawners tagged at the lower river ‘stables’ locations was generally higher than those tagged at the upper river ‘gauge pool’ due largely to the fact that the fish were earlier in their in-river spawning migration. Some fish captured at the lower river site were observed displaying sea lice on their opercular flap or body. During tagging efforts the majority of the lower river fish were in acceptable condition for tagging (for example in 2010, 536 of 564 fish were tagged). Generally in all years, condition 1 fish were dominant in the tag sample at >60% in most tagging stanza although condition typically declined during the sampling period. 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 2010 only 335 of 543 fish encountered were tagged as condition factors were generally lower. Typically about equal numbers of condition 1 and condition 2 fish were tagged. These selective processes may affect the ratio of male to female fish tagged compared to that which is captured but as we select for pre-spawned fish that are relatively new to the capture area, tagged fish data is likely a better representation of the true male to female ratio in the spawning population than the total catch data.

3.1.3 Radio Telemetry and Spawner Distribution

Over the four years that radio tags were applied (2007-2010) a total of 356 radio tags were applied at the lower marking site. This ranged from 69 to 111 tags each year and were generally applied in a near even male:female ratio (Table 3). Using a combination of fixed station and mobile radio tracking the location of spawning was inferred by determining the furthest distance upstream an individual tagged spawner held in one location (usually 2-3 days) before becoming moribund, whereupon post-spawned fish either move back down river or expire close to their spawning location. Across all years an average of 93% of males and 89% of females were assigned a spawning site. Tag loss, predation, undetected emigration out of the sampling area and harvest may account for the missing tags.

Spawning reach selection based on lower river radio tagged fish has varied greatly through the study period. Initially a minority of tagged fish, 8% of males and 6% of females, spawned upstream of the juvenile monitoring site. This pattern was repeated in 2011, when just 11% of males and 9% of females spawned in this area. In comparison, in 2008 and 2009, 44 and 51% of tagged males and 23 and 44% of tagged females spawned upstream of the RST site respectively (Table 3). No data are available for 2012 as no tags were applied. Overall data indicate tagged males were inclined to migrate a greater distance upstream prior to spawning than tagged females in all years with the largest difference (approximately 2-fold) being observed in 2008.

In 2010, 52 chum adults were tagged with radio tags at the upper tagging site. The intention of this change in methods was to ascertain what if any proportion of fish tagged at the upper site may be dropping out of the area above the RST prior to spawning. This would tend to bias the spawner estimate and egg deposition calculations high if untagged/unhandled fish were more likely to remain above the RST site. Of the 52 tagged fish 36 or 70% were assessed to remain above the RST prior to spawning. Of these 21/23 (or 91%) of females exhibited this behavior, males apparently being affected more negatively post tagging or more likely to exhibit a straying pattern. There was no link between fish condition (1 or 2) and subsequent behavior at this site, and while fish radio tagged later in the run (post November 1st) at the upper site were more likely to enter the sidechannels, this was linked to an increasing proportion of females being tagged in the later part of the season, rather than any temporal variation in behavior of fish. A total of 17 of the 52 (33%) radio tagged fish marked at the upper 'gauge pool' site were detected on the PIT tag antennas in one of the spawning channels.

3.1.4 Side Channel Walks

All reaches of BC Rail, and the NVOS channel complex were surveyed by three to four person crews approximately twice a week from October 15th through December 15th, in each sample year. The total number of live and dead chum salmon spawners in each channel was recorded during each survey and any tags recovered or observed were noted. Counts of live chum spawners generally increased through early November with numbers peaking for NVOS and BC Rail channels before November 14th (Figure 4 & 5) and returning to near zero by December 1st. Carcass counts slowly increased after mid-November, and numbers for all channels peaked late in November, approximately 10 to 14 days after peak live spawner counts were observed. No difference in average peak count of live or dead fish was observed between the two channel complexes (Figure 6).

3.1.5 Visual Tag Recoveries

During stream walks visual tag recoveries of Peterson disks on fish carcasses and of those found on the stream bed, having become detached from fish were infrequent with only 147 of 5387 (2.7 %) tags applied, recovered (Table 4). Of these 16, or 10% of the total recovered were detached from fish.

3.1.6 PIT Tag Detection

Adults tagged with PIT tags were classified as detected when the unique PIT tag code was first logged on the most upstream receiver unit. Only spawners that transited through the downstream and upstream antennae were considered as being detected. In the majority of cases, multiple PIT detections were logged for each tagged spawner that moved through the PIT directional arrays. Total numbers of detections were then used during mark-recapture estimates for reconstructing the total upper river and whole river escapement estimates.

The highest recorded tag recovery of spawners was in 2008, when 32% of tags applied at the upper site, and 11.8% of tags applied at the lower site were recorded in the three monitored sidechannels combined. Average detection rates have been less at 18.9% of upper site applied tags and 5.9% of lower site applied tags. Tag recovery rates comparing lower site and upper site tags have varied greatly with between 1.25 and 7 times more upper river tags detected. Thus as confidence limits on population estimates are generated based on marked fish recoveries, they are more precise on upper river data, where the number of recoveries is in general much larger. The one exception to this observation was in 2009 when a nearly equal proportion of tags applied were recorded from both the lower river marks (14.8%) the upper river applied marks (11.8%) Table 5.

3.1.7 Sex Ratio

The male-to-female sex ratio of side channel remote PIT detected marked spawners was examined from 2008 through 2011, to the proportion marked at the tagging sites and to that of dead fish observed during stream walks. In general, for both tagging locations the ratio of PIT tag detected spawners was slightly skewed towards males compared to the tags applied although the sample size of recoveries is small in some years. This was more noticeable in fish tagged at the lower site than the upper site which is closer in proximity to the channels. Stream walk data indicated a higher proportion of female spawners when the peak day of count was observed, but this data may be biased by observer error (males are easier to sex when dead than females due to the extended kype), residence time of the different sexes on the spawning areas, and differential kelting rates. Tenderfoot trap data indicated a similar sex ratio to our upper site tagging data (Table 6).

Therefore for the purposes of egg deposition targets, the upper river site capture data is utilized for evaluating the proportion of female spawners in the upper river and off-channel escapements. The proportion has declined annually from a high of 35% in 2007 to a low of 17% in 2011 (Table 6).

3.1.8 Pit Tag Detection Efficiency and Retention

From 2008 through 2011 an estimate of the detection efficiency of the PIT arrays was calculated by comparing the logged records at each detection site to those tagged fish recovered during subsequent stream walk surveys. The combined detection efficiency of PIT tagged spawners 2008-2011 was estimated at 99.2% (137 of 138 carcass/PIT recoveries). Based on the tag application and stream walk recovery timing of the one undetected PIT tagged spawner it is hypothesised that this unrecorded fish in 2009 transited through the detection array during a period where there was a temporary power interruption to the detection field at the NVOS site. No correction factor for missed tags is thus required in our mark-recapture estimates of spawner escapement.

PIT tag loss is also not a cause for concern during escapement and egg to fry survival calculations as observed PIT tag retention has been 100% for all recovered carcasses exhibiting a Peterson disc tag recovered during stream walks (2008-2011, N= 132).

3.1.9 Spawners versus total detected tags and correction of 2007 PIT tag channel spawners.

In 2007 there were no directional antennas at the NVOS or BC rail sites. Since it has been observed (2008-2011) that not all fish detected on the lower antenna at each location, subsequently pass through the upper antenna as spawners, PIT tag detection rates previously reported (Troffe and McCubbing 2008) for 2007 require correction. We undertake this by using an average of all the years “pass through” rates (2008-2011) specific to each location. The correction factor for the previously reported PIT tag detections was calculated as 80% passage at BC Rail and 60% passage at NVOS.

3.1.10 Total Counts, Run Time and Video Validation

The distribution of peak signal size (PSS) for up and down counts recorded by resistivity counters were similar for the NVOS and BC Rail channel counters and in each case PSS distribution was positively skewed with over 70% of counts with signal sizes of 90 units or greater (e.g. Figure 7) in all years. By design, larger fish create larger signal sizes when counted by resistivity counters, and the PSS distribution observed during 2007-2011 operations, coupled with observations made through video validation indicated that the up and down counts recorded at the side channels with a PSS > 50 were generated by adult chum salmon, and not by debris, entrained air, or other fish species through the end of November. In BC Rail channel coho were often observed as the only upstream migrants post Dec 5th and large numbers of coho were observed in the NVOS channel in 2011 from early December on. Differences in the distribution of PSS between counter locations are largely attributable to discharge differences among sites and the relationship of PSS and fish passage height over the electrode array.

3.1.11 Kelt Behaviour

During the first year of escapement estimation (2007) and in an absence of data to the contrary, we assumed that all upstream enumerated migrants die post-spawning and remained in the side channels above the counter sites. In 2008 through 2011 the PIT arrays were successfully upgraded to provide directionality and were able to gain inference about this key escapement assumption. The same set-up was used each year and based on analysis of all PIT tagged spawner detection movements through the gated PIT arrays, 13-16% of fish kelted annually at BC Rail, while at the NVOS site between 11 and 53% of annual down counts could be attributed to the downstream movement of post-spawned kelts, Table 7. Kelts were assigned as fish that spent greater than 48 hours resident in the channel above the fish counter prior to a directional outmigration. These fish were mainly males at NVOS channel (53 of 60 or 88% over three years, 2009-2011) and at BC Rail channel (8 of 10 or 80%, 2009-2011).

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. The higher variance at the NVOS channel site was likely due to the greater variance in flows this channel experiences during high water events flushing out kelts and the greater area for fish passage in a downstream direction.

3.1.12 Validation of Counters and Discharge Correction

Video validation evaluation was conducted at both counter sites annually. Counter efficiency varied annually with fish numbers, river discharge, and site set up. Counter efficiency varied from 68 to 96% at the NVOS site for up counts and 68 to 99% for down counts except for several high water periods in 2009. At the BC Rail site counter efficiency varied from 66 to 100% for up counts and 52 to 95% for down counts again except for several high water periods in 2009, Table 8.

3.2 Escapement Estimates

3.2.1 Adult Spawners

Estimates of spawners in the side channels were calculated as described in Section 2.1.8 and varied from 2170 (2007) to 9357 (2009) spawners, an over four fold variance at the NVOS channels, mean 3950 (SD 3064). Data from BC Rail indicated greater variance in spawner numbers with a range of 367 (2010) to 3243 (2009), or over 8 fold, with a mean of 1223 (SD 1175) while Tenderfoot trap catch data supplied by DFO ranged from 293 (2010) to 3309 (2008), a variance of over 11 fold, mean 1774 (SD 1334), Table 9. Proportionally the NVOS channel complex is the area with the greatest number off channel spawners (42-76%), although Tenderfoot Creek is important in some years (11-42%). BC Rail has the least but most consistent proportion of spawners (12-21%, Table 10).

Estimates of the number of spawners in the whole river upstream of RK 1.5, and above the RST juvenile monitoring location RK 5.5, were calculated by a simple Pooled Petersen model using the number of known tags applied and the number of unique tag detections/observations from spawners in the side channels to the corrected number of net upstream spawners counted at each resistivity counter site or fish trap.

Using the Pooled Petersen population estimator outlined previously, whole river escapement estimates of between 73K and 223K spawners were derived for habitats upstream of the lower site tagging location at River KM 1.5, (Figure 8 & Table 11). In general as recaptured PIT tag numbers have been low from lower site tagged fish (N=13-57), confidence limits have been relatively high at an average of 31% of the estimate (+/-95%, Table 12).

In comparison, a total escapement of between 12,624 to 105,540 chum spawners was estimated using the simple Pooled Petersen estimator above the RST juvenile monitor site at RK 5.5 between 2007 and 2011 (Figure 8, Table 11). In general as recaptured PIT tag numbers have been higher from upper site tagged fish (N=54-138, excluding 2007), confidence limits have been better with an average of 19% of the estimate (+/-95%) excluding 2007 when very few upper site tags were applied (Table 12).

3.2.2 Outmigrant Fry

The outmigration timing of chum fry based on estimated weekly abundance at the RST site, indicates that outmigration is either just commencing or has not yet started when sampling commences February 15th. On average only 10% (2-21%) of the total yield was estimated to have migrated by the fourth weekly strata. The peak of migration for chum fry in 2001-2012 generally occurs between April 4th and May 2nd (weekly strata 8-11) when on average 53% of the outmigration occurs (Figure 9 and 10). In comparison in 2012 it is observed from model output data that a second peak of migration could have been in process when high water suspended fry capture mid strata (strata 11), although it is likely that this stratum estimate is biased high.

It appears that increased rivers temperature (4.5 to 8^{o}C) but not discharge affects the migration timing of chum fry (Figure 9 and 10). It is likely spawner timing in conjunction with water temperature during incubation and emergence driving migration timing of chum fry.

Estimates of chum fry production from the Cheakamus River at the RST site were calculated for every year of the study 2001-2012. Estimated production has varied from a low of 1,685,668 in 2001 to a high of 7,264,443 fry in 2010 (Table 13 and Figure 11). Average relative error (CV) of these data was 0.39.

There have been six pre-WUP and six post-WUP estimates of chum fry production. Average pre-WUP and post-WUP abundance was 3,795,110 and 4,364,196 fry respectively, this equates to an average change in abundance of 569,086 or a 15% increase (Table 14). Several power analyses were undertaken on the data to establish if the expected modeled change of 75% or greater in production could be determined based on the length of the study and the mean and variance of pre and post-WUP years fry production. These analyses indicated that with the data collected a 75% change in population size, with a 0.05 Type I error and power of detection of 0.8, would take 6 years of data collection in each group to detect. No such change has been observed. To statistically determine a change of 50% with the same power will take and additional 12 years of data, while a 25% change would require 24 years of pre and post data assuming the current annual population variance continues.

Estimates of chum fry production have been derived annually from 2007 through 2012 from Site F1 at the NVOS channel. The estimates range from a low of 557,908 in 2012 to a high of 1,986,853 in 2010. The 2010 estimate is double the next highest estimate of 965k fry in 2008 (Table 5). Similar estimates of chum fry production have been derived from Site F7 at BC Rail channel. These estimates range from a low of 23,022 in 2011 to a high of 391,018 in 2008. These data indicate that in the five years that both mainstem and side-channel estimates have been calculated for chum fry the production from the NVOS and BC Rail side-channel complexes combined represented a range of between 28-43%, of total production above the RST site (Table15). These data exclude Tenderfoot Creek where no fry estimates have been derived.

3.3 Juvenile Outmigrant Bio-sampling

Mean length for chum fry sampled at the RSTs ranged from 30-65mm, and the average length has ranged from 36.7mm in 2012 to 40.9mm in 2003 (Table 16).Weight data for chum fry was not analysed as it is very difficult to get accurate weights of fish this size in the field. No length data were recorded for fish captured at the side channels. There was a statistically significant observed difference in mean length of chum fry between the twelve years of capture (ANOVA, $p<0.001$, $F=59$, $df=11$) but this difference was only 4 mm. A statistical test was conducted to compare the mean lengths of chum fry pre and post WUP which had equal variance (F test, $df=10$, $F=1.89$), and a statistical difference was evident (T test equal variance, $df=10$, $F=2.56$, $p=0.01$). In general chum fry have been slightly smaller in the period 2007-2012 than during sampling pre 2007.

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

Egg to fry survival, H' was calculated for the entire area above the RST site (RK 5.5) based on the estimated number of spawners, the sex ratio, and the average fecundity of females. A range of values were calculated from 9 to 22% with an average of 15% (Table 17). Highest egg to fry survival was observed for the 2011 brood year, while the lowest was recorded for the 2009 brood year. A plot of H' to female spawner density indicates a very high negative correlation ($r^2 = 0.90$) between survivorship and the number of females in the spawning population (Figure 12).

We also evaluated the same data, removing the side-channel data from NVOS and BC Rail. In this case Tenderfoot Creek is still included in the analysis as we have no estimate of fry production from this area although we have data from the DFO trap that the production may be a significant contribution in some years to that observed at the RST site. A range of values were calculated from 7 to 18% with an average of 12%. Highest egg to fry survival was observed for the 2011 brood spawner year, while the lowest was recorded for the 2009 brood year. A plot of H' to female spawner density indicates a high negative correlation ($r^2 = 0.85$) between survivorship and the number of females in the spawning population (Figure 12).

Egg to fry survival, H' was also calculated independently for the NVOS channel complex and the BC Rail channel complex based again on the estimated number of spawners, the sex ratio, and the average fecundity of females. A range of values for the NVOS channel were calculated from 28 to 54% with an average of 43%. Three brood years, 2007, 2010 and 2011, exhibited very similar results with between 470-760 spawners and between 47-54% egg to fry survival (Figure 13). A strong correlation was observed between egg to fry survival and female spawner density (r2 = 0.83) but this relationship is dominated by one large spawners year (2009). Data from BC Rail channel indicated a quite different pattern of H'. Values of between 11-36% (mean 25%) were recorded but no relationship between female spawner densities was observed despite a large variance in spawner abundance (180-970, Figure 13).

3.5 Bio-physical Analyses

3.5.1 Discharge

Evaluation of the index of discharge variance through the period that adult data have been collected post WUP (2007-2011) suggests limited variance in the discharge between years, thus limited negative affects to the population such as redd stranding and/or the habitat area available for incubation is predicted. The index derived for redd stranding risk, i.e. days with discharge above $18m^3$sec within the spawning period averaged 28 days per year with a standard deviation of 9 days. No correlation between egg to fry survival rates and this index was evident in the data. Equally, during the five years examined since the WUP was implemented the average daily discharge in December through March, the incubation period was within $1m^3$s of the base flow of 15 m^3s and only in 2007/2008 and 2008/2009 did the discharge fall below 14 m^3s; for 5 days and 10 days respectively.

Comparisons of spawner index days (2001-2006 to 2007-2011) indicate that there were 28 high water days (>$18m^3$/sec) on average with a standard deviation of 7 days pre-WUP. Thus, under the post-WUP regime there has been an approximately 12% annual average decrease in the days that fish could spawn in habitat well above the water levels subsequently maintained at the new base flow (15 m^3/sec).

Direct examination of discharge data does indicate that there have been significant changes in daily mean discharge between the two flow regimes but the changes are small in nature. Statistical analysis (T Test, p=0.05) of the 10^{th} and 50^{th} percentile discharge (Table 18) indicated that flows were generally lower during the post-WUP regime by approximately 6 and 8.5 m^3s respectively in the November spawning period. Evaluation of incubation flows indicates that there has been a reduction in the number of days with discharge of less than 14 m^3s from on average 23 per year pre-WUP to 2.3 days post-WUP. However the changes to the 10^{th} percentile of discharge in the incubation period which would presumably control egg survivorship indicate that the change in base flow (pre to post WUP) while generally statistically different are relatively modest at an average of just 1.8 to 2.5 m^3s per month (December through March).

3.5.2 Temperature

Average daily water temperature at the RST data logger in the juvenile migration period of Feb 15th to June 15th during pre-WUP years of the study (2001-2005) ranged from 2.7°C to 10.3°C (sd: 2.1), in comparison post-WUP (2006-2012) temperatures ranged from 3.3°C to 9.4°C; sd: 1.8. In an effort to compare differences in average daily temperature under the two discharge regimes the 10th, 50th and 90th percentile were plotted and the pre and post-WUP values were compared statistically. Statistical evaluation by T-test for significant differences in river temperature indicates that pre-WUP river temperatures were generally higher than recent post 2006 data (Table 19, Figure 14). However data for pre-WUP years is limited to two years (2001 and 2005), except during the spring period, thus summer temperatures could be affected greatly by variation in the annual size of snow pack and melt run off patterns which may not be fully captured in pre 2006 data. Spring temperatures i.e. March through May have however significantly changed within the data collected and analysed with cooler conditions dominating. The reasons for this change are unclear as flows are generally lower in this time period

4.0 DISCUSSION

The primary goal of this monitor is to evaluate the total spawner escapement and potential egg deposition of chum salmon to the Cheakamus River, in particular the numbers utilizing the area above the juvenile monitoring site located at RK 5.5 and the BC Rail and NVOS spawning channels. These data are required when linked with fry production data (Melville and McCubbing 2012, Bonner and Schartz 2012) to establish if post WUP related changes in river discharge compared to the pre-WUP may be affecting egg to fry survival and or spawner distribution. To achieve these goals we require 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 our methods we have included a number of validation checks to confirm data assumptions. These include validation of counter data by video records of observed fish movement, comparison of visual tag recovery to remote logged data for tag reader efficiency, evaluation of tag loss through carcass examination and visual stream walks to compare migration timing and for sex ratio assessments. In 2010, we also examined the potential effect of tagging on subsequent fish behavior at the upper tagging site to establish if fish drop out prior to spawning due to handling stress potentially affecting spawner estimates and therefore egg deposition above the RST site.

Chum fry outmigration estimates on the mainstem calculated since 2001 indicate that production has varied greatly on an annual basis from a low of 1,685,668 in 2001 to a high of 7,264,443 fry in 2010 but that only a small average change in population size (15%) has been detected between the two treatment groups. Data estimates have generally been of high precision for mark recapture methods (average CV =

0.39) and the study has in the majority of years been observed to encompass the entire migration period of juveniles. The key goal under examination utilizing this data 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. A power analysis on the annual estimates including their confidence limits, indicates that the change predicted in chum fry production has not been observed, although enough years data have been collected should the predicted size of change have been manifest. Thus operational changes post-WUP have not as yet resulted in the expected benefits to chum fry production. Reasons for this are likely complex and will relate to spawner abundance, egg deposition rates, spawner distribution and habitat selection, the actual variance in effective habitat area that has occurred under the WUP, as well as factors beyond this study's parameters (i.e. marine survival). Several of these possible factors will be examined in the context of data collected from 2007-2012 during the WUP.

The study null hypothesis as regards fry production states that discharge variance within the spawning and incubation period would not result in a variance in fry production. To reject this hypothesis we need to be able to state there has been a measurable observed change in fry production since the implementation of the WUP. For context, the CC indicated for other salmonid species under examination that any measured negative change in production that was 25% or greater than pre-WUP estimates would be deemed an unacceptable result. As such we use a 25% variance as being the target measurable change in production for accepting of rejecting the null hypothesis. The power analysis undertaken in this respect indicates that to establish this level of change with the current annual variance in annual estimates and precision would take 24 years each of pre and post study data. Clearly chum fry data alone are unlikely to allow within a reasonable time frame a statistically defensible result for that metric of change.

Understanding the problems of utilizing one single life stage of an anadromous salmonid to evaluate the effects of river discharge on population abundance, the study of chum salmon biology on the Cheakamus River was expanded in 2007 to encompass an adult component and separation of mainstem and sidechannel fry production. These additional data should allow for varied marine survivorship (Fukuwaka and Suzuki 2011, Irvine and Fukuwaka 2011) to be removed in part from the analysis of population variance. Adult spawner data collection is intended to assist in the evaluation of changes in outmigrant fry production between years, by providing data on spawner distribution and egg deposition rates. 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 this sampling location. The former is evaluated through data analysis of mainstem to side channel production estimates and egg to fry survivorship which require independent fry production estimates for side-channels, while the latter is evaluated by comparing mainstem upper (above RST) to lower river spawner estimates.

Adult spawner density post-WUP has varied by a factor of 8-fold above the RST site with a high of 105,249 spawners in 2009, and a low of just 12,584 spawners in 2010. Not all of this variation appears to have been the result of entire river spawner returns as total watershed estimates have varied from a low of 73,285 in 2011 to a high of 267,185 in 2007 resulting in the area above the RST contributing between 15 and 64% of the total spawners. Reasons for the highly varied spawner distribution appear related in part to observed changes in mainstem habitat conditions that occurred after a large boulder dam entered the Cheakamus River by way of the Cheekye River during a storm event in the summer of 2009. The boulder weir resulted in the backwatering of a substantial area of spawning habitat above the Cheekye confluence for some 1.5 km upstream. Subsequently, in 2009, a relatively large (164k) spawner year class returned, of which 105k spawned above the RST likely in part due to the loss of suitable habitat between the RST site and the Cheekye River. 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. High variance in chum spawner numbers above the juvenile enumeration site (RST) would be expected to provide highly varied fry production estimates which they have, but the magnitude of this variance at 3.9 fold is much less than the adult spawner variance (8 fold). Comparisons of egg to fry survival rates (H') between years (2007-2012) indicate that at higher female spawner densities, lower egg to fry survival is observed above the RST site. In fact a reduction in H' from 22% to just 9% a 2.5 fold decrease was measured. In comparison Beacham and Starr (1982), reported a 6 fold variance in chum egg to fry production from 19 years of Fraser river data, while Bradford (1995) reported survivorship in BC rivers of 7 to 9%, and Parker (1962) a broader range survivorship, 1-22% from 14 years of sample data. Reasons for these varied values of H' include, highly varied winter discharges and competition for the best spawning habitat between spawners as spawner density increases, which will most likely result in selection of less than ideal nest locations and/or redd superimposition occurring. On the Cheakamus River, the observed change in egg to fry survivorship indicates that with limited data, at higher spawner densities, habitat or access to habitat may be a limiting factor and that unless habitat area is increased substantially the capacity of the upper river area to maximize fry production appears increasingly limited above 15,000 female spawners.

The relative contribution of mainstem spawners to off channel spawners is still somewhat unclear as while we have observed high variance in spawners abundance in the channels in the five years of study, only one of the two sample locations indicate a density dependent relationship (NVOS) and a large area, Tenderfoot Creek has not been evaluated. The reasons for the variance in egg to fry survival in BC Rail channel may be linked with habitat changes associated with beaver activity at Daves pond. These assumptions could be evaluated in the future by pairing the data collected at BC Rail channel with the ground water channel in the NVOS complex (Kisutch) where fry yield is also monitored. In one channel (BC Rail) natural spawner escapement would be allowed to occur while at Kisutch a predetermined number of females over the assumed capacity would be seeded into the channel. A subsequent correlation in annual egg to fry survival would most likely indicate a habitat/groundwater relationship to survivorship rather than local habitat impacts.

Evaluation of an index of discharge variance through the period that adult data have been collected (2007-2011) suggests limited variance in the discharge parameters between WUP years that would affect redd stranding or the habitat area available for incubation. The opportunity of spawners to create nests in areas which would be subsequently dewatered under base flows in December through March was similar among years and made up the majority (>50%) of the spawning period, while incubation flows were very consistent between years as they related to the base flow of 15 m^3s which persisted for much of the period that the eggs were in the gravel.

As adult data prior to 2007 were not collected, we have no direct measure of what egg to fry survival might have been at this time. Examination of discharge data does indicated that there have been significant changes in daily mean discharge between flow regimes but the changes are small in nature. Comparisons of spawner index days (2001-2006 to 2007-2011) indicate that there were 32 higher water days on average with a standard deviation of 8 pre WUP, and 28 higher water days during the WUP with a standard deviation of 10 days. Thus, under the WUP there has been a slight decrease on average ~12.5% in the days that fish could spawn above the water level that was subsequently maintained at the new base flow. Statistical analysis of the 10th and 50th percentile discharge in November indicated that flows were generally lower during the post-WUP regime by 6 and 8 m^3s. Thus spawning conditions available for chum salmon may have changed only slightly between the two operating regimes. Evaluation of incubation flows indicates that there has been a reduction in the number of days with discharge of less than 14 m^3s from on average 23 per year to just 2.3 days. However on further examination, the actual changes to the lower 10th percentile of daily average discharge during the incubation period indicate that the change in base flow is relatively modest at an average of just 1.8 to 2.5 m^3s per month. Additional modeling work are required to establish the relative change in incubation habitat area that this creates and if an increase in fry production, or egg to fry survival might therefore have been expected. Overall data collected to date tend to support the observations of the fry production index, in that modest changes to discharge have resulted in modest changes to fry production, but that habitat is increasingly limited at higher spawner escapements.

In general the methodology utilized in the study of juvenile and adult escapement appears robust in the study years to date. Juvenile data collection methods have been well refined since 2001 and statistical analysis is now using the most up to date techniques. Increasing the geographic scope of side channel chum fry estimates to include Tenderfoot Creek is required in years 6 through 10 if we are to report true separation of off-channel and mainstem fry production and egg to fry survival. This is important as our current reported data in part reflects a blend of survivorship in two separate habitat types (side channel and mainstem). Data from the NVOS site only indicates a very high egg to fry survivorship while data from the mainstem RST site combined with Tenderfoot creek indicates a much lower survivorship, but the relative contribution from each habitat type is as yet unknown. Adult escapement estimates (channel and above RST) based on remote sensing appear reasonably robust as they are largely unaffected by tag detection rates, tag loss, "drop out" pre spawning (females only) or poor precision on estimates of side channel spawner abundance, all of these factors being validated each year. In comparison data that may have been used for estimates derived from streamwalks within spawning channels suffer from; difficulty in evaluating female spawner numbers, loss of Peterson disc tags, missing PIT tags due to predator removal of carcasses and outmigration of kelted fish prior to enumeration. Presumably these factors would be compounded if streamwalk enumeration of the larger mainstem area was the target method. Full river estimates in comparison suffer from low recapture rates of tagged fish and thus exhibit broader confidence limits although they do explain large scale variance in spawning behavior which in part affects fry production above the RST site. Some components of the existing adult study can yet be improved upon. Egg per female data should be collected specific to the size and age of Cheakamus chum salmon as this will assist in refining egg deposition rates. Estimates of female abundance in spawning channels could be better derived at the fish counters using underwater video surveillance than from streamwalks and full river estimates of escapement could be derived from marking a much smaller number of lower river fish with radio tags and utilizing the proportion of fish spawning above the RST to back calculate the whole river estimate while also providing additional data on mainstem spawning site selection.

5.0 RECOMENDATIONS

Several operational suggestions are proposed for Year 6-10 of the study. These advances will aim to continue to increase confidence and provide inference about the assumptions underlining the escapement estimates, the egg to fry survival index H' and its relationship to discharge:

1) Undertake a fish aging and fecundity evaluation annually on a portion of female spawners.
2) Restricting placement of PIT tags to the upper tagging site only with an annual maximum target of 900 fish.

3) Add video based analysis of sex ratios of spawners at NVOS and BC Rail.
4) Add fry enumeration in Tenderfoot Creek
5) Re-instate a radio telemetry program with 120 fish tagged from the lower river site to explain watershed wide variance in spawner locations, sex ratios, provide a basic full river estimate of escapement and add additional information of spawning locations and habitat selection in particular to spawner migration and discharge relationships.
6) Utilize the new NVOS hatchery fish trap at Site 6 (Figure 3) to evaluate sex ratios of spawners in the NVOS complex and tag retention in spawners.
7) Installation of a trap/block on Kisutch channel to evaluate spawner density for comparison with fry production, potentially use fixed escapement at capacity to assess groundwater flow/production correlations in a complimentary evaluation with BC Rail channel.
8) Suspend stream walks except in the case of PIT tag logger failure when PIT tag recovery rates would be required.

6.0 TABLES

Table 1. Numbers and distribution of PIT tags applied o chum salmon adults on the Cheakamus River, 2007-2011.

Year	Lower River (STABLES)				Upper River (GAUGE)				All Locations Total
	Totals	Males	Females	M:F Ratio	Totals	Males	Females	M:F Ratio	
2007	795	349	446	56%	75*	45	30	40%	870
2008	569	328	241	42%	382	252	130	34%	951
2009	391	224	165	42%	371	261	110	30%	762
2010	537	334	204	38%	377	292	85	23%	914
2011	970	766	204	21%	920	763	157	17%	1890

Table 2. Mean fork length of sampled chum salmon adults during tagging operations, Cheakamus River 2007-2011.

Mean Chum Fork Length ± S.D. (mm) by Tagging Location and Year				
	Gauge		Stables	
Year	Female	Male	Female	Male
2007			743 ± 34	801 ± 20
2008	719 ± 43	763 ± 51	718 ± 42	765 ± 50
2009	734 ± 26	760 ± 46	722 ± 31	769 ± 44
2010	748 ± 52	764 ± 52	737 ± 46	769 ± 49
2011	708 ± 33	730 ± 46	700 ± 35	727 ± 45

Table 3. Distribution of spawning location for radio tagged chum salmon spawners in the Cheakamus River, 2007-2011.

		Total Stables Tagged	Below Cheekeye Spawners	Cheekye to RST Spawners	Above RST Spawners	Side Channel Spawners	No data tag not recovered
2007	Male	37	0%	76%	8%	0%	16%
	Female	32	0%	69%	6%	0%	25%
2008	Male	55	2%	51%	44%	0%	4%
	Female	56	2%	57%	23%	2%	16%
2009	Male	59	14%	36%	51%	0%	0%
	Female	48	2%	52%	44%	0%	2%
2010	Male	37	30%	49%	11%	0%	11%
	Female	32	34%	53%	9%	0%	3%
2011	Male	0	0	0	0	0	0
	Female	0	0	0	0	0	0

Table 4. Recovery of Peterson Disc tags from Chum adult spawner carcasses, Cheakamus River 2007-2011.

	2007	2008	2009	2010	2011	Total
Visual tags applied (all tagging sites)	870	951	762	914	1890	5387
Recovered tags *in fish*	3	30	30	21	48	132
Recovered tags *not in fish*	0	7	3	4	2	16
total tags recovered	3	37	32	25	50	147

Table 5. Recoveries (%) of PIT tagged Chum salmon on the Cheakamus River, broken down by tagging location and recovery site.

	Year				
Location	2007	2008	2009	2010	2011
BC Rail					
Gauge	1.3	7.3	3.5	3.2	2.7
Stables	0.6	2.3	3.1	0.5	1.4
NVOS					
Gauge	9.3	17.2	9.4	11.1	10.3
Stables	1.6	2.8	5.9	1.8	3.6
Tenderfoot					
Gauge	4	7.9	1.9	3.1	1.9
Stables	0.3	1.4	2.8	0.2	0.8

Table 6. Female chum spawner % on the Cheakamus River assessed at various periods of study. *denotes at peak count, data in red indicate very small sample size.

Type	Location	2007	2008	2009	2010	2011
Tagging	Stables	44	42	43	28	31
Tagging	Gauge	40	34	30	23	17
PIT Detect	NVOS	nd	27	24	18.5	8
Streamwalk (live)	NVOS	nd	18	20	19	8
Streamwalk (dead*)	NVOS	nd	nd	38	33	21
Streamwalk average	NVOS	nd	nd	nd	35	27
Trap	Tenderfoot	23	36	38	23	21

Table 7. Estimate of chum salmon kelt outmigration from sidechannels, total numbers and % of PIT tagged spawners detected in channel.

NVOS	Males	Females	Total	% of Spawners
2007				29%*
2008				38%
2009	26	0	26	53%
2010	5	1	53	11%
2011	26	2	130	22%
	57	3		
BC Rail	**Males**	**Females**	**Total**	**% of Spawners**
2007				13%*
2008				10%
2009	2	1	25	16%
2010	1	1	14	14%
2011	5	0	40	13%

Table 8. Resistivity fish counter efficiency based on video validation (grey data indicate at normal flows).

		Up	Down
NVOS	2007	96	99
	2008	72	84
	2009	85	74
	2010	71	68
	2011	68	69
BC Rail	2007	nd	nd
	2008	100	95
	2009	68	52
	2010	76	78
	2011	66	78

Table 9. Estimates of chum salmon spawner numbers at NVOS and BC Rail spawning channels and Tenderfoot Creek, 2007-2011.

Location	Year				
	2007	2008	2009	2010	2011
NVOS	2170	3263	9357	2048	2915
Tenderfoot	1555	3309	3003	293	713
BC Rail	522	1279	3243	367	754
Total Channels	4247	7851	15603	2708	4382

Table 10. Proportion of chum spawner distribution between channels on the Cheakamus River 2007-2011.

Location	Year				
	2007	2008	2009	2010	2011
NVOS	51%	42%	60%	76%	67%
Tenderfoot	37%	42%	19%	11%	16%
BC Rail	12%	16%	21%	14%	17%

Table 11. Side-channel data calculations for estimating chum salmon spawner abundance on the Cheakamus River 2007-2011.

Year & Channel								
	Gauge	Stables		Gauge	Stables	Est	Est	% of Spawners
2007	Recapture	Recapture	Count	Marked	Marked	Upper	Total	above RST
NVOS	4.2	7.8	2609	75	795	37630	235699.5	16%
BC Rail	0.8	4	810	75	795	33750.56	128790.2	26%
Tenderfoot	3	2	1555	75	795	29156.5	412075.3	7%
Combined	8	13.8	4974	75	795	41450.11	267184.5	16%
2008	R	R	C	M	M	Upper	Total	
NVOS	66	16	3263	382	569	18603.99	109214.6	17%
BC Rail	28	13	1279	382	569	16847.55	51982.29	32%
Tenderfoot	30	8	3309	382	569	40775.45	209202.4	19%
Combined	124	37	7851	371	391	23301.78	80782.68	29%
2009	R	R	C	M	M	Upper	Total	
NVOS	30	19	9357	371	391	111982.2	182929.4	61%
BC Rail	13	10	3243	371	391	85939.57	115274	75%
Tenderfoot	11	7	3003	371	391	92842.83	146771.8	63%
Combined	54	36	15603	371	391	105249.3	164885.8	64%
2010								
NVOS	42	10	1409	377	577	12353.35	73908.55	17%
BC Rail	12	2	367	377	577	10643.08	70586.67	15%
Tenderfoot	6	1	293	377	577	15780.29	84531	19%
Combined	60	13	2069	371	577	12583.61	85272.43	15%
2011								
NVOS	95	35	2915	920	970	27935.43	78543.08	36%
BC Rail	25	14	754	920	970	26680.04	48758.73	55%
Tenderfoot	18	8	713	920	970	34524.26	76845.67	45%
Combined	138	57	4382	920	970	29003.17	73285.19	40%

Table 12. 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	95% CL	95% CL	Estimate	95% CL	95% CL
	Upper River	LCF	UCF	Total River	LCF	UCF
2007	42011	22506	75020	267574	163234	431396
2008	23368	19626	27817	81000	59189	110569
2009	105540	81235	136954	165318	120309	226566
2010	12624	9844	16173	85461	51453	139344
2011	29041	24610	34264	73377	56861	94590

Table 13. Eleven-year summary (2001-2012) of juvenile chum caught and marked at the rotary screw trap on the Cheakamus River. Bold = WUP estimates

Relative sd. >0.3 = Poor precision.

Species	Year	Total Caught (live)	Total Marked	Total Recap	BTSPAS EST.	+95%	-95%	SD.	Rel. SD
Chum Fry	2001	122,044	43,520	3,557	1,685,668	1,798,406	1,595,828	52,172	0.04
Chum Fry	2002	105,221	23,685	1,101	4,173,706	4,836,441	3,642,305	311,447	0.07
Chum Fry	2003	50,143	11,537	181	4,501,682	6,620,388	3,335,970	898,827	0.20
Chum Fry	2004	126,216	63,006	2,775	3,699,539	4,001,317	3,461,175	138,533	0.04
Chum Fry	2005	174,469	62,312	4,425	4,101,706	5,073,701	3,548,635	654,281	0.16
Chum Fry	2006	355,391	94,235	7,998	4,608,359	4,751,038	4,477,697	69,200	0.02
Chum Fry	**2007**	**382,087**	**82,802**	**6,746**	**5,842,755**	**6,097,001**	**5,618,684**	**121,051**	**0.02**
Chum Fry	**2008**	**81,115**	**35,469**	**1,878**	**3,806,330**	**5,014,920**	**3,261,866**	**497,455**	**0.13**
Chum Fry	**2009**	**283,383**	**48,382**	**6,759**	**3,024,765**	**3,329,535**	**2,793,071**	**136,382**	**0.05**
Chum Fry	**2010**	**366,185**	**94,647**	**10,102**	**7,264,443**	**7,825,972**	**6,735,949**	**280,858**	**0.04**
Chum Fry	**2011**	**188,897**	**59,734**	**7,718**	**1,882,688**	**1,973,763**	**1,804,029**	**43,817**	**0.02**
Chum Fry	**2012**	**186,073**	**42,369**	**4,350**	**2,760,670**	**2,913,866**	**2,619,252**	**74,013**	**0.03**

Table 14. Power analysis on Juvenile Chum Outmigration data Cheakamus River, 2001-2012

	Years of Data		Average Abundance					
Sp.	**IFA**	**WUP**	**IFA**	**WUP**	**Change in Abundance WUP-IFA**	**Change in Abundance (%)**	**Average SD.**	**Average relative error (CV)**
CMF	6	6	3,795,110	4,109,163	569,086	15%	1,600,026	0.39

			Years per Group to Detect:				
Sp.	**Power at Type I=0.05**	**Rel. Change in Abundance achieve Power=0.8**	**+1% Power=0.8**	**+25% Power=0.8**	**+50% Power=0.8**	**+75% Power=0.8**	**Power with 5 additional WUP years**
CMF	0.09	76%	27,254	46	12	6	0.11

Table 15. Five-year summary (2007-2012) of juvenile chum BTSPAS estimates from side channels upstream of the rotary screw trap on the Cheakamus River.

Relative sd. >0.3 = Poor precision.

Fyke Site	2007	Rel. SD.	2008	Rel. SD.	2009	Rel. SD.	2010	Rel. SD.	2011	Rel. SD.	2012	Rel. SD.
NVOS Enumeration Fyke (F1)	5,972,095	0.08	965,069	0.04	924,726	0.03	1,986,853	0.02	557,908	0.02	668,231	0.02
Kisutch Enumeration Fyke (F3)	665,434	0.17	965,096	0.80	300,640	0.27	488,798	0.14	157,933	0.50	68,854	0.16
BC Rail Enumeration Fyke (F7)			156,740	0.02	391,018	0.12	268,755	0.02	23,022	1.05	98,153	0.05
Side-channel Yield assessed upstream of RST	5,972,095		1,121,836		1,315,744		2,255,608		580,930		766,366	

Table 16. **Summary of mean chum fry lengths (mm) 2001-2012 from the Cheakamus River.**

Species	Year	N	Mean Length	Range
Chum Fry	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**

Table 17. **Egg to Fry Survival calculations for Cheakamus River above the RST site and mainstem (with Tenderfoot) only.**

Brood Year	2007	2008	2009	2010	2011
Total Spawners above RST	42011	23368	105540	12624	29041
Side Channel Estimates	4247	7851	15603	2708	4369
Above RST Mainstem only	37764	15517	89937	9916	24672
Females above RST	14704	7945	31662	2904	4937
Females Mainstem only	13217	5276	26981	2281	4194
Females mainstem and Tenderfoot	13394	6373	28023	2336	4288
Eggs per Female	2500	2500	2500	2500	2500
Egg Deposition above RST	36759625	19862800	79155000	7258800	12342425
Egg Deposition mainstem only	33043500	13189450	67452750	5701700	10485600
Fry Above RST	3806330	3024766	7264444	1882689	2760670
NVOS	965096	924726	1986853	557908	668231
BC RAIL	156740	391018	268755	23022	98135
Hatchery above RST	91286	164973	272027	335891	90504
Fry Above RST (exclude channels and hatchery)	2442758	611599	3851109	919118	1823900
H above RST all	10%	14%	9%	21%	22%
H Above mainstem and Tenderfoot Creek	8%	10%	7%	17%	18%

Table 18. Comparison of pre and post WUP discharge on the Cheakamus River, statistical results (T-test) by month

	10 Percentile	50 Percentile	90 Percentile	Mean
January	Pre < Post*	Pre > Post*	Pre < Post*	Pre > Post*
February	Pre < Post*	No difference	No difference	No difference
March	Pre < Post*	No difference	No difference	No difference
April	No difference	Pre > Post*	Pre > Post*	Pre > Post*
May	Pre > Post**	No difference	No difference	No difference
June	No difference	Post > Pre*	Post > Pre*	Post > Pre*
July	Pre > Post*	Post > Pre*	Post > Pre*	Post > Pre*
August	Pre > Post*	Post > Pre*	Post > Pre*	Post > Pre*
September	No difference	No difference	Post > Pre*	Post > Pre*
October	Pre < Post*	No difference	Pre > Post**	Pre > Post**
November	Pre > Post*	Pre < Post*	No difference	No difference
December	No difference	Pre < Post*	Pre > Post*	Pre > Post*

*p value = 0.01
**p-value = 0.05

Table 19. Comparison of pre and post WUP river temperatures on the Cheakamus River, statistical results (T-test) by month

	10 Percentile	50 Percentile	90 Percentile	Mean
January	No data	No data	No data	No data
February 15-28	No difference	No difference	No difference	No difference
March	No difference	Pre > Post*	Pre > Post*	Pre > Post*
April	Pre > Post*	Pre > Post*	Pre > Post*	Pre > Post*
May	Pre > Post*	Pre > Post*	Pre > Post*	Pre > Post*
June	Pre > Post*	Pre > Post*	Pre > Post*	Pre > Post*

July	Pre > Post*	Pre > Post*	Post > Pre*	Pre > Post*
August	Pre > Post*	Pre > Post*	Post > Pre**	Pre > Post*
September	Pre > Post*	Pre > Post**	No difference	Pre > Post*
October	No difference	No difference	Post > Pre*	No difference
November 1-10	Pre > Post*	Post > Pre*	Post > Pre*	Post > Pre*
December	No data	No data	No data	No data

*p value = 0.01
**p-value = 0.05

7.0 FIGURES

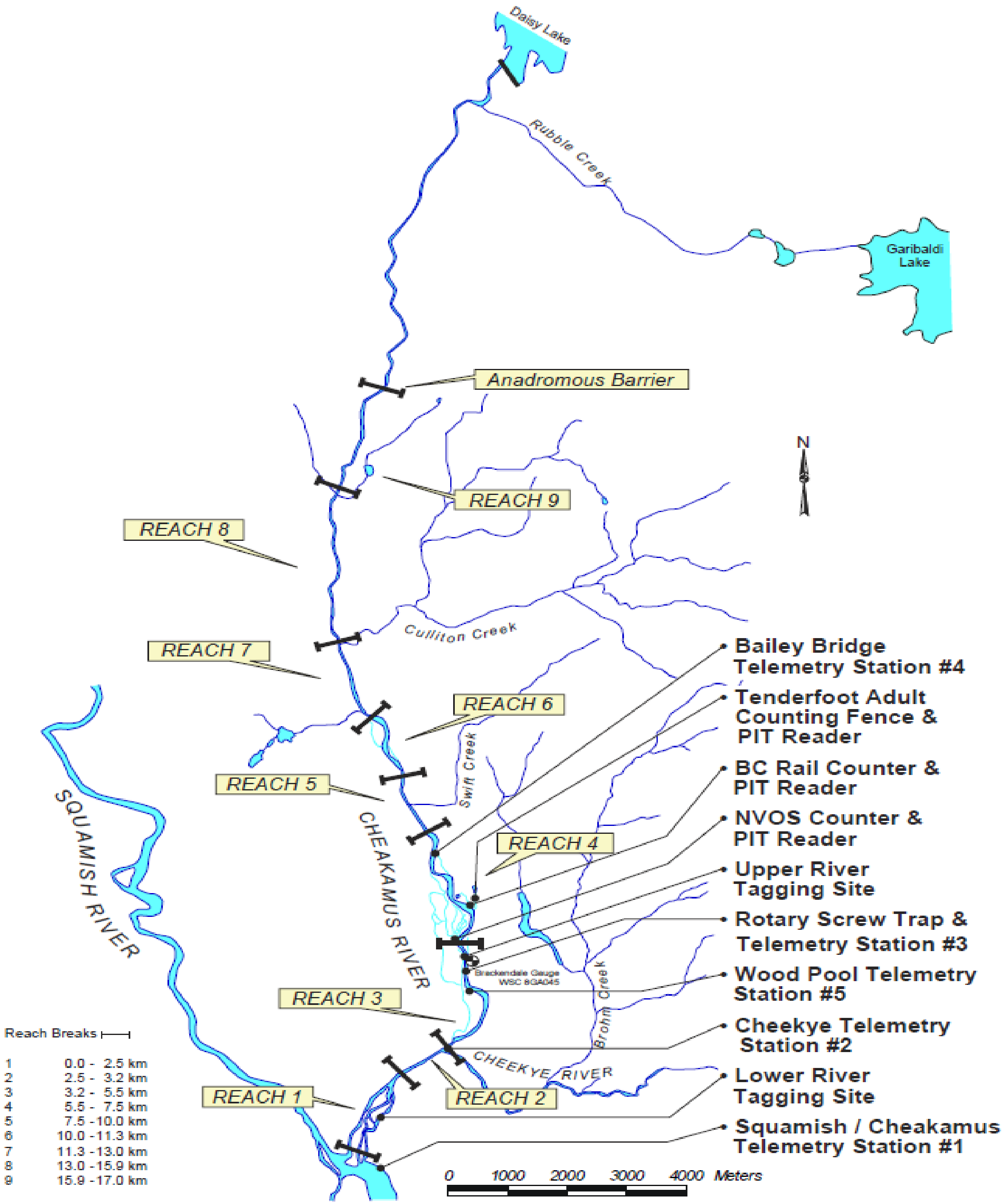


Figure 1: Study area for Cheakamus River chum salmon escapement monitoring (River KM 0.5- 8.0) with tagging sites, side channel resistivity counter / PIT detection sites, and fixed radio telemetry receiver locations.

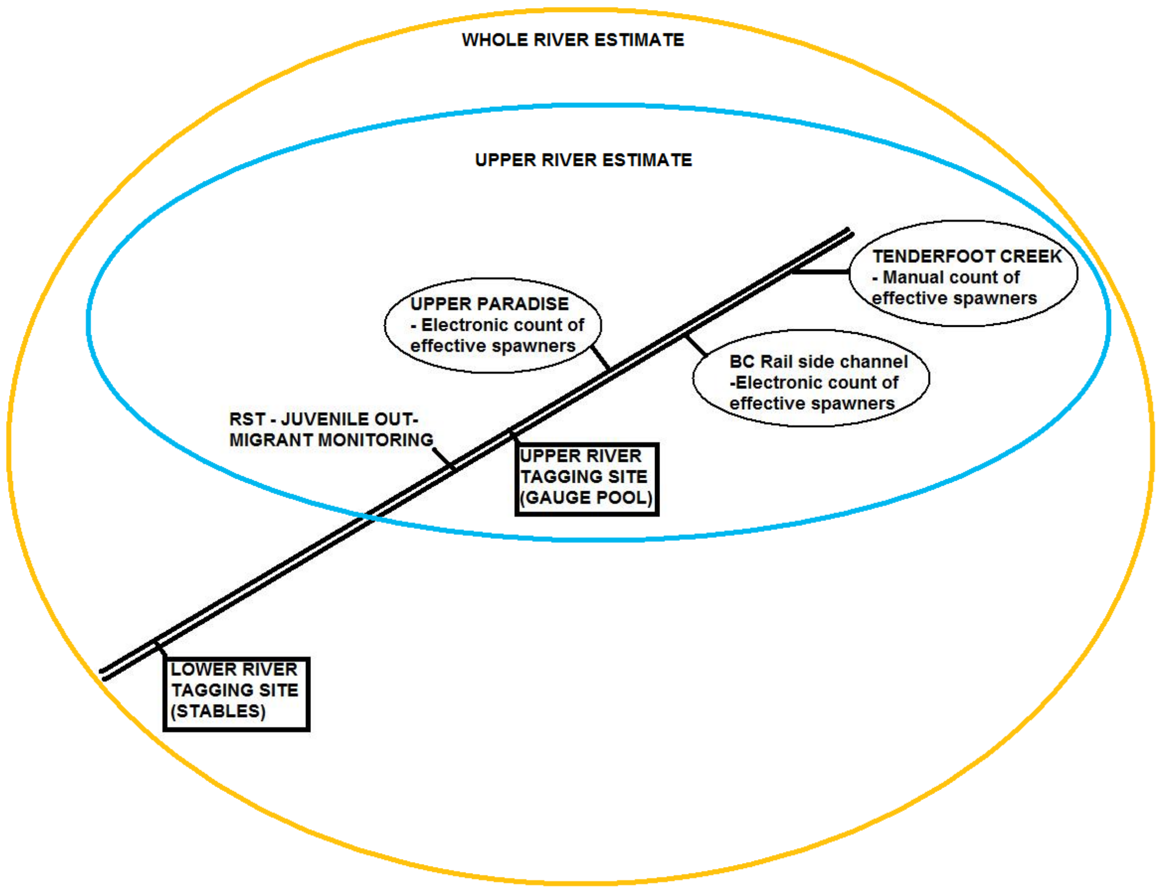


Figure 2: **Conceptual diagram of the Cheakamus River chum salmon spawner enumeration monitor illustrating the spatial relationship of tagging and monitoring locations. Whole river (yellow ellipse), Upper river (blue ellipse), and individual side channel (black ellipses) spawner estimates are highlighted.**

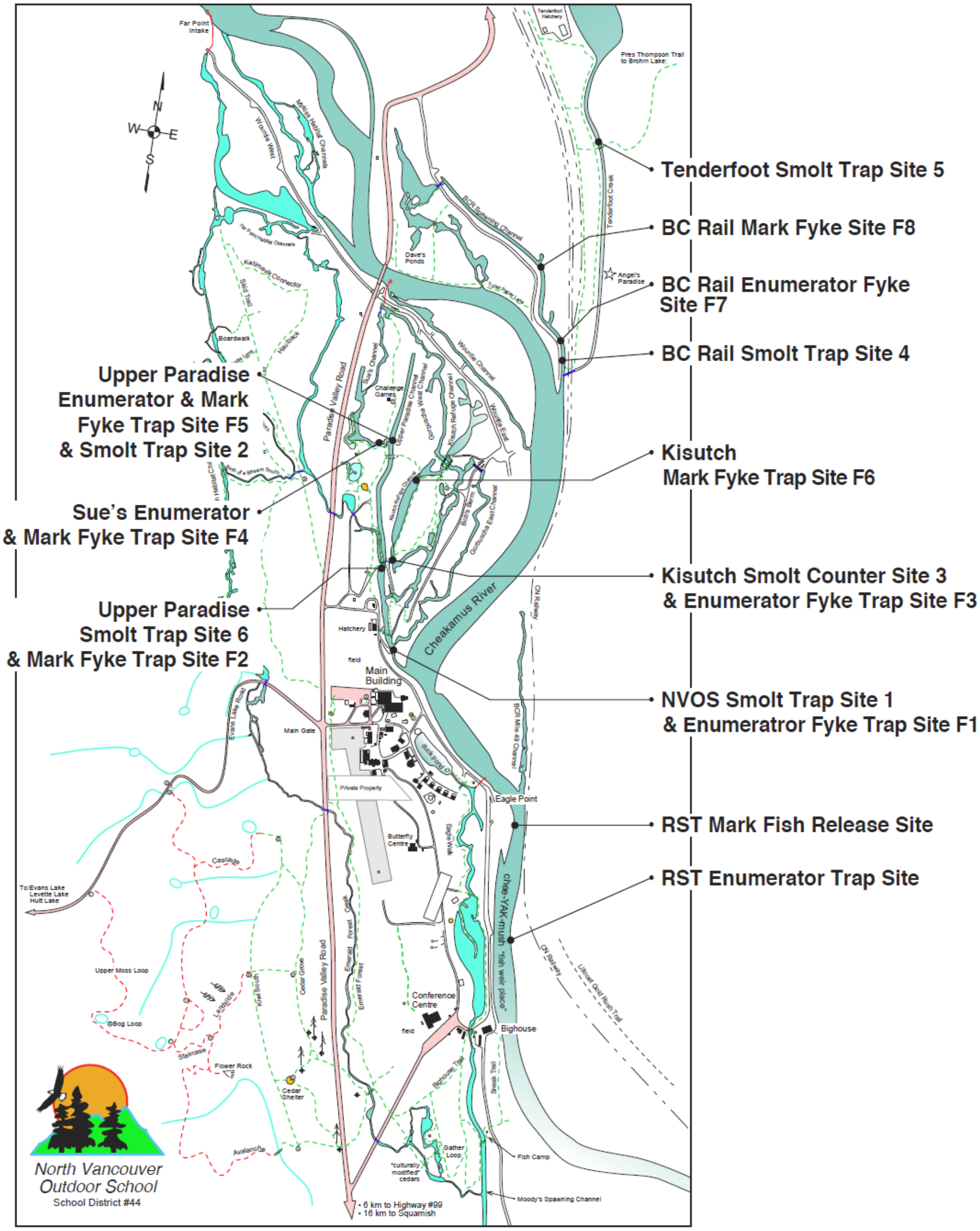


Figure 3. Site Map indicating trap sites utilized for the Cheakamus River Juvenile Outmigration Monitor 1a.

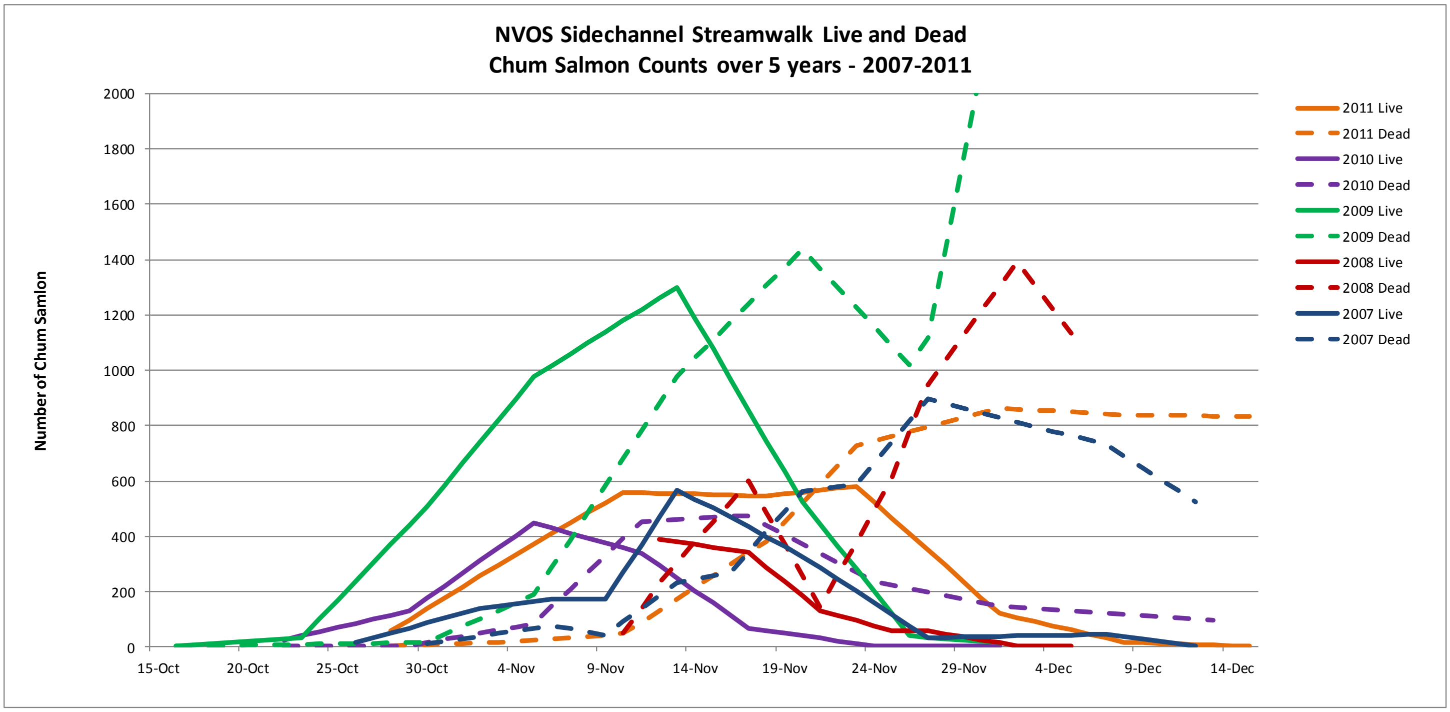


Figure 4. Live and dead chum salmon counts in the NVOS spawning channels, 2007-2011.

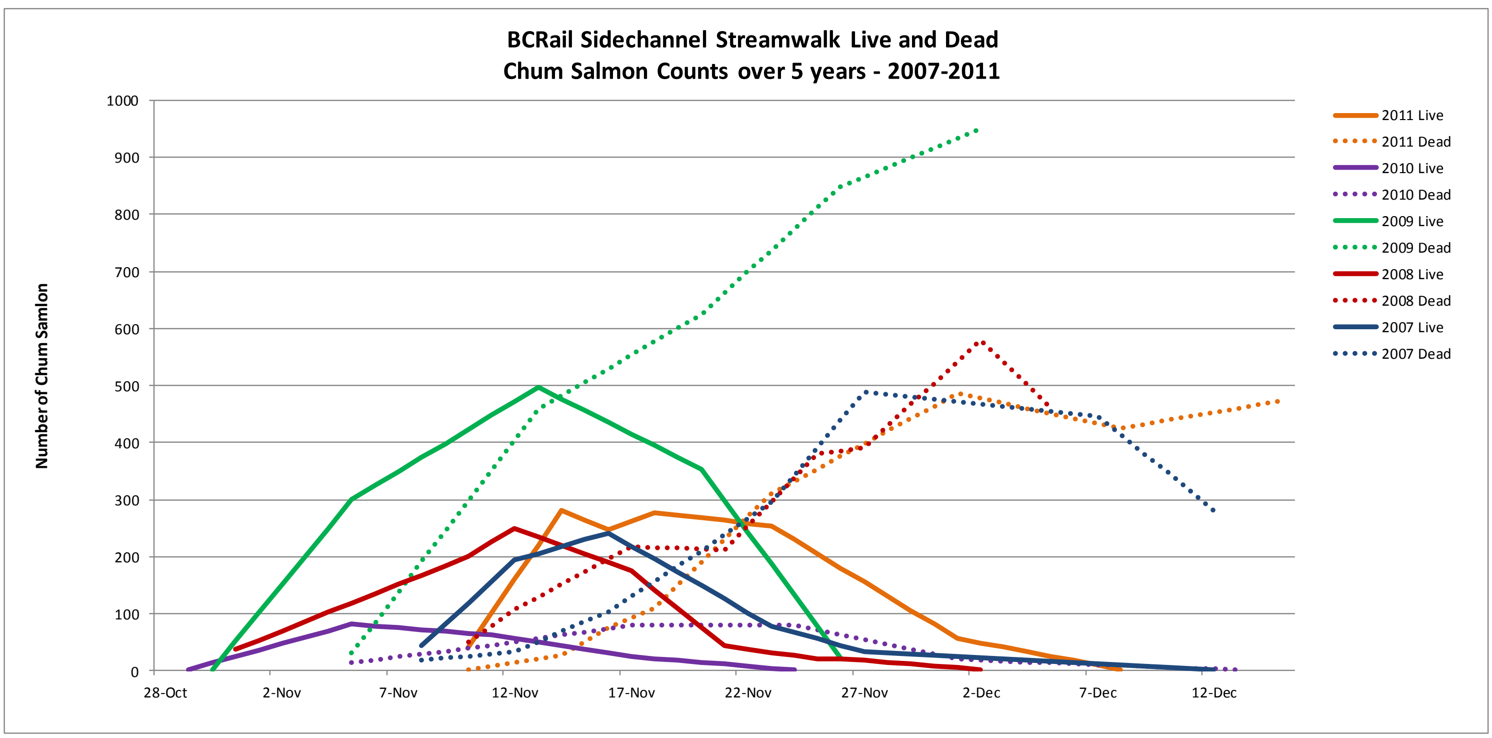


Figure 5. Live and dead chum salmon counts in the NVOS spawning channels, 2007-2011.

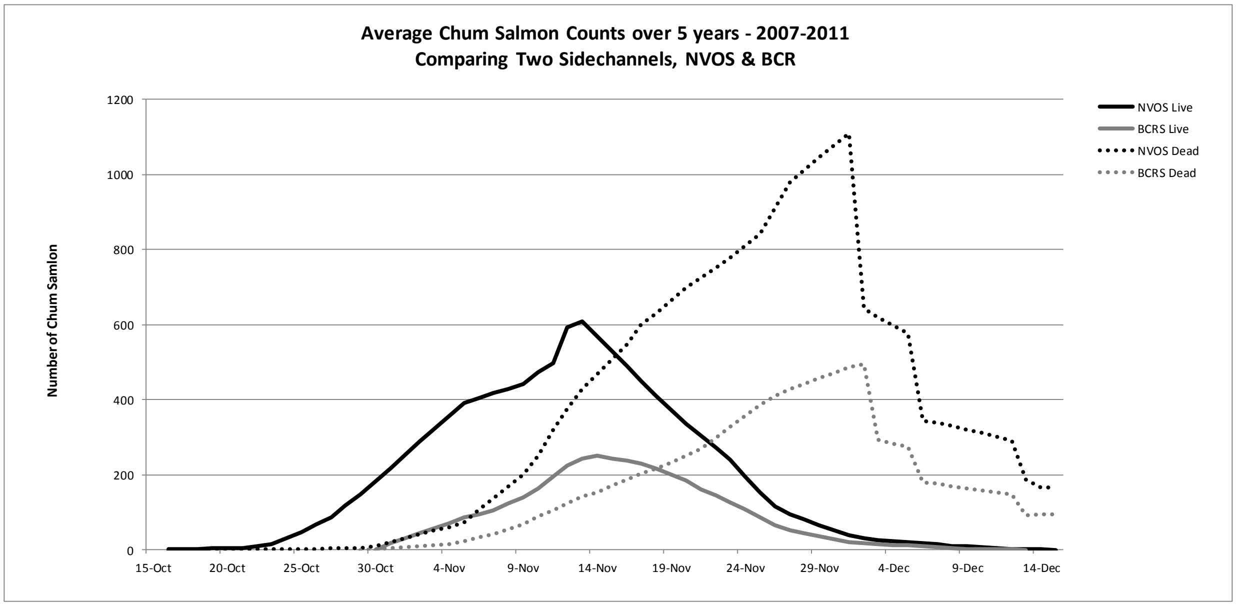


Figure 6. Comparison of average spawner numbers and timing for 2007-2011, NVOS versus BC Rail Channel

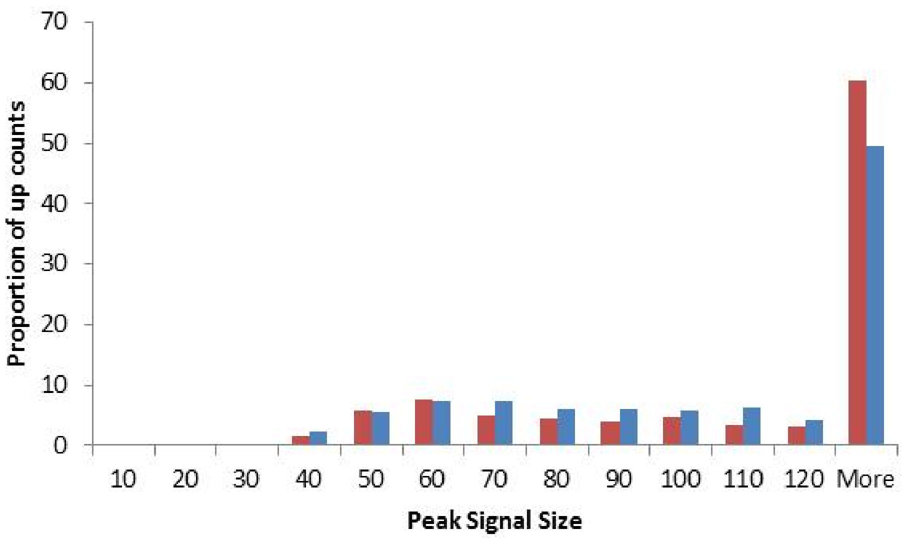


Figure 7. Example of the proportional distribution of peak signal size for up counts recorded at BC Rail (blue bar) and NVOS (red bar) spawning channels during the 2010 monitoring season.

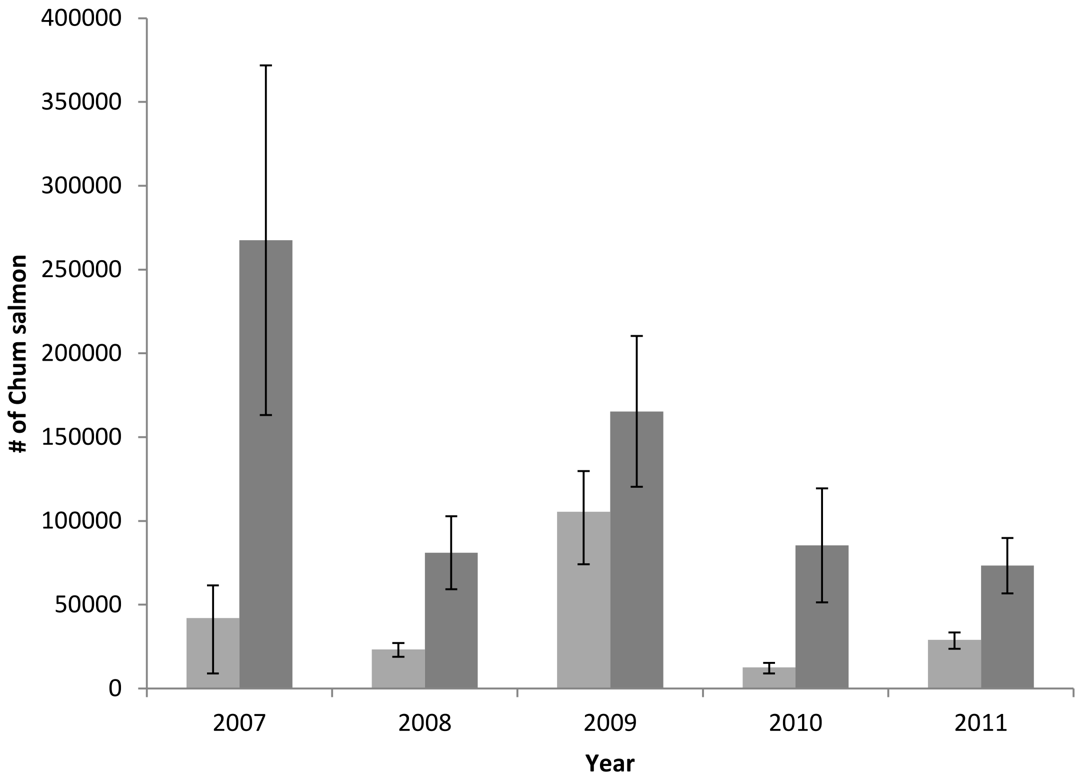


Figure 8. Estimates of chum salmon spawners above the RST site (light grey) and whole river (dark bar) at the Cheakamus River, 2007-2011, with 95% confidence intervals (bars).

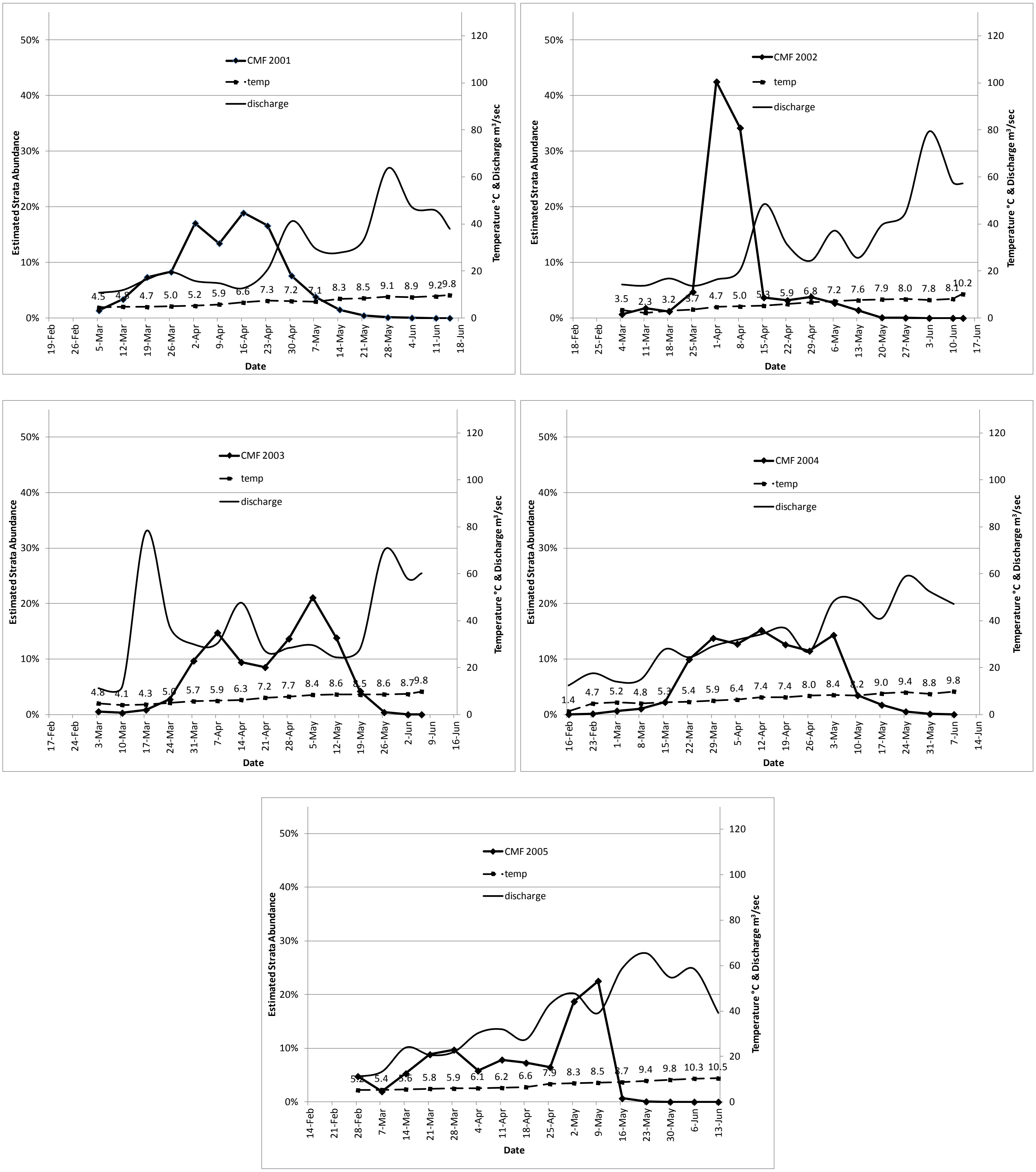
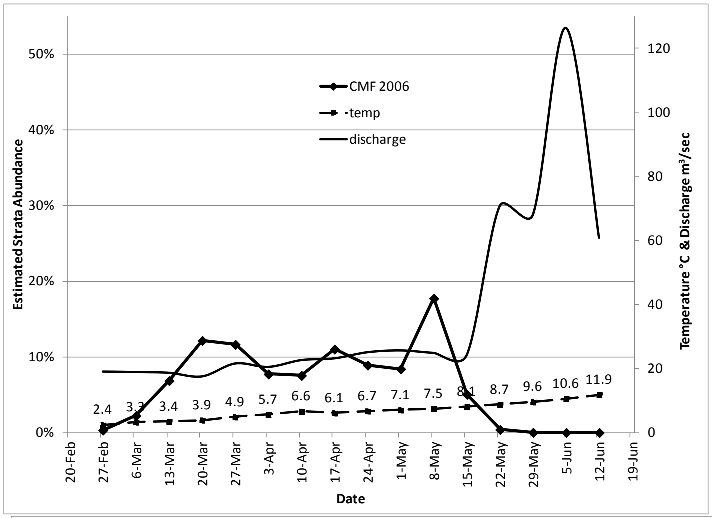


Figure 9 . PRE-WUP Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in ^{0}C (broken line, squares) and discharge (solid line) from the Cheakamus River.


CMF 2006
temp
discharge
Estimated Strata Abundance
Temperature °C & Discharge m³/sec
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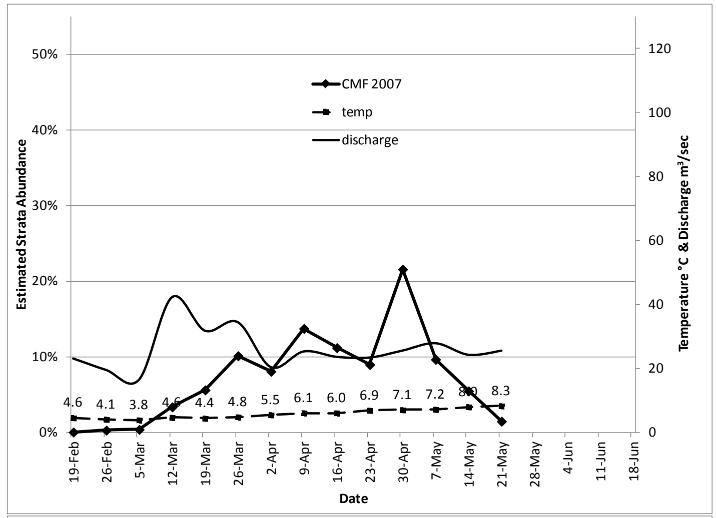
CMF 2007
temp
discharge
Estimated Strata Abundance
Temperature °C & Discharge m³/sec
Date
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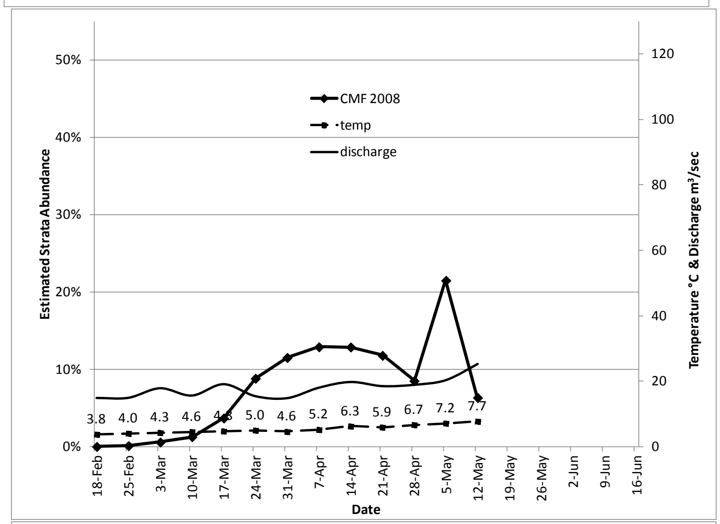
CMF 2008
temp
discharge
Estimated Strata Abundance
Temperature °C & Discharge m³/sec
Date
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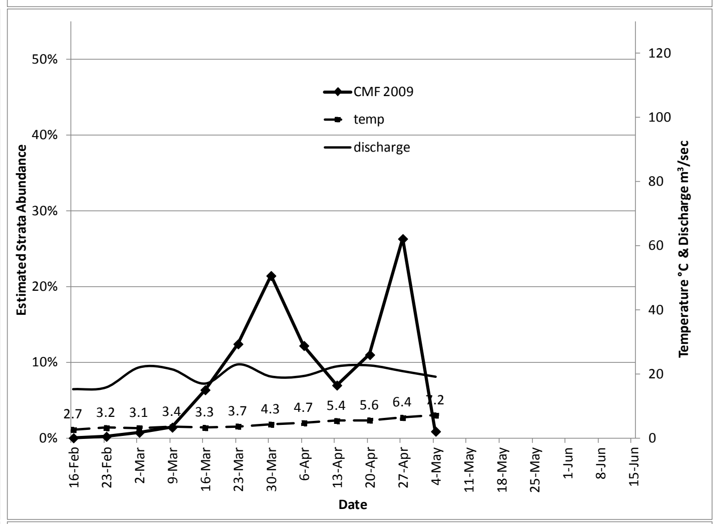
CMF 2009
temp
discharge
Estimated Strata Abundance
Temperature °C & Discharge m³/sec
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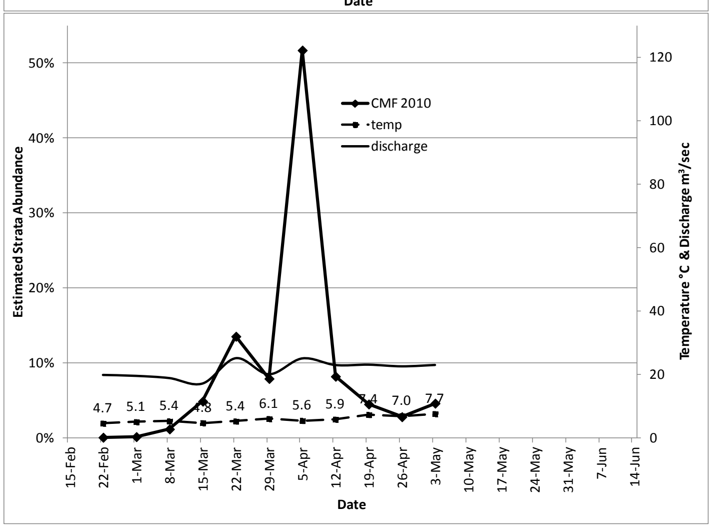
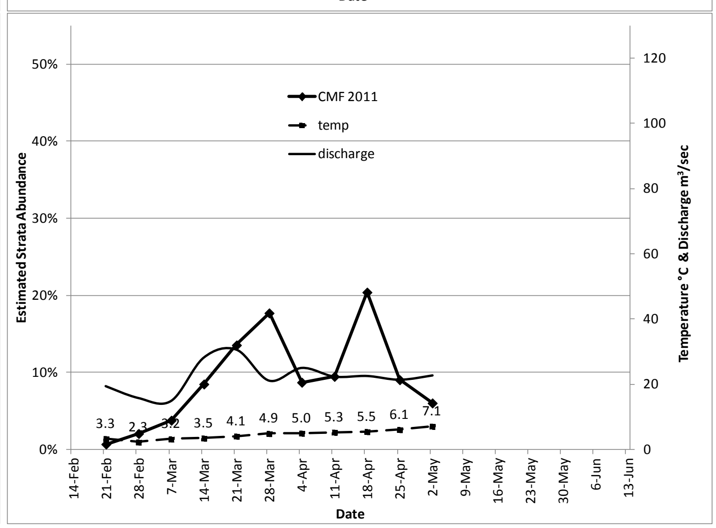

CMF 2010
temp
discharge
Estimated Strata Abundance
Temperature °C & Discharge m³/sec
Date
4.7 5.1 5.4 4.8 5.4 6.1 5.6 5.9 7.4 7.0 7.7


CMF 2011
temp
discharge
Estimated Strata Abundance
Temperature °C & Discharge m³/sec
Date
3.3 2.2 3.2 3.5 4.1 4.9 5.0 5.3 5.5 6.1 7.1

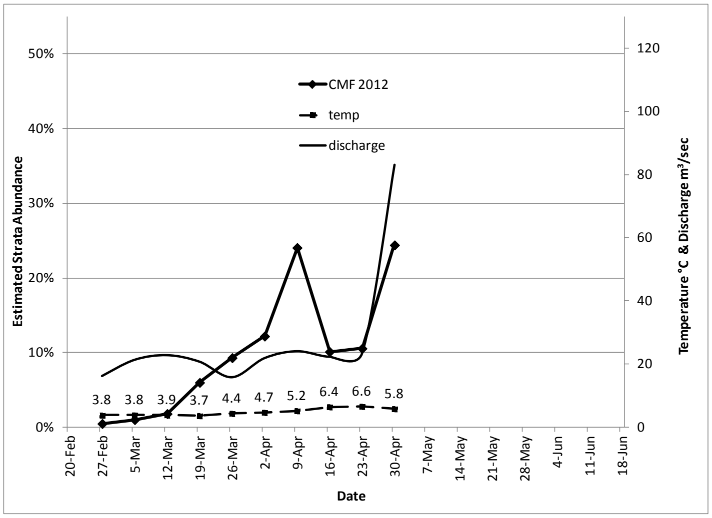


Figure 10. POST-WUP Weekly abundance estimates of chum fry (solid line, diamonds) related to temperature in ^{0}C (broken line, squares) and discharge (solid line) from the Cheakamus River.

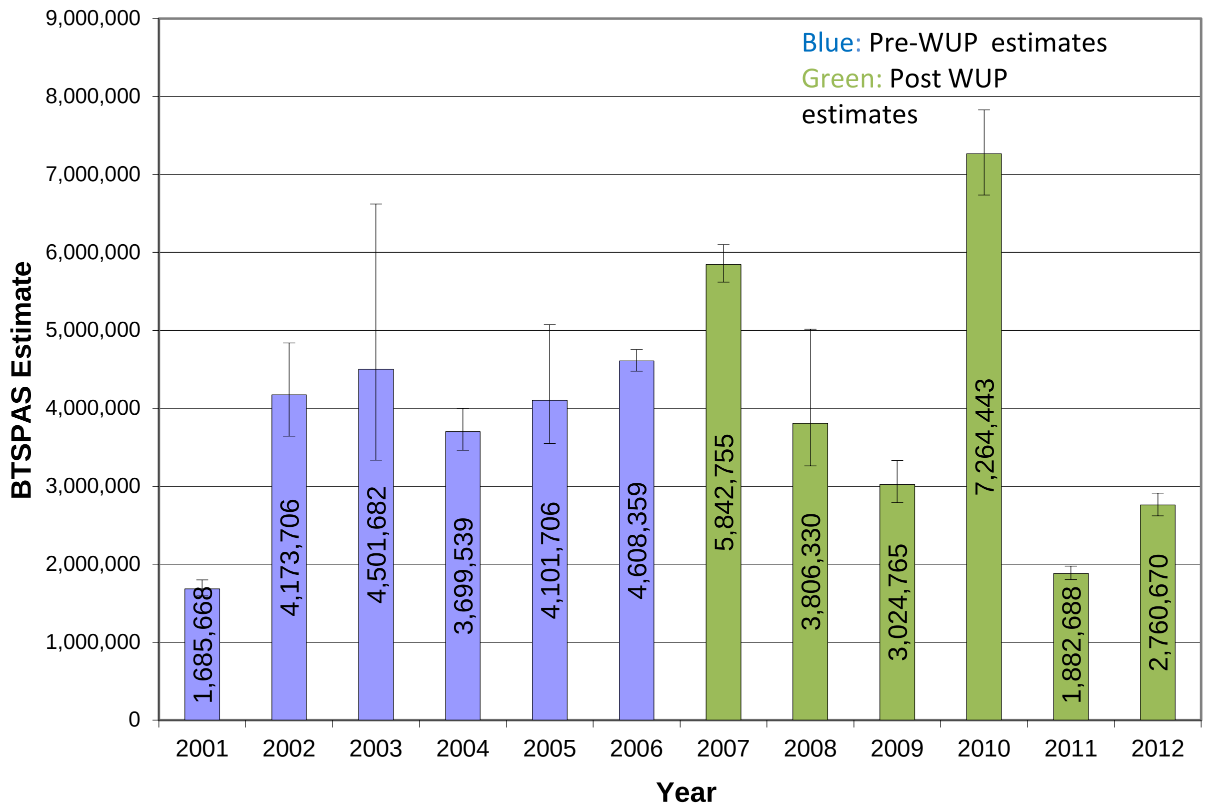


Figure 11. RST derived BTSPAS estimates of chum fry yield from Spring 2001 to 2012, including 95% confidence limits.

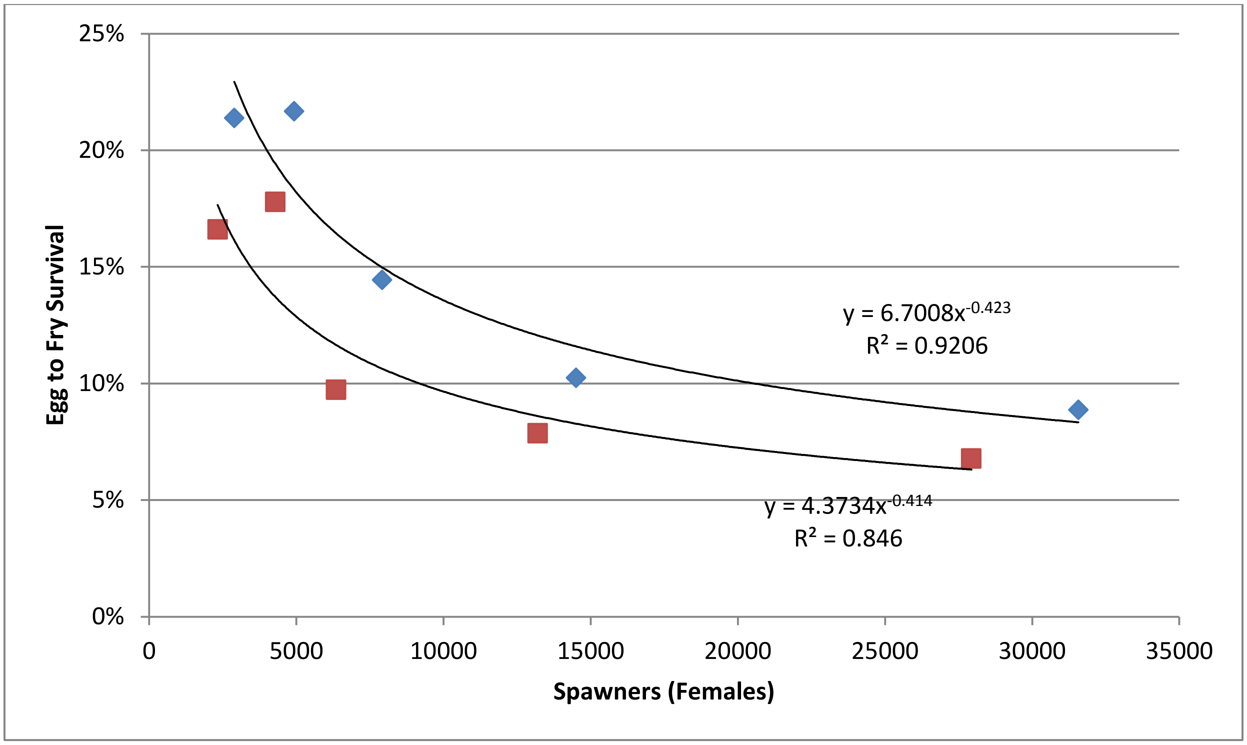


Figure 12. Estimated egg to fry survival (H') for chum salmon: above the RST site (blue diamond) and above the RST excluding NVOS and BC Rail production, compared to female spawner abundance.

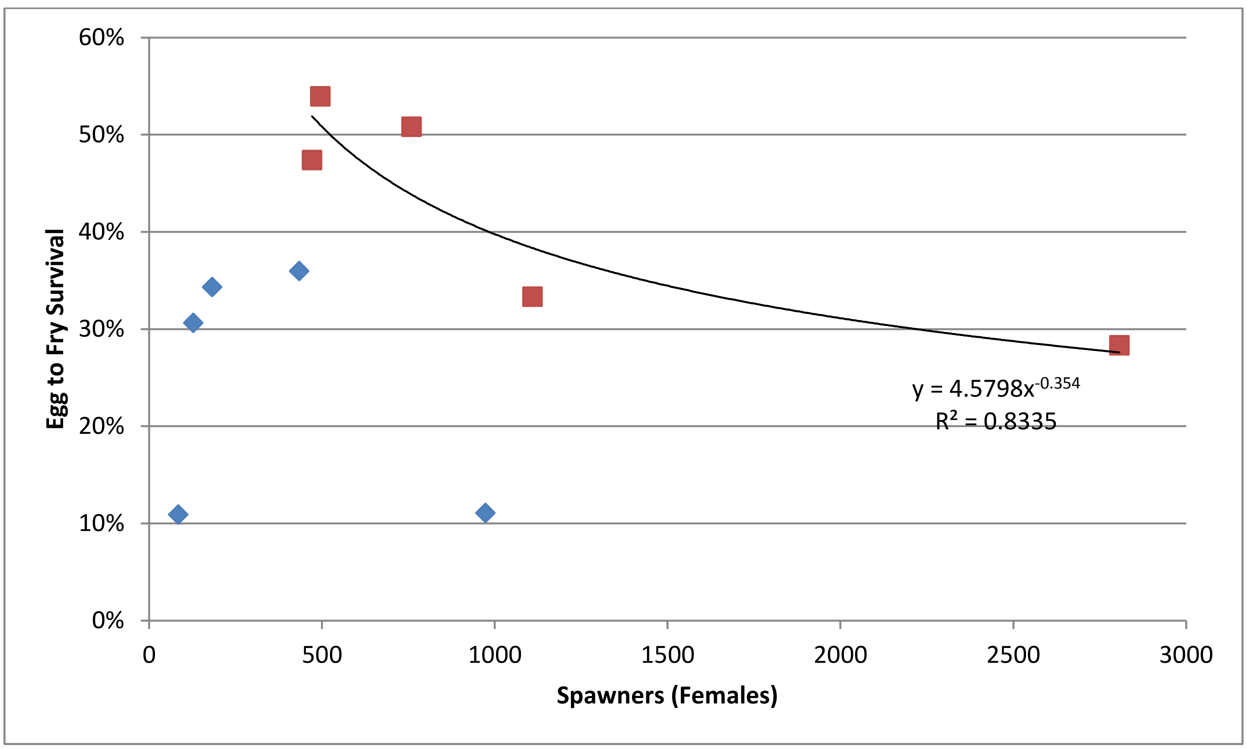


Figure 13. Estimated egg to fry survival (H') for chum salmon: at BC Rail channel (blue diamond) and the NVOS channel complex, compared to female spawner abundance.

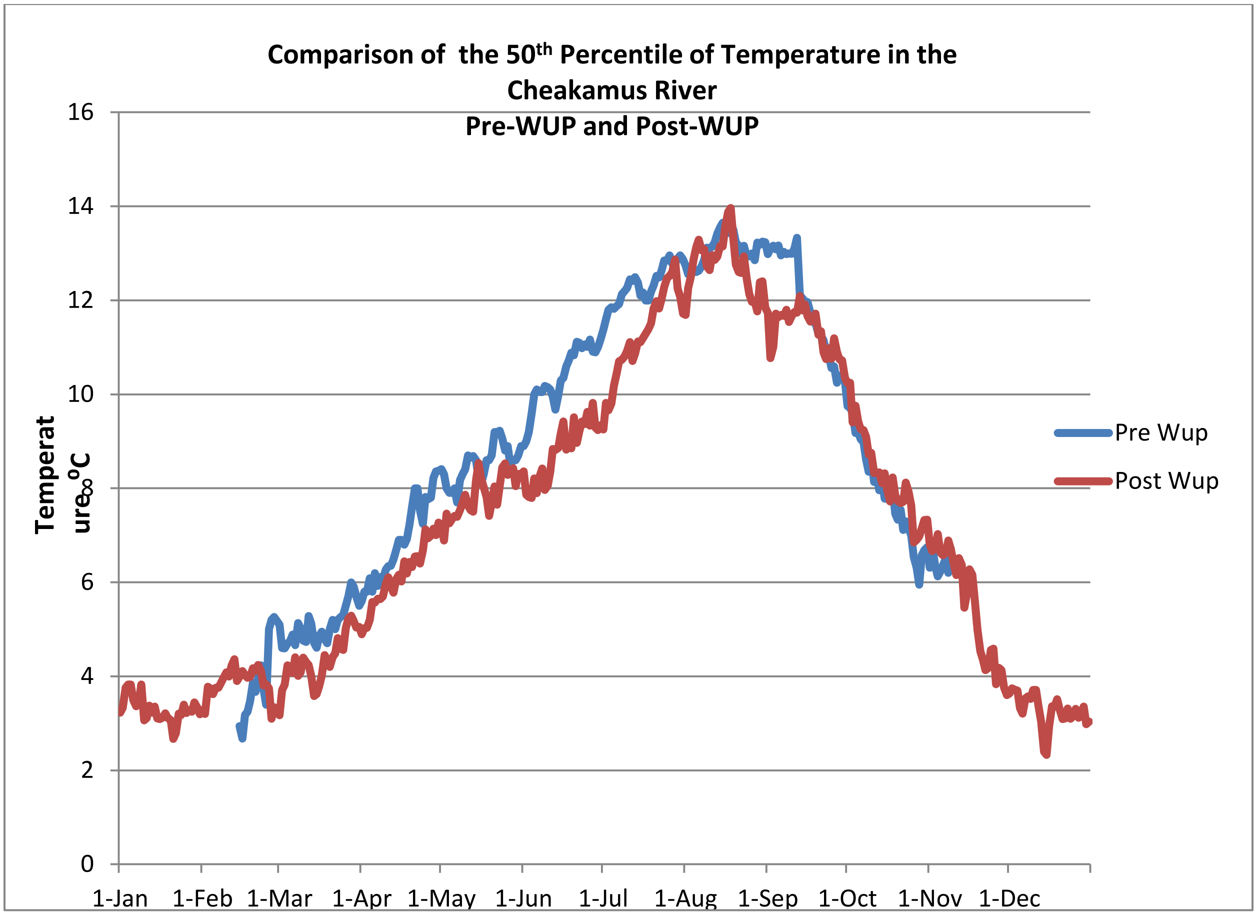


Figure 14. Comparison of the 50th percentile of river temperature pre and post WUP on the Cheakamus River

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