Cheakamus River Project Water Use Plan

Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Survey

Implementation Year 11

Reference: CMSMON1b

Evaluations of the Cheakamus River Chum Salmon Escapement Monitoring and Mainstem Spawning Groundwater Surveys from 2007-2017, and Chum Fry Production from 2001-2018

2007-2017 report

Study Period: October 2017 – May 2018

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EXECUTIVE SUMMARY

A recent 10-year synthesis (2007 – 2016) of CMSMON1b revealed remaining uncertainties associated with the effects of the WUP discharge regime on groundwater upwelling, adult Chum Salmon spawning site selection, distribution, and overall productivity. Groundwater data were scarce and often limited to one year and stock-recruitment analyses suggested increased variability in the Cheakamus River hydrograph between 25 and 80 m^3s^{-1} during the fall adult migration likely increases juvenile productivity. We recommended additional years of monitoring to further investigate the groundwater/spawning site relationship and strengthen the stock-recruitment hypothesis of greater discharge variability leading to increased juvenile Chum Salmon productivity. To address these uncertainties and recommendations, BC Hydro initiated an additional year of monitoring during the 2017-2018 adult migration and juvenile incubation/rearing periods. This year was characterized by three distinct periods of experimental pulse flows during the fall adult migration in which discharge was manipulated between 25 and 80 m^3s^{-1}, and increased groundwater monitoring during the incubation period. This report discusses results from this 11th year of monitoring and how they address the uncertainties described in the 10-year synthesis and guiding management questions for CMSMON1b.

During the fall 2017 migration, the majority of adult Chum Salmon were distributed throughout spawning habitats in the lower reaches of the Cheakamus River between RK 2.0 (Stables) and below RK 7.5 (Bailey Bridge), with 21% of the estimated population utilizing lower river side-channel habitats and 0% of radio tagged individuals observed above the Bailey Bridge. Despite more discharge variability during the fall migration from pulsed flows, there was no relationship between discharge and maximum migration distance achieved by radio-tagged fish. This result in combination with low estimated adult escapement in 2017 supports the hypothesis that movement into the modeled effective habitat above the Bailey Bridge is density dependent rather than discharge-related.

We modeled the 2017 side-channel data and found that two peaks of daily entries into side-channels were related to increases in mean daily discharge from 15.8 – 71.7 m^3s^{-1}. The models suggested that daily entries could be increased by pulsing discharge above the daily mean of 32.4 m^3s^{-1} during the adult migration. Increasing entry into side channels could potentially increase Chum Salmon productivity, as egg-to-fry survival is consistently higher in side channels relative to the mainstem river (Fell et al. 2018).

Continued groundwater monitoring in 2017 found evidence of upwelling throughout the study site. Sites with the strongest upwelling evidence were located downstream of the Bailey Bridge, where the majority of adult Chum Salmon are observed spawning; however, there was also evidence of weak groundwater upwelling upstream of the Bailey Bridge. Throughout all of the monitored sites, the degree

of groundwater upwelling varied substantially both within and between sites. Our observations of Chum Salmon spawning do not align completely with usage predicted by the original models developed during the WUP consultative process, or with areas of strong groundwater upwelling. Thus, we suspect that spawning site selection in the Cheakamus River is likely driven by a combination of the characteristics used during the WUP modelling, groundwater upwelling, and additional micro- and macro-level habitat characteristics.

Experimental pulse flows during the 2017 fall adult migration resulted in a more variable hydrograph in the Cheakamus River than is typical during standard WUP operations. However, this experiment did not increase the number of days when discharge during adult migration was >25 and <80 m3/s relative to the previous 10 years of the study, and the resulting egg-to-fry and adult-to-fry stock-recruitment estimates were very similar to the 10-year means. Despite the average migration conditions and stock-recruitment estimates, the addition of 2017 data to both the egg-to-fry and adult-to-fry models continued to support the hypothesis that more variability in flows during the adult migration period increases juvenile productivity. These results suggest that regulating discharge during adult migration and juvenile incubation could be used as a management tool to increase Chum Salmon productivity in the Cheakamus River. We caution, however, that because Chum Salmon are a long-lived species with highly variable abundances, inferences drawn from these stock-recruitment relationships with relatively small sample sizes (i.e. years of monitoring) could be biased or inaccurate. And while this year's results add more confidence to the predicted stock-recruitment relationships, we recommend a precautionary approach to any management decision made based on these findings. Moreover, the current continuation of the pulse flow discharge experiment (fall 2018) based on this recommendation and designed to improve the robustness of stock-recruitment analyses and predictions will only be complete with the collection of juvenile Chum Salmon data in 2019. Without juvenile data, stock-recruitment modeling cannot be completed and the long-term data set of Chum Salmon productivity in the Cheakamus River would be compromised. These complete and accurate stock-recruit relationships are critical to understanding whether annual fluctuations in productivity are related to adult escapement or characteristics of the WUP discharge regime.

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1.0 INTRODUCTION

1.1 Project Background

The Cheakamus River watershed drains an area of 1,010 km^2 in the Coast Mountain Range of southwestern British Columbia and supports populations of Chinook (*Oncorhynchus tshawytscha*), Coho (*Oncorhynchus kisutch*), Chum (*Oncorhynchus keta*), and Pink Salmon (*Oncorhynchus gorbuscha*); resident Rainbow and Steelhead Trout (*Oncorhynchus mykiss*); Bull Trout (*Salvelinus confluentus*); and additional forage fish species. The Cheakamus is a primary tributary of the Squamish River, and is ecologically, culturally, and recreationally important to multiple stakeholder groups. Members of the Squamish First Nation harvest salmon for food, social, and ceremonial purposes, and the river also provides opportunities for commercial and recreational angling and rafting communities.

In 1957, the Cheakamus River was impounded by Daisy Lake Dam to divert a portion of water from the Daisy Lake Reservoir to the Cheakamus Generating Station for hydroelectric power production in the Squamish Valley. Following this diversion, the Cheakamus River downstream of the dam now receives only a portion of its natural discharge. There is considerable stakeholder interest in understanding how this altered flow regime affects fish populations, particularly in the portion of the river that is accessible to anadromous salmonids (river kilometer [RK] 0 to RK 17.5).

BC Hydro operates the Cheakamus River hydroelectric system and water release requirements from the dam have varied since the system was impounded in 1957. From 1957 to 1997, the water use license for the Cheakamus River specified that a minimum of 5 m^3s^{-1} of water be released to protect fish; however, the license did not specify detailed discharge regulations or targets (Mattison et al. 2014). In 1997, the Department of Fisheries and Oceans (DFO) issued an instream flow order (IFO) to BC Hydro after decades of unregulated flow releases (driven largely by power demand) were found to negatively affect fish populations. The IFO was amended in 1999 to become the instream flow agreement (IFA), which specified that greater than 5 m^3s^{-1} or 45% of the previous seven-day average inflows into Daisy Lake Reservoir must be released downstream of the dam in an effort to mimic the natural variability of the river hydrograph and potentially reduce negative impacts to fish.

In 2006, the Cheakamus River Water Use Plan (WUP) modified the IFA and instituted a flow regime that aimed to balance minimum flows at the dam with social, economic, and environmental values of the river – one of which being sustained healthy salmon populations (BC Hydro 2007). The effect of WUP flows on fish populations in the Cheakamus River was uncertain as productivity increases were predicted using assumed rather than empirical relationships. Indeed, the productivity model upon which the WUP flows were based was found to overestimate spawning habitat availability relative to empirical measures (Marmorek and Parnell 2002). As a result, environmental monitoring programs (including

CMSMON1b) were instituted in conjunction with the WUP order that aimed to determine how the WUP discharge regime influenced fish populations in the Cheakamus River.

1.2 Management Questions

Chum Salmon were identified during the WUP consultative process as an important indicator of fish health in the Cheakamus River (BC Hydro 2007). CMSMON1b (monitoring adult Chum Salmon) and CMSMON1a (monitoring juvenile Chum Salmon) were established to explore the effects of discharge on Chum Salmon productivity (BC Hydro 2007). These monitors are not mutually exclusive, as data from both are required to develop stock-recruitment relationships critical for determining whether annual fluctuations in adult-to-fry and egg-to-fry survival are related to adult escapement or characteristics of the WUP discharge regime (Bradford et al. 2005).

Adult monitoring has been conducted for the past 11 years (2007 – 2017) with two primary objectives: 1) estimate the annual escapement of adult Chum Salmon in the Cheakamus River, and 2) examine the relationships between WUP discharge, groundwater upwelling, and adult Chum Salmon distribution and spawning site selection (BC Hydro 2007). These objectives were designed to address management questions developed by BC Hydro (2007) and explore the effects of WUP discharges on fish populations. Three targeted questions were addressed by the monitor:

1. What is the relationship between discharge, adult Chum Salmon spawning site selection, egg incubation conditions, and juvenile productivity?
2. Do the models used to calculate effective spawning area (based on depth, velocity, and substrate) provide an accurate representation of Chum Salmon spawning site selection and the availability of spawning habitat under the WUP flow regime?
3. Are there alternative metrics that better represent Chum Salmon spawning habitat?

Although monitoring from 2007-2016 provided valuable insights towards answering the management questions described above, a 10-year synthesis of the monitor (Fell et al. 2018) concluded there are still uncertainties in the effect of the WUP flow regime on Chum Salmon productivity. In particular, the relationships between discharge and groundwater-influenced egg/juvenile incubation conditions and adult spawning site selection/distribution required additional investigation. Additionally, stock-recruitment models indicated discharge pulses between 25 and 80 m^3s^{-1} during the fall adult migration likely increase juvenile productivity; however, additional years of stock-recruitment data and experimental pulse flows are required to strengthen this hypothesis.

To address the above uncertainties, BC Hydro initiated an additional year of monitoring during the 2017-2018 adult migration and juvenile incubation/rearing periods. Monitoring included increased groundwater investigation and three distinct experimental pulse flows during the fall Chum Salmon migration, during which discharge was manipulated between 25 and 80 m^3s^{-1} over three (approx.) 1-week periods. This report discusses methods and results from 2017-2018 and how they address the CMSMON1b management questions and focusses primarily on addressing uncertainties described in the 10-year synthesis (Fell et al. 2018) and the effects of experimental discharge pulses. For detailed descriptions of the methods, analyses, results, and discussions relevant to previous years of CMSMON1a & b (2007 – 2016), refer to technical reports available from: https://www.bchydro.com/about/sustainability/conservation/water_use_planning/lower_mainland/cheakamus.html.

2.0 METHODS

2.1 Study Area

The glacially-fed Cheakamus River is a primary tributary of the Squamish River, which flows into the Pacific Ocean via Howe Sound and the Strait of Georgia (Figure 1). Annual water temperatures in the Cheakamus River range from 0.5-15 ºC, and the typical hydrograph is characterized by low discharge (15-20 m^3s^{-1}) in winter (December - March) and late summer/early fall (August - September), and two freshet periods from spring snow-melt (April - July) and fall storm events (October – November). Mainstem fish habitat in the Cheakamus River extends 17 km from its confluence with the Squamish River to a natural fish barrier 9 km downstream of Daisy Lake Dam. Mainstem habitat is complimented by a large network of man-made restoration channels fed either by groundwater or diverted river water (Figure 1).

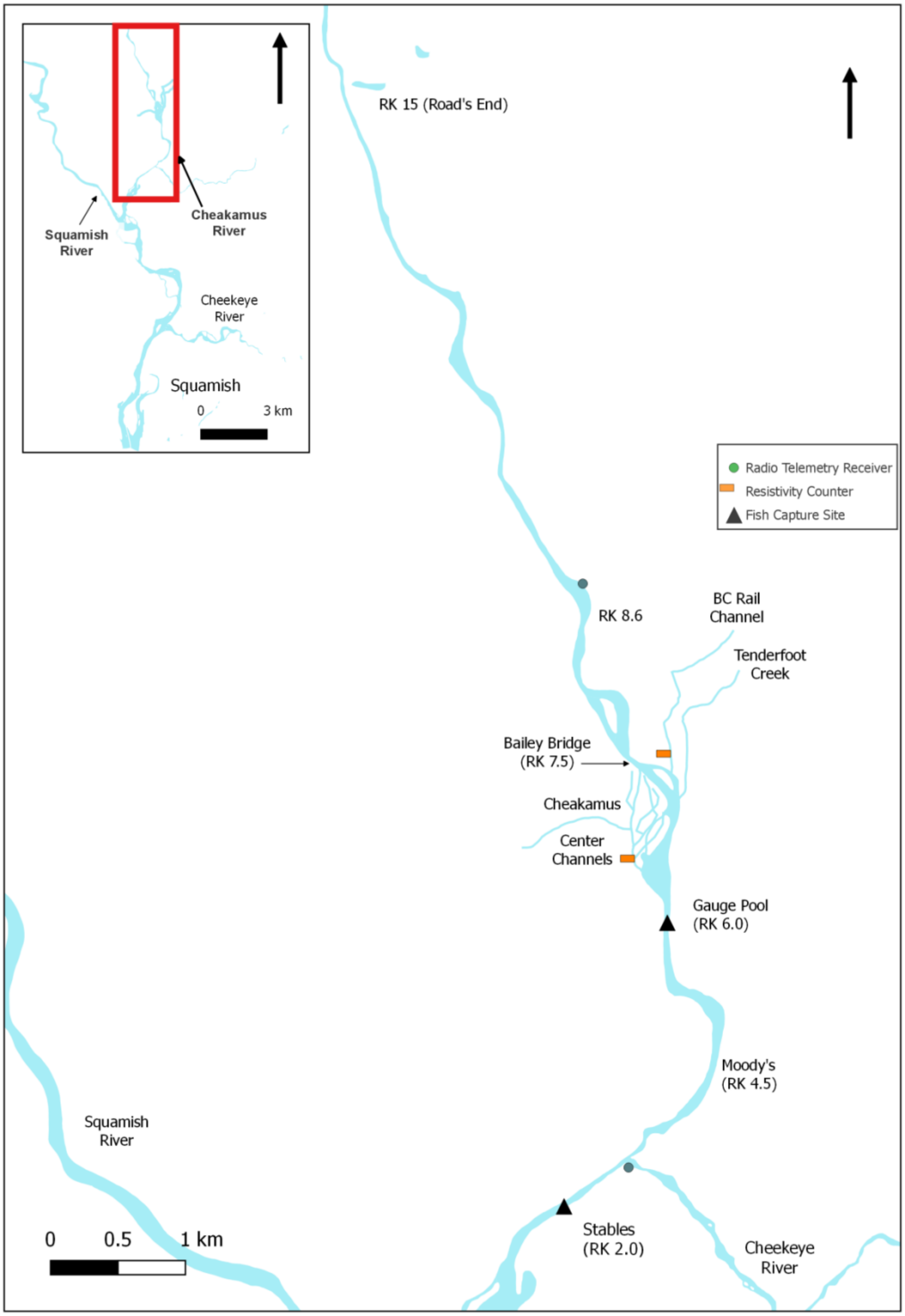

Figure 1. Cheakamus River study site showing locations of fish collection sites, radio-telemetry receivers, artificial spawning channels, and rotary screw trap. Inset shows location relative to the greater Squamish River watershed.

2.2 Cheakamus River Discharge Data

Hourly discharge data were acquired from the Water Survey of Canada (WSC) gauge at Brackendale (08GA043; located 100 m upstream of the RST site). Discharge data were summarized across four Chum Salmon life-history periods: the entire spawning season (Oct 15-Dec 15), the upstream migration (Oct 15-Nov 7), the peak spawning period (Nov 1-Nov 15), and the egg incubation period (Dec 1 – Mar 31). Discharge metrics included minimum, maximum, mean, and median discharge, as well as the standard deviation and variance in discharge, and the number of days between 25 and 80 m^3s^{-1} (see Lingard et al. 2018). These discharge metrics were considered as covariates during stock-recruitment modelling and models of adult Chum Salmon distribution and movement patterns.

2.3 Groundwater Monitoring at Spawning Sites

Management question 2 of CMSMON1b asks whether models used during the WUP consultative process accurately predicted Chum Salmon spawning habitat area and spawning site selection under the WUP flow regime. Groundwater upwelling is known to strongly influence Chum Salmon spawning site selection (Hale et al. 1985), but upwelling was not included in the original WUP modelling. Two alternative hypotheses were proposed in CMSMON1b to examine the effect of groundwater on Chum Salmon spawning site selection:

> H_2: Spawning chum salmon do not select areas of upwelling groundwater for spawning in the mainstem.
>
> H_3: Discharge during the chum salmon spawning and incubation period does not affect the upwelling of groundwater in mainstem spawning areas.

We monitored redd temperatures in the Cheakamus River from December 12, 2017 to January 31, 2018 at thirteen sites distributed between Moody's Bar (RK 4.5) and Road's End (RK 15) to identify areas of groundwater upwelling. Monitoring sites were selected based on their suitability for Chum Salmon spawning (i.e., appropriate depth, velocity, and substrate composition) and/or previous observations of confirmed Chum Salmon spawning behaviour. Temperature loggers (n = 70; Onset HOBO TidbiT v2 data loggers; UTBI-001) buried 25 cm below the substrate surface (approximate redd depth) recorded hourly temperature, and an additional temperature logger at each site recorded hourly surface water temperature. Replicate loggers were installed at each site to account for spatial variability in groundwater upwelling; however, the number of replicates was variable and ranged from 2 to 8 depending on the size of the site and the variability of site characteristics.

To test H_2 we compared locations of confirmed Chum Salmon spawning with study sites demonstrating strong groundwater upwelling using data from 2016-2017 and previous years of groundwater monitoring. Consistent with previous years of monitoring, areas of groundwater upwelling were identified using differentials between redd temperatures and surface water temperatures (see details in Fell et al. 2018). Fall and winter groundwater temperatures are generally warmer and more stable than surface water temperatures in Pacific Northwest streams (Constantz 1998), thus we considered groundwater upwelling to be present at sites where surface water temperatures were lower than redd temperatures, and/or where temperature fluctuations in the water column were not observed within the redds. We further designated the presence of groundwater as either strong (i.e., evidence was consistent amongst years and replicate temperature loggers, and/or there was a large temperature differential) or weak (i.e., evidence was inconsistent, and/or the temperature differential was minor).

We used time series' of redd temperature and Cheakamus River discharge at Brackendale (Water Survey of Canada gauge: 08GA043) to qualitatively test hypotheses H_3 and determine whether discharge pulses interact with groundwater upwelling. We did not quantitatively relate discharge and redd temperature due to the complex nature of groundwater upwelling (i.e., the difficulty in fitting predictive models), the variability in the location of groundwater upwelling, and the variability in the magnitude and direction of differentials between redd temperatures and surface water temperatures.

2.4 Adult Escapement Estimation

We estimated adult Chum Salmon escapement in 2016-2017 (and in all previous monitoring years) using a Pooled-Petersen mark-recapture model (Ricker 1975; Fell et al. 2018). This method combines a passive mark-recapture model with PIT tag detections and adult counts from resistivity counters in the Cheakamus Centre and Tenderfoot Creek side channels. Additional details on model specification and refinement as well as the capture and recapture methods described below can be found in previous CMSMON1b annual reports (e.g. Fell et al. 2016).

2.4.1 Capture and Tagging

Two locations were used for adult Chum Salmon capture and tagging based on ease of river access, suitability for fish capture, and proximity to resistivity counters (Figure 1). The lower river tagging site (Stables), located at RK 2.0, was fished at discharges between 15 and 30 m^3s^{-1}, while the upper river tagging site (Gauge Pool) at RK 6.0 was fished at discharges between 15 and 45 m^3s^{-1}. The maximum fishable discharge for both sites was 45 m^3s^{-1}. Daily site selection was based on real-time discharge and capture effectiveness, and both sites were often fished on the same day to maximize capture rates.

All Chum Salmon tagged during this study were captured using a tangle net deployed using an inflatable pontoon boat and secured by an on-shore crew (see details in Fell et al. 2016). All fish were tagged with a 20 mm half-duplex PIT tag (BioMark, Boise, USA) in the dorsal musculature, and fitted with an external Petersen Disk Tag for visual identification. Sex, fork length, and condition were recorded for all individuals. A subset of captured fish (n = 74), in addition to being PIT tagged, were gastric-tagged with a radio transmitter (MCFT-3A, Lotek Wireless Inc., Newmarket, Canada; or TX-PSC-I-1200-M, Sigma Eight Inc., Newmarket, Canada) programmed with a unique identification code and 5 second burst rate. Data from these radio-tagged fish were used to assess adult movement and distribution patterns.

2.4.2 Detection and Enumeration

Adult Chum Salmon recapture data were collected at three locations in the Cheakamus from October 15, 2017 to December 15, 2017: at the entrances of the Cheakamus Centre and BC Rail side-channels, and proximate to the Tenderfoot Creek Hatchery (Figure 1). All adults were directed over or through PIT antennas located at the three recapture sites to determine which tagged individuals migrated into which site. Adult migrants were enumerated at each site by a pass-over Logie 2100C resistivity fish counter (Aquantic Ltd.) at the Cheakamus Centre and BC Rail side channels, and by DFO observers at the Tenderfoot Creek hatchery entrance fence. It is important to note that the passive counting methods (i.e. resistivity counters and PIT antennas) employed in this study do not function at discharges >80 m^3s^{-1}.

2.4.3 Adult Mark-recapture Modelling

Pooled-Petersen mark-recapture estimates were used to calculate adult escapement for the entire river and the area upstream of the RSTs (including side channels). The estimate for the whole river was derived from individuals marked at the Stables and Gauge Pool tagging sites and recaptured at the three upstream PIT locations. The population estimate for the upper river (above the RST site, RK 5.5) was derived from fish tagged at the Gauge Pool tagging site and recaptured at the three upstream locations. Escapement was estimated using the equation:

$$\widehat{N} = \frac{MC}{m}$$

Where $\widehat{N}$ is the estimated escapement in each area (entire river or upstream of RST), M is the total number of fish marked with PIT tags, C is the total number of fish entering the side-channels (i.e., enumerated by the resistivity counter), and m is the number of PIT tagged fish entering the side channels (i.e., recaptures; Ricker 1975).

Pooling in the Petersen method refers to combining all mark-recapture trials into a single estimate of ‘trap efficiency’ (or recaptures, m) and generating a single escapement estimate for the entire study period ($\widehat{N}$).

2.5 Juvenile Abundance Estimation

A Bayesian Time-Stratified Spline Model (BTSPAS) was used to estimate annual juvenile Chum Salmon abundance in the Cheakamus River as a part of CMSMON1a (see Lingard et al. 2017 for more details). The BTSPAS model is a modified Petersen mark-recapture model that estimates weekly abundance using splines to model the general shape of the migration. The Bayesian hierarchical method shares information on catchability among strata when data are sparse; see Bonner and Schwarz (2011) for a detailed explanation of the model and its development. Abundance estimates were generated for weekly strata for both the mainstem Cheakamus River and the side channels. Juvenile Chum Salmon in the mainstem Cheakamus River were enumerated by two six-foot rotary screw traps (RSTs) operated adjacent to the Cheakamus Center property at RK 5.5 from February 18 – April 28, 2018 (Figure 1). Fyke nets were used during the same period to enumerate juveniles in side-channels at the Cheakamus Center complex, BC Rail channel, and at the Tenderfoot Creek Hatchery adult fence (Figure 1). Weekly strata for Chum Salmon ran from Tuesday to Monday. Fish captured between Monday and Thursday were marked with a biological stain and released upstream of the RSTs or Fyke nets. Fish were not marked between Friday and Sunday to allow the mark group to move past the trap before the next strata began. Estimates generated from the RSTs represented the combined mainstem and side-channel estimate. Estimates from side-channel traps were subtracted from the RST estimate to determine comparative production from side-channel and mainstem habitat. Hatchery production totals were not included in the population estimates generated from this study.

2.6 Egg-to-fry Survival

Egg-to-fry survival accounts for inter-annual variation in egg deposition per female resulting from changes in fecundity and spawning success and is an important indicator of incubation and emergence conditions and overall juvenile productivity. Egg-to-fry survival (*H'*) was estimated for the mainstem Cheakamus River upstream of the RST site, and for all monitored side-channels (i.e. Cheakamus Centre, BC Rail, Tenderfoot Creek); see Fell et al. 2018 for a detailed explanation of the calculations used to produce this estimate. Egg-to-fry survival (*H'*) was estimated using the following equation:

$$H' = \left(\frac{N_t \times N_{tf} \times N_{epf} \times N_{ed}}{N_{tfry}}\right)$$

Where N_t is the adult abundance estimated by the upper river Pooled-Petersen estimate for year *t*. N_{tf} is the proportion females in the population based on the sex ratio of all individuals tagged in year *t*. N_{efp} is female fecundity as evaluated by Tenderfoot Creek Hatchery in year *t* or inferred using the fork length-fecundity relationship developed for 2012-2016 ($p<0.001$, $R^2=0.34$; Fell et al. 2016). N_{ed} is the estimated proportion of eggs successfully deposited per female in year *t*, assessed by annual pre-spawn mortality surveys in the mainstem and site-channel habitats. And lastly, N_{tfry} is the BTSPAS estimate of juvenile abundance in year *t*.

2.7 Juvenile Productivity and Stock Recruitment

Stock-Recruitment (SR) analyses examine the relationship between adult escapement and subsequently density-dependent juvenile productivity, and how this relationship can vary given the influence of additional independent factors. In this report, we continued to build on the SR relationship developed in CMSMON1b (years 1 through 10) to examine the effect of the WUP discharge regime and experimental pulse flows on productivity (i.e. egg-to-fry and adult-to-fry survival; Fell et al. 2018). We re-examined the suite of annual discharge metrics described in Fell et al. 2018 that summarised flow conditions occurring over four distinct time periods associated with adult spawning and egg incubation for all habitat types combined (mainstem and side channels). These metrics were used as covariates in a Ricker SR analysis (based on *a-priori* hypotheses about discharge and juvenile salmon life history) to explore the effects of discharge on juvenile productivity (summarized in Table 7 of Fell et al. 2018). All covariates used in SR modelling were standardized (i.e., re-scaled to have a mean of one and standard deviation of zero) to compare the relative effect of each covariate on the SR relationship (Gelman 2008). A detailed description and equations for the modified-Ricker model used in these analyses is described in Fell et al. 2018.

We fit SR relationships with single discharge covariates as well as interactions between covariates and compared to a base Ricker model (no discharge covariate) using Deviance Information Criteria (DIC). DIC quantifies the trade-off between fit and complexity for Bayesian models (Gelman 2003), and models with lower DIC values are considered to provide a better fit to the data. The importance of each covariate was also evaluated by determining the probability that the covariate coefficient (γ) was greater than zero. Because the covariates were standardized, differences in the magnitude of coefficient estimates among covariates reflect their utility for explaining variation in recruitment. All modeling was performed in JAGS and R (R Core Team 2017) using package ‘jagsUI’.

2.8 Adult Chum Salmon Distribution

Discharge pulses have been hypothesized to affect adult Chum Salmon distribution by increasing side-channel usage by adult Chum Salmon, which may lead to improved egg-to-fry survival (Fell et al. 2018). To examine this relationship, we modelled daily entries of fish into side channels as a function of daily average discharge and day of year using a negative binomial generalized linear model that accounted for over-dispersion in count data. We created two independent estimates of daily entries into side-channels (i.e., PIT entries and counter entries). For the ‘counter’ model, we combined the daily number of ‘UP’ counts from resistivity counters at the Cheakamus Centre and BC Rail side-channels with daily counts from the Tenderfoot Creek hatchery fence (TF). For the ‘PIT’ model, we combined the daily number of unique PIT tag detections on entry antennas at the Cheakamus Centre, BC Rail, and TF channels. Both models only included count and discharge data that occurred when flows were <80 m^3s^{-1}, as both PIT and resistivity counting operations cease to function above this threshold. Model fits were assessed by over-dispersion and Chi-square tests.

We also examined how discharge affects adult Chum Salmon distribution and spawning site selection in the mainstem using radio telemetry data collected from 74 adult Chum Salmon (40 males, 34 females) in the fall of 2017. Data from fixed radio-receiver stations at Cheekeye (RK 3.2) and Campground Corner (RK 8.6) were combined with weekly mobile tracking data (from RK 15.0 – 3.0; October 15 to December 15, 2017) to determine individual migration histories and maximum river kilometer achieved. We used a linear model to examine the maximum RK achieved by radio-tagged fish in 2017 as a function of individual sex, tagging date to account for migration timing, the maximum discharge an individual encountered while migrating in the Cheakamus River, and the number of days during this migration characterized by 'pulsed-flows' (i.e. discharge >25<80 m^3s^{-1}). All covariates were standardized to allow for the direct comparison of the relative effect of each explanator variable (Gelman 2008), and model residuals were examined for linearity and homogeneity.

3.0 RESULTS

3.1 Cheakamus River Discharge

Mainstem Cheakamus River average daily discharge during the fall adult Chum Salmon migration (October 15 – December 15) ranged from 15.8 – 280.83 m^3s^{-1} (48.1 ± 7.1[1]), with 3 distinct pulse flow periods and 39% (24 of 62) of days falling within 25 – 80 m^3s^{-1} (Figure 2A). Discharge during the egg incubation and juvenile rearing period ranged from 15.9 – 82.2 (22.1 ± 1.0) (Figure 2B).

[1] Data throughout the results are presented as mean ± standard error.

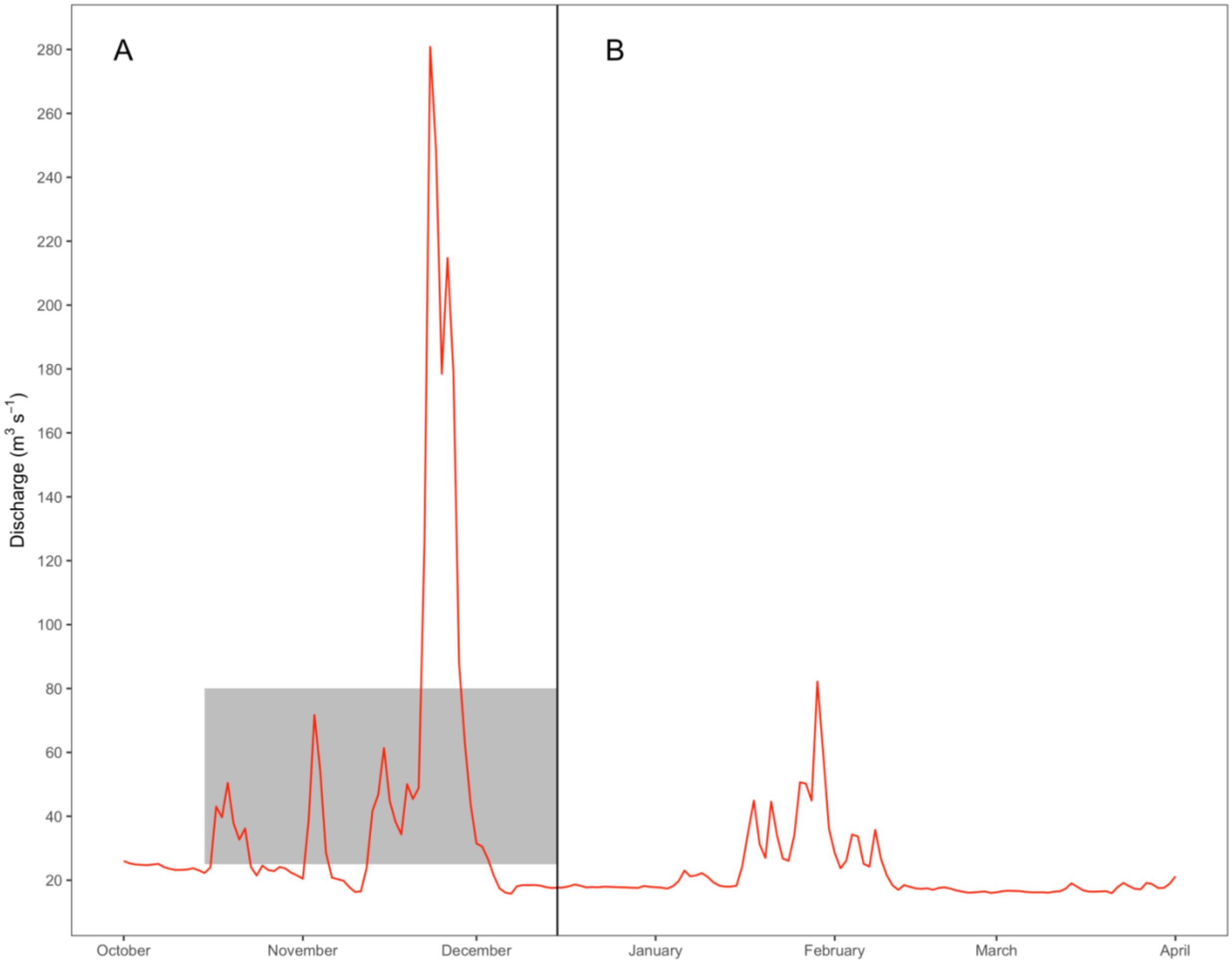

Figure 2. Mean daily discharge of the Cheakamus River during the adult spawning migration period from October 1 – December 15, 2016 (Panel A), and the egg incubation / juvenile rearing period from December 15, 2016 – April 1, 2017 (Panel B) at the WSC Brackendale gauge (08GA043). Grey shaded box highlights period during the adult migration when discharge was between 25 – 80 m^3s^{-1}.

3.2 Groundwater Analysis

A total of 52 sub-surface temperature loggers were recovered from the Cheakamus River on January 31, 2018. The remaining 18 loggers (i.e., of the 70 deployed in December of 2017) were not recovered or were displaced during the monitoring period (Figure 3).

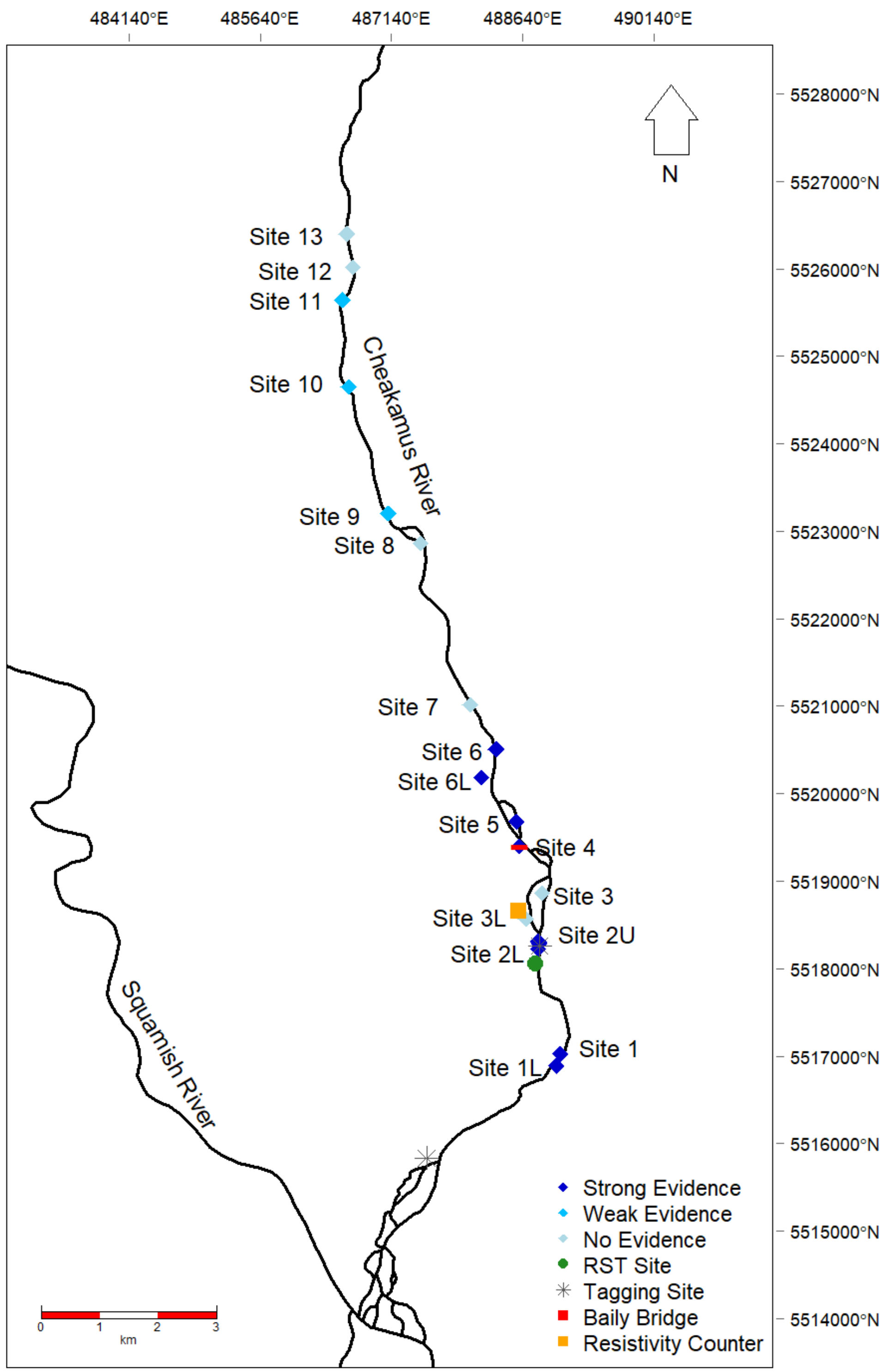

Figure 3. Map of the Cheakamus River study area showing points of interest and groundwater monitoring sites showing strong, weak, or no evidence of groundwater upwelling.

We examined the temperature differential between redd temperature and surface temperature to identify sites with strong, weak, or zero evidence of groundwater upwelling. For example, Site 1 Lower demonstrated strong evidence of groundwater upwelling (Figure 4), while Site 11 demonstrated weak groundwater evidence (Figure 5), and Site 6 Upper showed no evidence of upwelling (Figure 6).

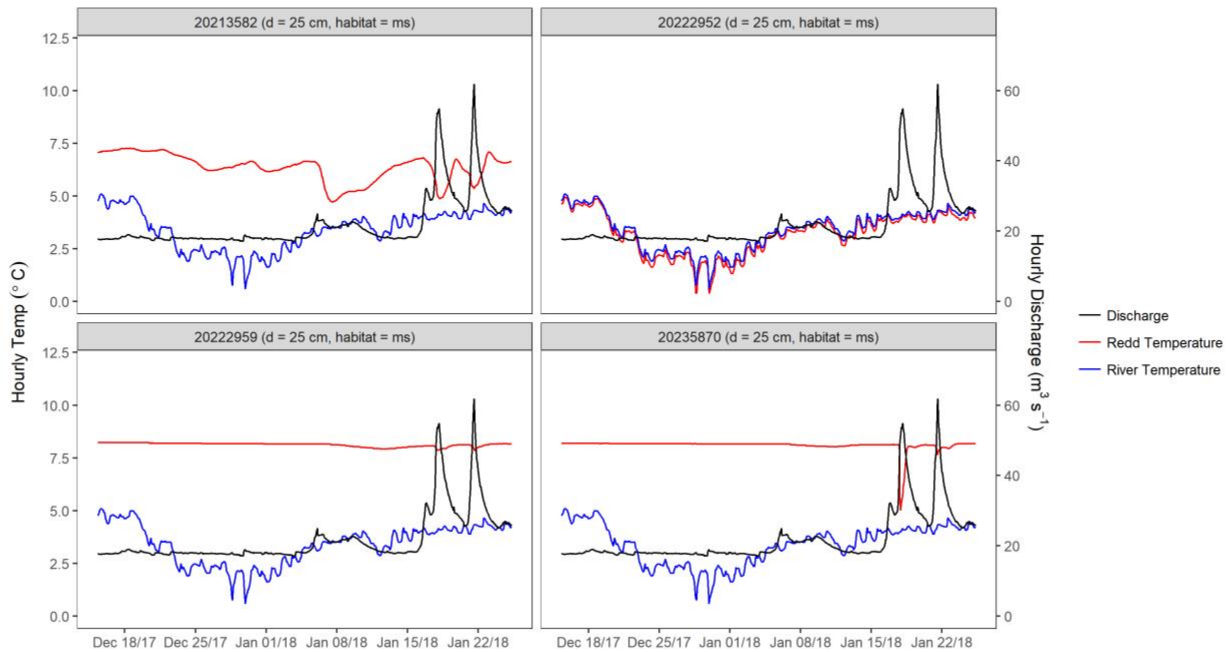

Figure 4. Redd temperature (red line), river temperature (blue line), and discharge (black line) at Site 1 Lower in the Cheakamus River.

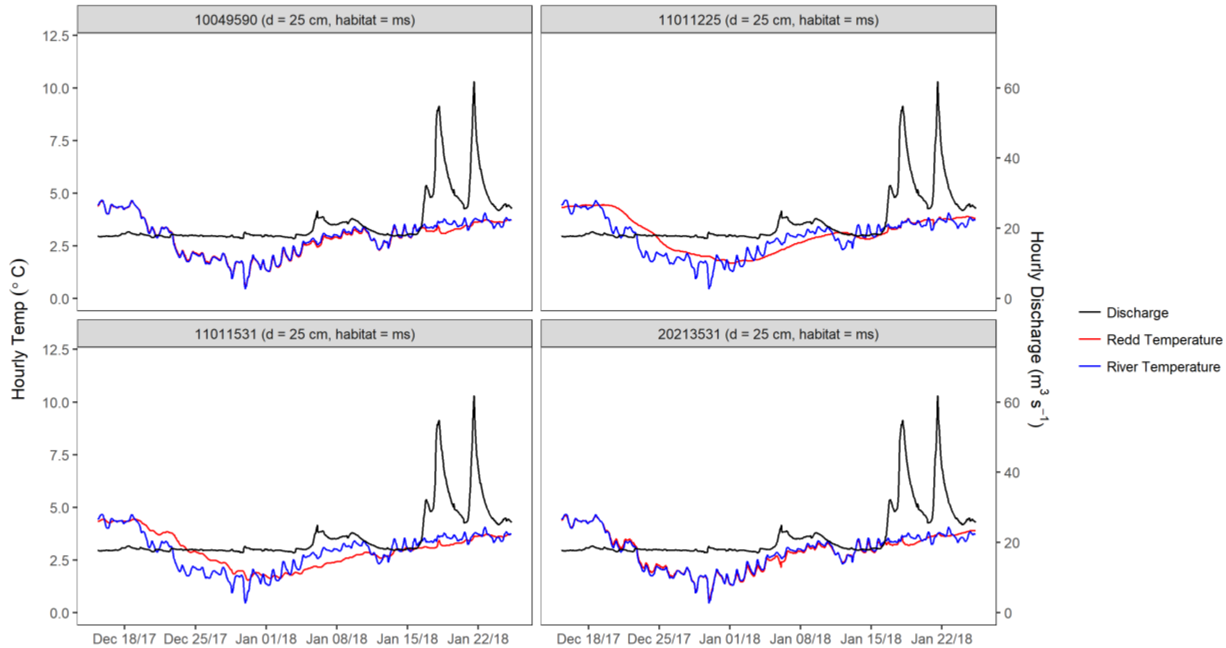

Figure 5. Redd temperature (red line), river temperature (blue line), and discharge (black line) at Site 11 Lower in the Cheakamus River.

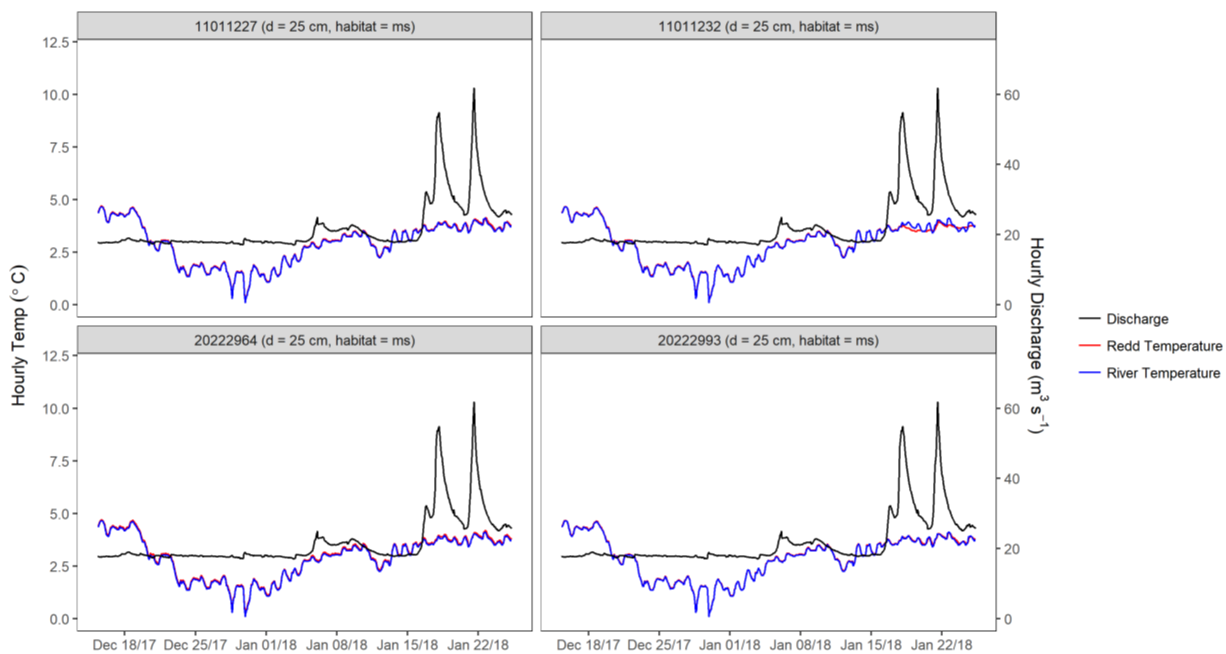

Figure 6. Redd temperature (red line), river temperature (blue line), and discharge (black line) at Site 6 Lower in the Cheakamus River.

We also compiled redd temperature data from previous years of CMSMON1b (Fell et al. 2018) to build on evidence observed during the current monitoring year. The degree of evidence for groundwater upwelling is summarized in Table 1 and the location of groundwater upwelling areas is shown in Figure 3.

Table 1. Evidence of groundwater upwelling and numbers of temperature loggers deployed and recovered throughout the Cheakamus River over the duration of CMSMON1b.

Location	Loggers Deployed	Loggers Recovered	Upwelling Evidence
December 12, 2017 to January 31, 2018			
Site 1 Lower	4	4	3 of 4 showed strong evidence
Site 1 Upper	3	1	Showed strong evidence
Site 2 Lower	3	1	No evidence
Site 2 Upper	3	2	No evidence
Site 3 Lower	3	3	No evidence
Site 3 Upper	5	2	No evidence
Site 4	2	0	No loggers recovered
Site 5	4	4	1 showed very weak evidence
Site 6 Lower	3	2	Strong evidence
Site 6 Upper	4	4	No evidence
Site 7	8	7	No evidence
Site 8	5	3	No evidence
Site 9	6	4	1 showed very weak evidence
Site 10	4	3	No evidence
Site 11	4	4	2 of 4 showed weak evidence
Site 12	6	5	No evidence
Site 13	3	3	No evidence
December 12, 2009 to March 3, 2010			
Site 1 Lower	8	8	Strong evidence
December 3, 2010 to March 18, 2011			
Site 1 Lower	6	5	4 of 5 showed strong evidence
Site 2 Upper	3	3	2 of 3 showed weak evidence
December 6, 2011 to April 5, 2012			
Site 1 Lower	30	28	Strong evidence
Site 2 Upper	15	11	Strong evidence
Site 2 Lower	15	9	2 of 9 showed weak evidence
Site 3 Lower	10	9	No evidence
December 4, 2014 to February 2, 2015			
Site 5	3	0	No loggers recovered
Site 6 Lower	3	0	No loggers recovered
Site 6	4	0	No loggers recovered
Site 12	7	0	No loggers recovered
January 5, 2016 to May 1, 2016			
Site 5	5	3	No evidence
Site 6	5	0	No loggers recovered
Site 12	10	2	No evidence
December 14, 2016 to February 15, 2017			
Site 5	2	0	No loggers recovered
Site 6 Lower	4	2	Strong evidence
Site 6	4	4	Strong evidence
Site 12	10	5	No evidence

We observed strong heterogeneity in redd temperature profiles within monitoring sites. At Site 1 Lower (Figure 3), three of the four temperature loggers showed a strong presence of groundwater upwelling (i.e., there was a large temperature differential between redd and surface water temperatures), while the fourth temperature logger showed no groundwater upwelling (i.e., redd temperature and surface water temperature were the same). We also found conflicts in the degree of groundwater evidence at Sites 2 Lower, 2 Upper, and 5 during different monitoring years. For example, during the current monitoring year, we did not observe evidence of groundwater upwelling at Site 2 Upper, but there was clear evidence of groundwater upwelling at this site during the 2010 and 2011 monitoring years (Table 1).

We overlaid strong groundwater upwelling sites with confirmed locations of Chum Salmon spawning to determine whether spawning chum salmon select areas of groundwater upwelling for spawning in the Cheakamus mainstem (H_2). Chum Salmon consistently spawn in high abundances at all sites downstream of the Bailey Bridge, which are characterized by both strong groundwater upwelling (Sites 1 Lower, 1, 2 Lower and 2 Upper) and sites with no evidence of groundwater upwelling (Sites 3 Lower and 3). Spawning is sometimes observed just upstream of the bridge (Sites 4 – 6 with strong groundwater upwelling), but at much lower densities relative to downstream sites.

Two large discharge pulses occurred in the Cheakamus River in late January 2018 that affected groundwater upwelling as described by redd temperature. Where redd temperature was higher and more stable than surface water temperature (Site 1 Lower; Figure 3), large discharge pulses resulted in a short-term decline in redd temperature. Redd temperature returned to pre-pulse values immediately following the end of the discharge pulse. At sites with weak groundwater evidence, the effect of discharge pulses was less pronounced or almost non-existent (Site 11; Figure 3), and in some cases, discharge pulses caused an increase in redd temperature rather than a decline (Site 6 Lower; Figure 3). The direction and magnitude of the effect of discharge on groundwater temperature varied considerably among sites and within the same site, highlighting the site-specific nature of groundwater upwelling in the Cheakamus River.

3.3 Adult Chum Salmon Escapement

The Pooled-Petersen Adult Chum Salmon abundance estimate for the Cheakamus River in 2017 was 50,588 (range: 44,839 – 56, 338) for the whole river and 38,512 (range: 33,852 – 43,173) for the upper river (i.e., upstream of the rotary screw trap site at RK 5.5, Figure 1). These estimates have ranged from 50,588 to 602,619 for the whole river and 12,827 – 241,048 for the upper river over the past 11 years of monitoring. Notably, the whole river estimate for 2017 is the lowest on record since the monitor began in 2007 (Figure 7).

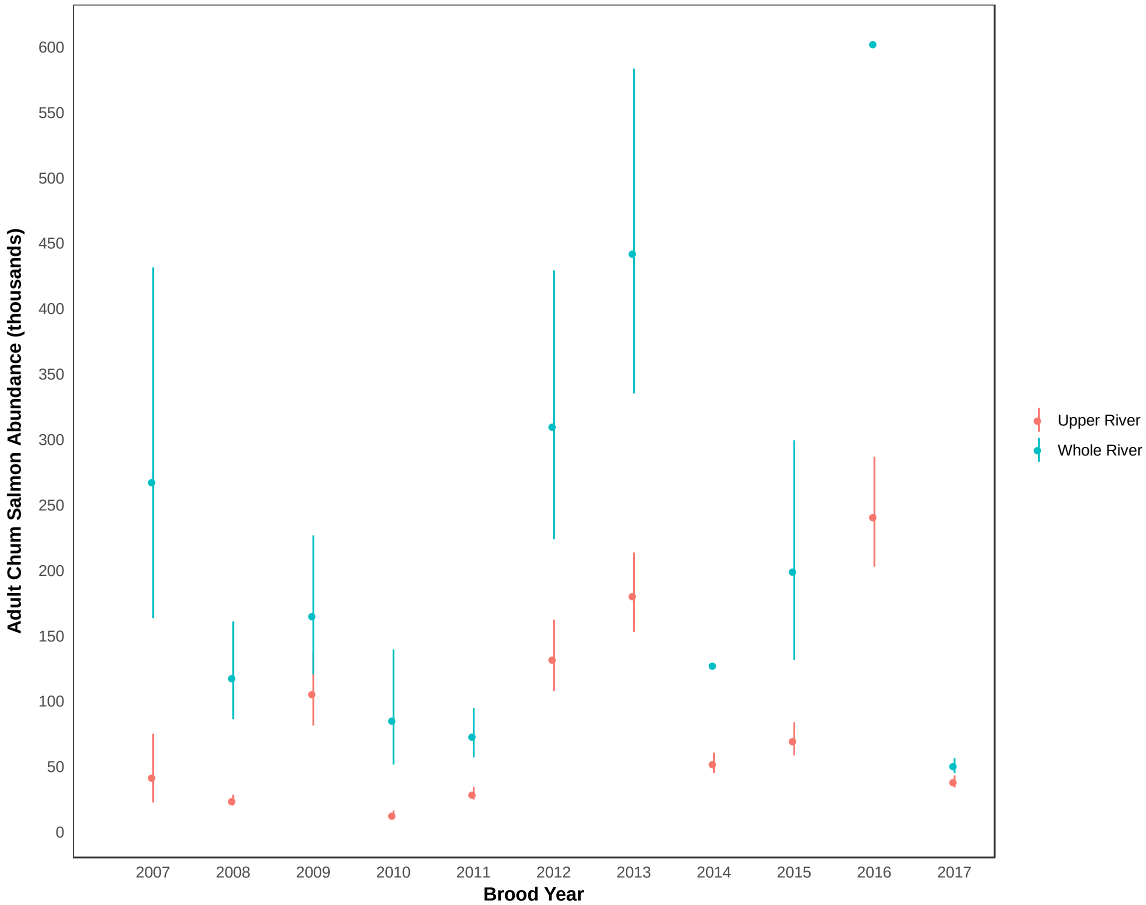

Figure 7. Annual Pooled-Petersen abundance estimates of adult Chum salmon from 2007 – 2017 for the upper (red dots) and whole (blue dots) Cheakamus River. Error bars indicate upper and lower 95% confidence intervals.

Resistivity counter data indicated that the proportion of adults utilizing mainstem habitat was 79%, with the remaining 21% estimated to be distributed amongst side-channel habitats; this is consistent with previous year's estimates of proportional distribution (Table 2.)

Table 2. Estimated proportional distribution of adult Chum Salmon among mainstem and side-channel habitat types in the Cheakamus River from 2007 – 2017.

Year	Mainstem	Side Channels
2007	0.9	0.1
2008	0.67	0.33
2009	0.85	0.15
2010	0.79	0.21
2011	0.85	0.15
2012	0.89	0.11
2013	0.87	0.13
2014	0.83	0.17
2015	0.85	0.15
2016	0.88	0.12
2017	0.79	0.21

3.4 Discharge-related Chum Salmon Distribution

Observations of combined daily entries into the Cheakamus Centre, BC Rail, and TF side-channels from both resistivity-counter and PIT datasets revealed a bi-modal distribution of entry timing, with peaks occurring in late October and again in mid-November (Figures 8 & 9). Negative-binomial generalized linear models were used to assess the relationship between daily entries (counter and PIT) into side-channels and mean daily discharge. Output from the counter model suggested a weak effect of discharge on up counts (p-value 0.07; Table 3; Figure 10), while the PIT model suggested a strong effect ($p = 0.003$; Table 4; Figure 11). Together, these models revealed that, when controlling for migration timing, daily side-channels entries increased with increases in discharge.

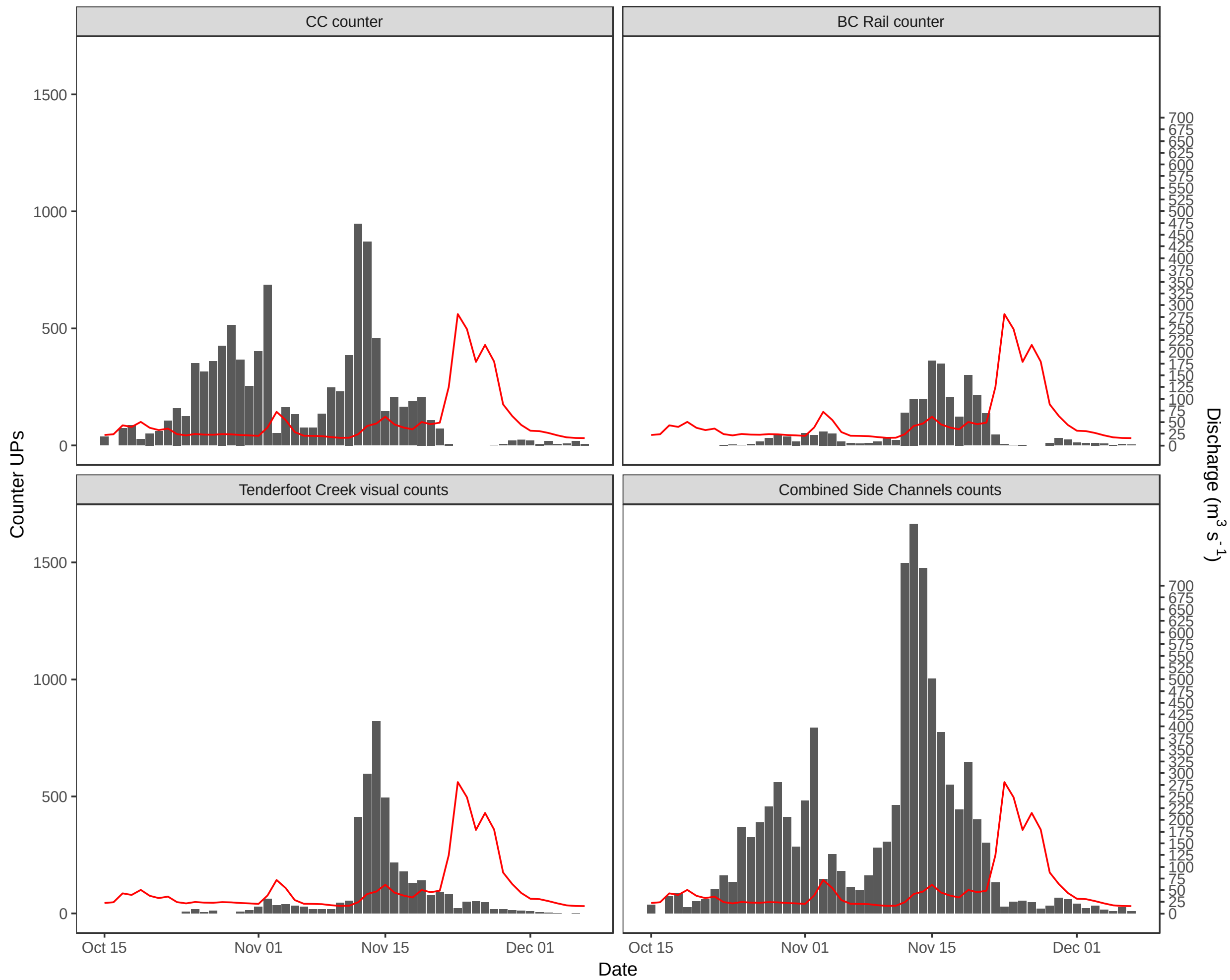

Figure 8. Daily UP (entry) counts from resistivity counters and visual counts at Cheakamus Centre, BC Rail, and Tenderfoot Creek side-channels (black bars) relative to the Cheakamus River daily average discharge (red line) from October 15 – December 15, 2017.

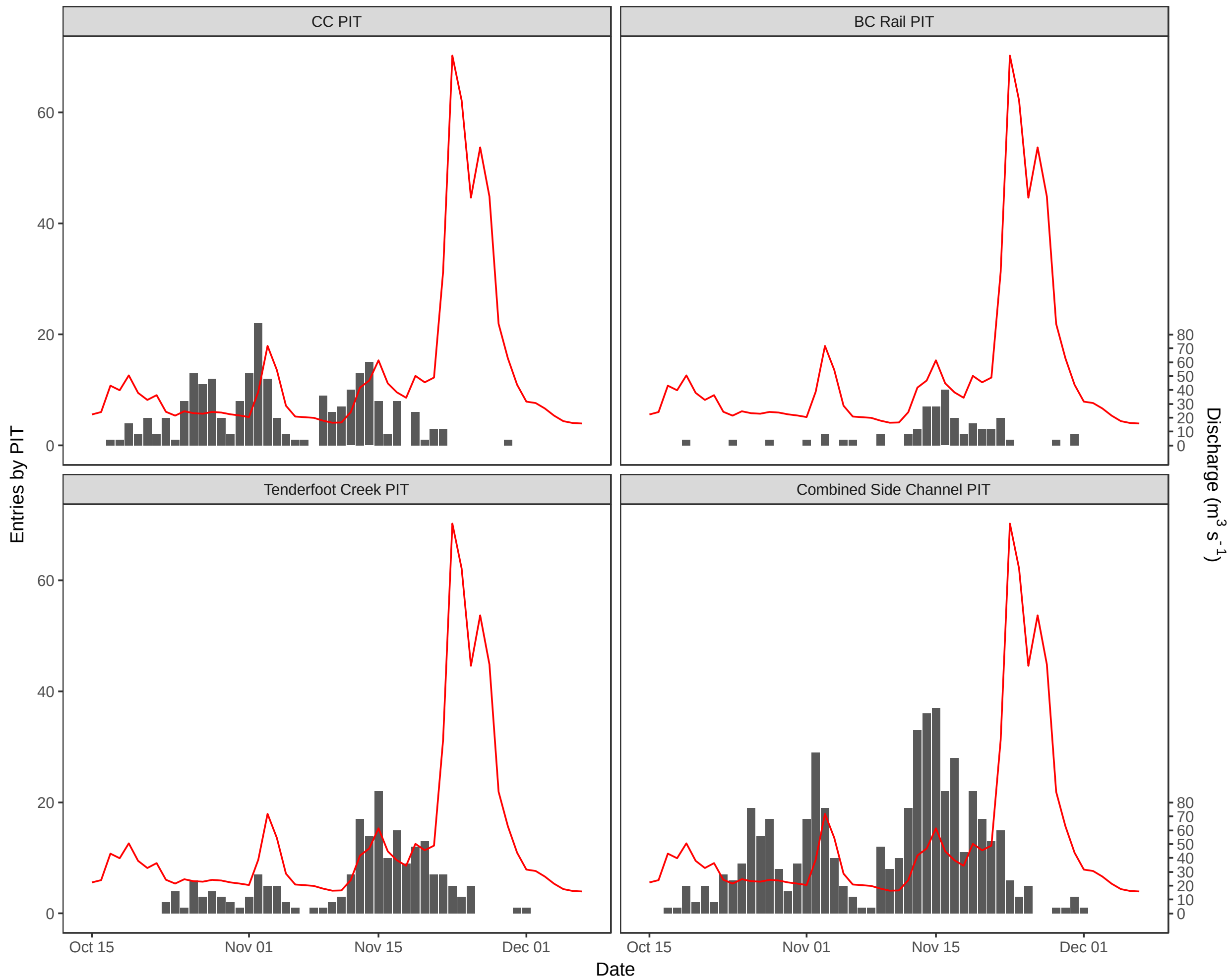

Figure 9. Daily unique PIT tag entry detections from the Cheakamus Centre, BC Rail, and Tenderfoot Creek side-channels (black bars) relative to the Cheakamus River daily average discharge (red line) from October 15 – December 15, 2017.

Table 3. Model statistics from negative-binomial GLM of the relationship between daily average discharge and the daily number of entries (resistivity counter 'UP' counts) into all monitored side channels in the Cheakamus River between October 15 – December 15, 2017.

	Coefficient estimate	SE	*p*	Lower 95% CI	Upper 95% CI
Intercept	5.79	0.17	$2.00\ e^{-16}$	5.48	6.13
Tagging date	-0.10	0.17	0.56	-0.73	0.53
Mean daily discharge	0.30	0.17	0.07	-0.09	0.72

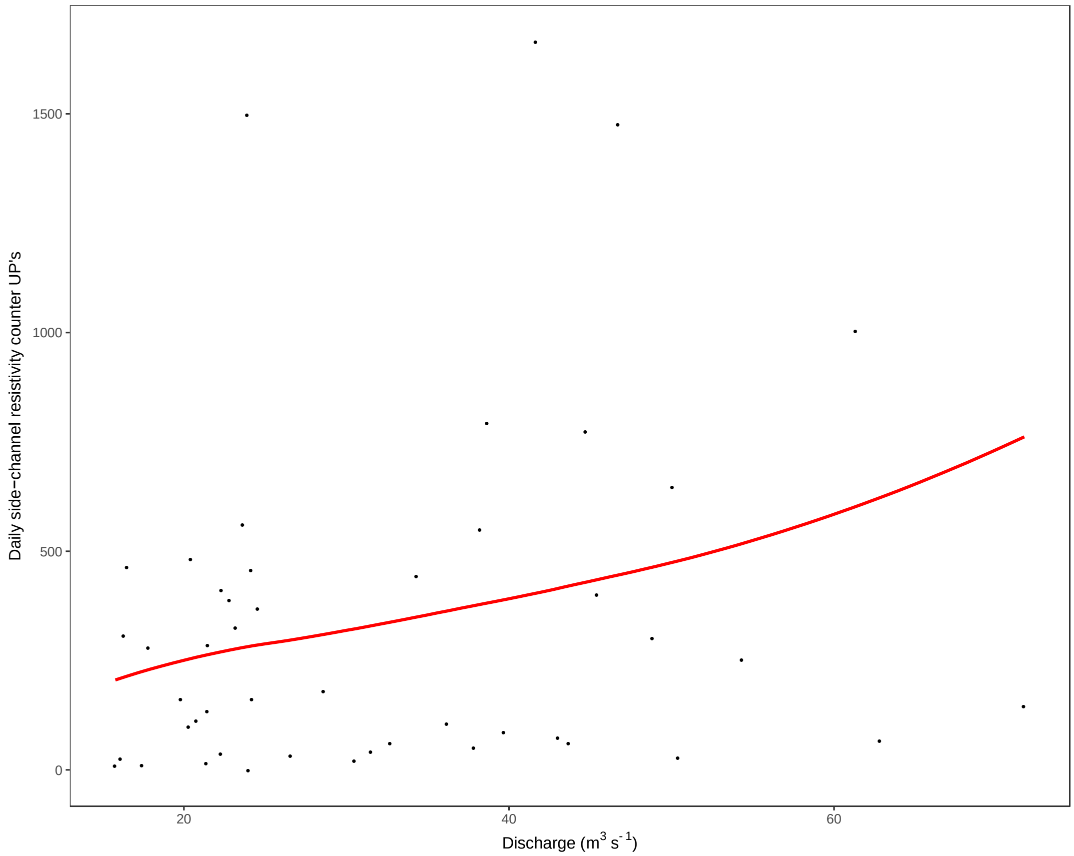

Figure 10. Predicted relationship (red line) between daily average discharge (m^3s^{-1}) and the daily number of entries (resistivity counter 'UP' counts) into all monitored side channels in the Cheakamus River between October 15 – December 15, 2017.

Table 4. Model statistics from negative-binomial GLM of the relationship between the daily number of entries of PIT tagged Chum Salmon into all monitored side channels in the Cheakamus River between October 15 – December 15, 2017.

	Coefficient estimate	SE	*p*	Lower 95% CI	Upper 95% CI
Intercept	2.19	0.17	$2.00e^{-16}$	1.87	2.54
Tagging date	-0.31	0.17	0.07	-0.87	0.25
Mean daily discharge	0.51	0.17	0.003	0.13	0.91

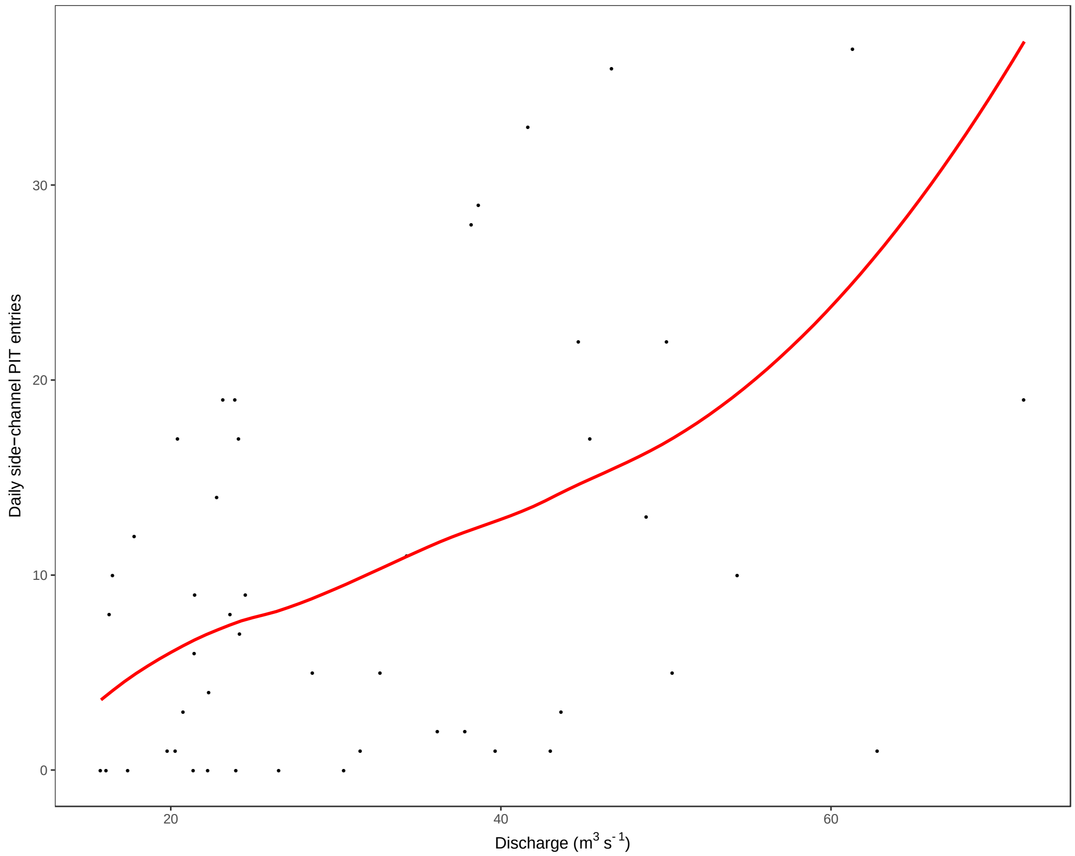

Figure 11. Predicted relationship (red line) between daily average discharge (m^3s^{-1}) and the daily number of entries from PIT tagged Chum Salmon into all monitored side channels in the Cheakamus River between October 15 – December 15, 2017.

Radio-tagged fish achieved maximum river kilometer migration distances that ranged from 2.2 – 7.3 RK's, with a mean maximum distance achieved of RK 4.5 (Moody's Bar). None of the 74 tagged individuals were detected above the Bailey Bridge (RK 7.5) in 2017. In the linear model examining the relationship between maximum river kilometer as a function of individual sex, migration timing, and maximum and variable discharge, there was a positive association between maximum river kilometer and the number of days fish encountered discharge >25<80 m^3s^{-1} during their migration (p = 0.02). However, this model only explained 7% of the variation in maximum RK data, suggesting additional factors likely affect distribution behaviour (Table 5).

Table 5. Model statistics from linear model of the relationship between the daily number of entries of PIT tagged Chum Salmon into all monitored side channels in the Cheakamus River between October 15 – December 15, 2017.

	Coefficient estimate	SE	*p*	Lower 95% CI	Upper 95% CI
Intercept	4.61	0.23	$2.00e^{-16}$	4.16	5.06
Sex (m)	-0.24	0.31	0.43	-0.86	0.37
Tag Date	0.26	0.16	0.10	-0.05	0.57
Max Q.	0.07	0.16	0.68	-0.25	0.38
Q. Days >25<80	0.40	0.16	0.02	0.08	0.72
F	2.41	p-value	0.06		
Adj. R^2	0.07				

3.5 Juvenile Abundance

Chum salmon fry abundance was estimated to be 4,471,361 (± 546,559) in 2018, which falls within the 95% confidence interval of the average 11-year abundance estimates (4,687,076 ± 862,313.7 SE) (Figure 12). Estimates of juvenile Chum Salmon abundance have been highly variable over the 11 years of monitoring, ranging from 10,795,444 (± 2,313,237.2) in 2013 to 1,610,535 (± 352,075.7) in 2015 (Figure 12). Statistical confidence is these estimates is particularly high given the intensive juvenile marking effort associated with this monitor (see Lingard et al. 2017).

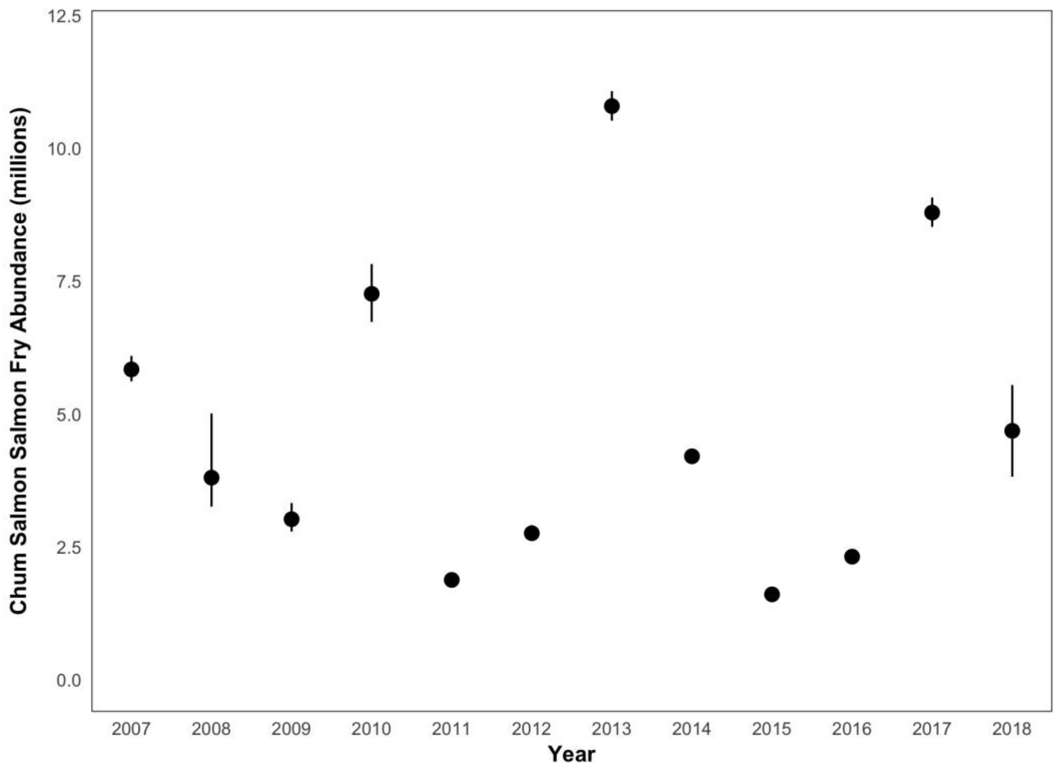

Figure 12. Annual BTSPAS abundance estimates of Chum salmon fry in the Cheakamus River from 2007 – 2018. Error bars indicate upper and lower 95% confidence intervals.

3.6 Egg-to-fry Survival

Estimates of Cheakamus River egg-to-fry survival in 2017 for side-channel, mainstem habitat, and both habitats combined were 15%, 4.6%, and 6.2%, respectively (Figure 13). The estimate of combined survival rates fell within the range of the previous 10-year estimate (1.6 - 12%); mean egg-to-fry survival across the 11 years of monitoring was 5.5% (± 3.7% SD) (Figure 13).

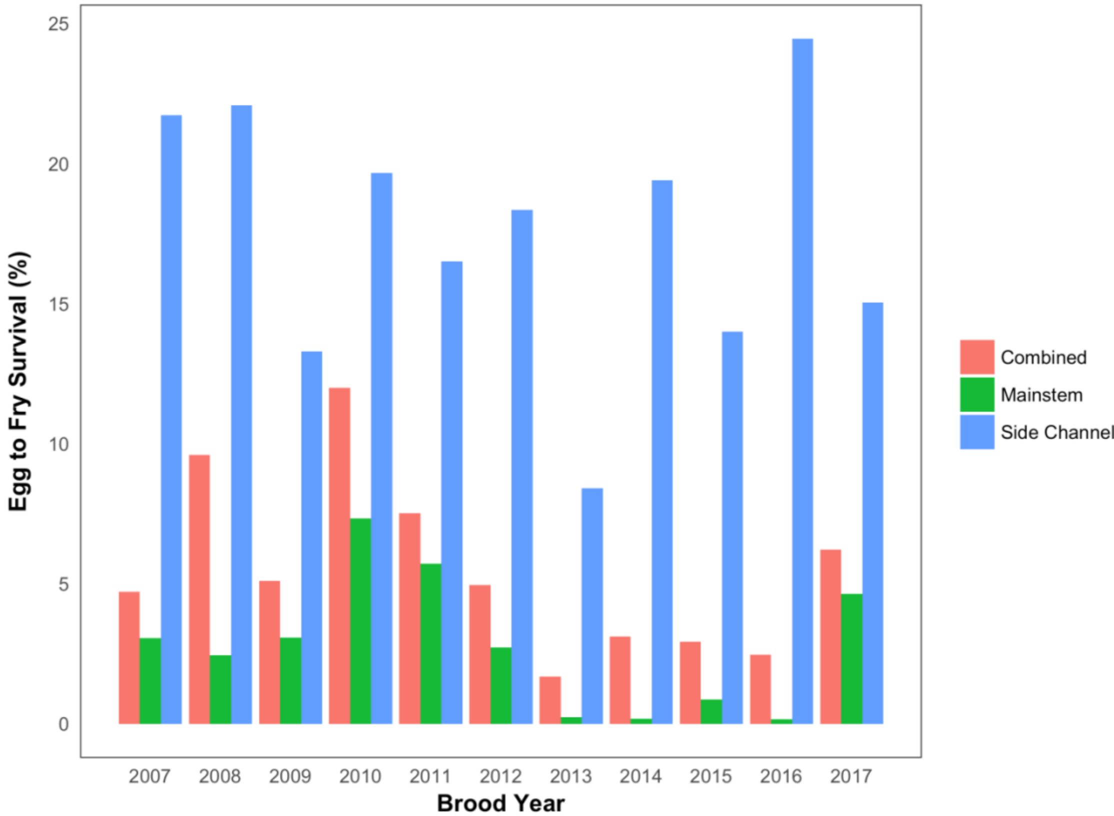

Figure 13. Estimated Chum salmon egg-to-fry survival in mainstem, side-channel, and all habitat types combined in the Cheakamus River from 2007 – 2017.

3.7 Juvenile Stock-recruitment

In total, 25 summary discharge covariates were modeled for four habitat types (mainstem, Cheakamus Centre side channel, BC Rail side channel, and all habitat types combined) for both adult-to-fry and egg-to-fry datasets, resulting in (25 × 4 × 2) 200 different model outcomes. The most supported egg-to-fry and adult-to-fry SR analyses are from models of *all habitat types combined*. Thus, below we present only the 5 top-ranked models from each of these analyses; see Appendix 1 for tables of all model results for each habitat type.

3.7.1 Egg-to-fry Recruitment

Consistent with egg-to-fry SR results from the 10-year synthesis (Fell et al. 2018), effects of discharge during the egg incubation period were again included in all the top-ranked models for Chum salmon egg-to-fry recruitment across all habitat types combined (11.5 km of mainstem and additional side-channel habitat; Table 13; Appendix 1). The two top-ranked models included covariate effects for discharge days >25 and < 80 m^3s^{-1} during the adult migration and maximum discharge during the egg incubation period (Table 6). These models explained 71% and 75% of the variation in egg-to-fry recruitment variance, respectfully, and had ΔDIC values that indicated similar levels of empirical support for each model (Table 6).

Coefficient estimates for discharge days >25 and < 80 m^3s^{-1} and maximum discharge during the egg incubation period were 0.36 and -0.28, respectfully. This suggests an increase in egg-to-fry recruitment when the number of days during the adult migration in which discharge was >25 and < 80 m^3s^{-1} increased from the 11-year mean (5 days; Figure 14 b,c,d), and a decrease in recruitment when maximum discharge increased during the egg incubation period (Table 6). We also examined the effect of interactions between yearly adult escapement and discharge days (>25<80 m^3s^{-1}) on the SR relationships, but did not find evidence that interactions were significant (see Appendix 1).

Table 6. DIC model ranking statistics and coefficient estimates for Ricker models with covariate effects of discharge on Chum salmon egg-to-fry recruitment in the Cheakamus River across all habitat types (combined mainstem and side-channels). Models are compared to a base Ricker model with no covariate effect and ranked by ΔDIC – the difference between model-specific DIC values indicate the level of empirical support for each model; prob. $\gamma > 0$ is the probability that the coefficient effect is greater than 0 and used is to evaluate the importance of the covariate; R^2 is an estimate of the proportion of variance explained by each model.

Model	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* $\gamma > 0$	R^2	DIC	ΔDIC
Base Ricker (BR)	-	-	-	-	0.53	23.48	4.9
BR + Discharge days >25< 80 m^3s^-	0.36	0.09	0.66	99.4	0.71	18.62	0
BR + Incubation discharge max	-0.28	-0.55	-0.01	2.2	0.75	19.45	0.8
BR + Incubation discharge SD	-0.25	-0.52	0.06	4.4	0.72	22.48	3.9
BR + Incubation discharge variance	-0.25	-0.53	0.05	4.0	0.71	23.53	4.9
BR + Incubation discharge median	-0.20	-0.50	0.11	8.8	0.68	24.43	5.8

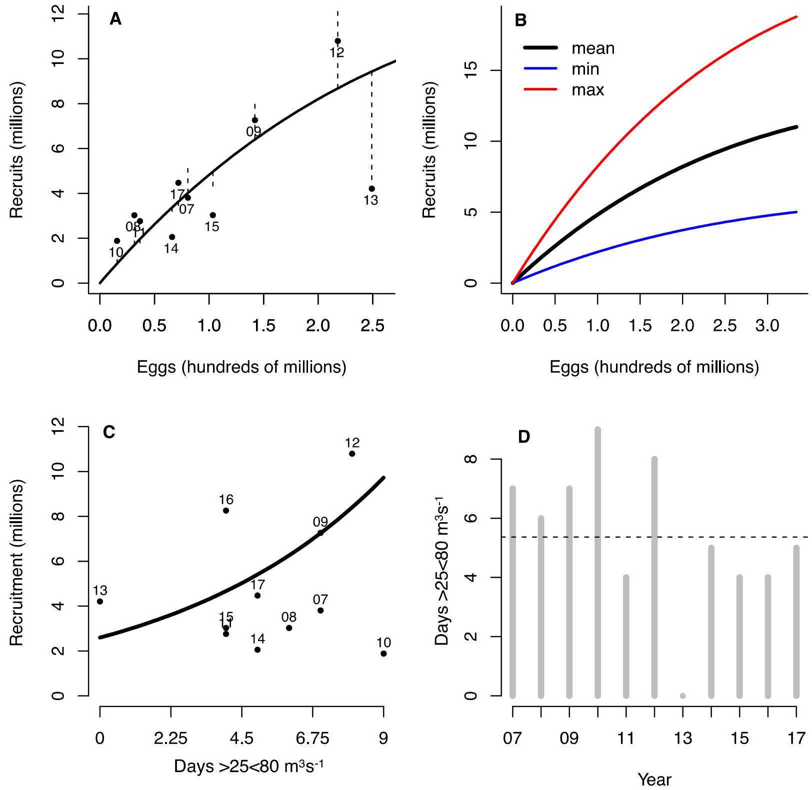

Figure 14. Stock-recruitment curve for the number of Chum Salmon fry produced per hundreds of millions of eggs; individual points are data from each of the 11 years of monitoring (panel A). Estimated numbers of recruits per hundred million eggs at the mean, minimum, and maximum values of discharge days >25<80 m^3s^{-1} during the adult migration period (panel B). Estimated juvenile recruitment by discharge days >25<80 m^3s^{-1} over the 11 years of monitoring (panel C). Average number of days per year from 2007 – 2017 when discharge was >25<80 m^3s^{-1} (panel D).

3.7.2 Adult-to-fry Recruitment

The estimated number of juvenile Chum Salmon recruits per adult spawner was consistent with previous year's estimated adult-to-fry SR relationships (Figure 15a). Moreover, the strong positive effect of discharge days > 25 < 80 m^3s^{-1} during the adult migration detected in the 10-year synthesis (Fell et al. 2018) was again included in the top-ranked model for adult-to-fry recruitment across all habitat types (Table 7). This model explained 74% of the variation in the data with 99.5% probability that the effect of discharge days (coefficient estimate = 0.40) was positive, further supporting the CMSMON1b hypothesis that adult Chum Salmon exposed to discharges >25 and <80 during adult migration have increased fry production (Table 7; Figure 15 b,c,d). The remaining models had ΔDIC values 3.9 – 5.2 times larger than the top ranked model, suggesting there was considerably less empirical support for the effects of other discharge covariates on the adult-to-fry SR relationship (Table X).

Table 7. DIC model ranking statistics and coefficient estimates for Ricker models with covariate effects of discharge on Chum salmon adult-to-fry recruitment in the Cheakamus River for all habitat types. Models are compared to a base Ricker model with no covariate effect and ranked by ΔDIC – the difference between model-specific DIC values that indicate the level of empirical support for each model; prob. $\gamma > 0$ is the probability that the coefficient effect is greater than 0 and used to evaluate the importance of the covariate; R^2 is an estimate of the proportion of variance explained by each model.

Model	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC
Base Ricker (BR)	-	-	-	-	0.54	23.1	6.8
BR + Discharge days >25< 80 m^3s^{-1}	0.40	0.13	0.68	99.5	0.74	16.30	0.0
BR + Incubation discharge SD	-0.26	-0.51	0.01	2.8	0.74	20.18	3.9
BR + Incubation discharge mean	-0.26	-0.52	0.01	2.7	0.75	21.10	4.8
BR + Incubation discharge median	-0.25	-0.54	0.03	3.6	0.72	21.30	5.0
BR + Incubation discharge max	-0.28	-0.54	0.02	2	0.76	21.51	5.2

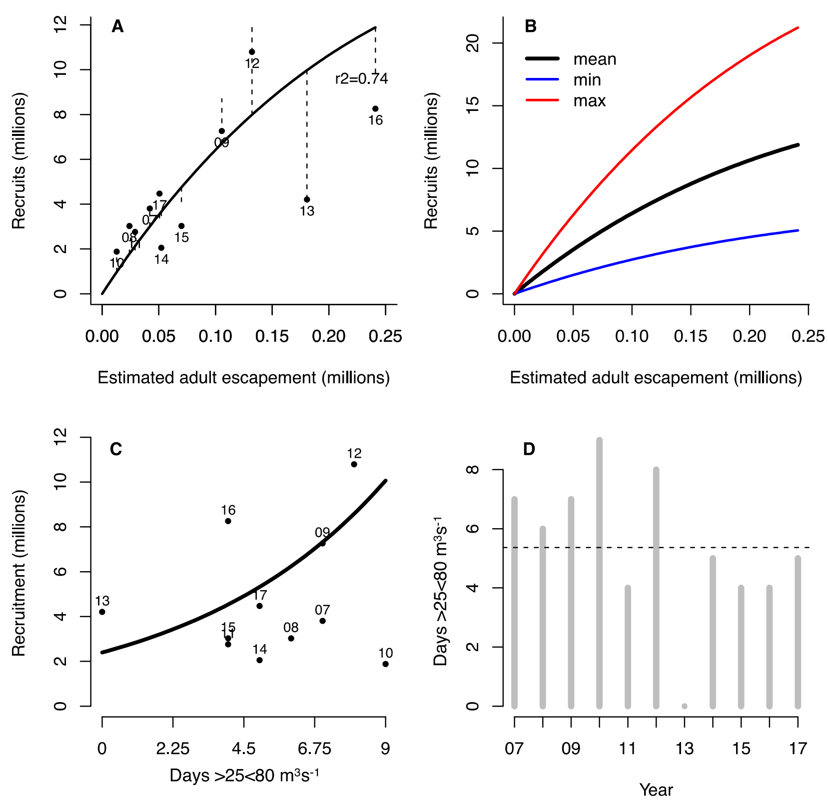

Figure 15. Stock-recruitment curve for the number of Chum Salmon fry produced per millions of adult spawners; individual points are data from each of the 11 years of monitoring (panel A). Estimated numbers of recruits per estimated spawner abundance at the mean, minimum, and maximum values of discharge days >25<80 m^3s^{-1} during the adult migration period (panel B). Estimated juvenile recruitment by discharge days >25<80 m^3s^{-1} over the 11 years of monitoring (panel C). Average number of days per year from 2007 – 2017 when discharge was >25<80 m^3s^{-1} (panel D).

4.0 DISCUSSION

A number of uncertainties were identified in the 10-year synthesis for CMSMON1b relating to the effects of the WUP discharge regime on groundwater upwelling, adult spawning site selection, and stock-recruitment relationships (Fell et al. 2018). Critical to these uncertainties was the lack of variability in discharge during the monitoring periods (December through April) which made it difficult to thoroughly address the management questions and null hypotheses (BC Hydro 2007). Following the recommendations of a continued and more experimental approach to address these uncertainties (Fell et al. 2018), BC Hydro implemented an additional year of monitoring in 2017 – 2018 that was characterized by three periods of experimental 'pulse flows' during the fall adult Chum Salmon migration. The following discussion focuses primarily on the effects of these pulse flows and their utility in addressing the uncertainties identified in Fell et al. (2018) and guiding management questions for CMSMON1b (BC Hydro 2007).

4.1 MQ1: discharge, adult distribution, spawning site selection, groundwater, and incubation conditions

Modelling of radio-tagged fish in the 10-year synthesis suggested that pulsed flows >25 and <80 m^3s^{-1} during the fall upstream migration may increase the probability of adults moving into the modeled effective habitat above the Bailey Bridge. However, despite more discharge variability in 2017 from pulsed flows, the model of maximum migration distance achieved by radio-tagged fish did not support this relationship and had little predictive power. The lack of association between discharge and distribution and the low estimated adult escapement in 2017 support the hypothesis that movement into habitat above the Bailey Bridge is density dependent rather than discharge-related.

Chum Salmon in 2017 were only distributed throughout spawning habitats in the lower reaches of the Cheakamus River between RK 2.0 (Stables) and below RK 7.5 (Bailey Bridge), with 21% of the estimated population utilizing side-channel habitats below the Bailey Bridge. Throughout all CMSMON1b monitor years, Chum Salmon were generally observed spawning in lower velocity areas (10 – 30 cm/s) and side-channel habitats, which is consistent with preferred conditions for this species (Geist et al. 2002). These areas of preferred habitat are abundant below the Bailey Bridge, suggesting Chum Salmon in the Cheakamus River are not likely to utilize the modeled 'effective' habitat above the Bailey Bridge unless driven by density dependant behaviour. Testing of pulsed flows during the 2018 adult Chum Salmon migration will allow for an additional testing of this hypothesis via a newly designed telemetry array and detailed exploration of migration behaviour during variable discharge.

Our analysis of discharge and Chum Salmon side channel usage suggested that side-channel entry increased during pulsed flows. In previous iterations of CMSMON1b annual reports, this relationship has only been hypothesized but never empirically examined (e.g. Fell et al. 2017). We modeled the 2017 side-channel data and found that two peaks of daily entries into side-channels were related to increases in mean daily discharge from 15.8 – 71.7 m^3s^{-1}. The models suggested that daily entries could be increased by pulsing discharge above the daily mean of 32.4 m^3s^{-1} during the adult migration. Increasing entry into side channels could potentially increase Chum Salmon productivity, as egg-to-fry survival is consistently higher in side channels relative to the mainstem river (Fell et al. 2018). Continued testing of the effects of pulse flows during the 2018 – 2019 will help further evaluate this relationship and add more certainty to this prediction.

The location of hyporheic exchange between groundwater and surface water is known to be an important aspect of Chum Salmon spawning site selection (Leman 1993; Geist et al. 2002). During the 10-year synthesis, we explored the presence of groundwater inflows at spawning sites, but data were scarce and often limited to only one year (Fell et al. 2018). We continued monitoring in 2017 and found evidence of groundwater upwelling throughout the study site (i.e., RK 4.0 – 16.0). All sites with strong upwelling evidence were located within six kilometers of the Bailey Bridge (between Site 1 Lower and Site 6), where the majority of adult Chum Salmon are observed spawning; however, there was evidence of weak groundwater upwelling as far upstream as Site 11 (RK 15). The degree of groundwater upwelling varied substantially both within and between sites, which is typical of upwelling characteristics in rivers (Malcom et al. 2004, Winter 1995).

Management Question 2 of this monitor asked whether models used to calculate effective spawning area provide an accurate representation of Chum Salmon spawning site selection and the availability of spawning habitat under the WUP flow regime. Consistent with our conclusions from the 10-year synthesis, our results continue to suggest that we can reject the hypothesis that Chum Salmon do not select areas of groundwater upwelling for spawning (H_2). However, we posit instead that localized groundwater upwelling may not be the sole predictor of spawning site selection, as we have suggested previously (Fell et al. 2018). Chum Salmon consistently spawn in high densities downstream of the Bailey Bridge, and although most groundwater monitoring sites downstream of the bridge were characterized by strong groundwater upwelling, two sites (3 Lower and 3) showed no evidence of upwelling. Moreover, several sites just upstream of the Bailey Bridge are characterized by optimal flow and substrate characteristics and have strong groundwater upwelling, but spawning is rarely observed. The discrepancy between optimal conditions (flow characteristics and groundwater upwelling) and spawning density and consistency suggests additional characteristics are required to predict Chum Salmon spawning site selection in the Cheakamus River.

Chum Salmon spawning site selection has been shown to be driven by water depth, velocity, and temperature; river discharge; substrate characteristics; surface water slope; substrate connectivity; woody debris and shoreline vegetation characteristics; channel morphology; and groundwater upwelling (Benjankar et al 2016, Malcom et al 2004, Burril et al 2010). Spawning site selection can also be driven by characteristics at the reach level or at a micro-habitat scale (Pasternack and Tu 2016). Our observations of Chum Salmon spawning in the Cheakamus River mainstem do not align completely with usage predicted by the original models or with areas of strong groundwater upwelling. We suspect that spawning site selection is therefore driven by a combination of the characteristics used during the WUP modelling, groundwater upwelling, and the additional characteristics described above.

Continued redd temperature monitoring from 2017 and previous years suggests we can reject H_3 that suggests discharge during the chum salmon spawning and incubation period does not affect the upwelling of groundwater in mainstem spawning areas. At sites with strong or weak groundwater upwelling, short-duration pulses of discharge in late January of 2018 resulted in corresponding changes in redd temperature but not river temperature. Consistent with previous years, the magnitude and direction of changes in redd temperatures was highly variable both amongst sites and within the same site, highlighting the heterogeneity of groundwater upwelling in the Cheakamus River mainstem. This heterogeneity makes it very challenging to develop predictive models of discharge and redd temperature and reduces the utility of such models as management tools. Large discharge pulses, particularly those of long duration during the incubation period, could potentially affect redd temperatures and the development of eggs or alevin by increasing scour and egg removal from redds, or the time required for gametes to reach adequate accumulated thermal units necessary for emergence (Casas-Mulet et al. 2014). The effect of discharge on redd temperature should be considered when developing flow regimes because of the potential effect of large and/or long discharge pulses during the incubation period could have on overall Chum Salmon productivity.

Heterogeneity in redd temperatures and discrepancies between groundwater upwelling evidence between different monitoring years demonstrates the value of continued redd temperature monitoring in the Cheakamus River mainstem. In tandem with continued experimental pulse flows, groundwater monitoring will continue during the 2018 – 2019 adult migration and incubation periods and will target areas upstream of the Bailey Bridge where weak groundwater upwelling was identified. Temperature loggers deployed in redds can shift during high discharge events. To address this issue, in 2018-19 we will use a smaller temperature sensor that can be deployed more securely within the sediment. This will reduce the number of loggers lost during monitoring and improve our ability to deploy loggers at an exact depth below the substrate surface. Groundwater monitoring will also be coupled with surveys of spawning adults and begin earlier in the migration period (approx. November 1) and continue until the end of the incubation period (approx. April 1). Together, these new groundwater/spawner monitoring methods in 2018 – 2019 will provide finer resolution data and lend to empirical tests that will help clarify any remaining uncertainties regarding adult distribution into habitats above the Bailey Bridge, and whether this is related to groundwater in potential spawning sites in these areas.

4.2 MQ1: discharge and juvenile productivity

Historically, the hypothesis for the Cheakamus River WUP flow regime was that discharge during the Chum Salmon spawning and incubation period does not affect productivity (BC Hydro 2007). We rejected this hypothesis in the 10-year synthesis for CMSMON1b because we identified a strong positive effect of the number of days during the adult migration with discharge between 25 and 80 m^3s^{-1} on juvenile productivity (Fell et al. 2018). In 2017, BC Hydro initiated an additional year of monitoring that tested three periods of experimental 'pulse flows' during the fall adult migration that were designed to add more contrast and variability to WUP flow regime and generate more confidence in the stock-recruitment prediction of increased productivity. Although the pulsed flows resulted in a more variable hydrograph in 2017, they did not increase the number of days when discharge during adult migration was >25 and <80 m3/s relative to the previous 10 years of monitoring, and the resulting egg-to-fry and adult-to-fry stock-recruitment estimates were very similar to the 10-year means (Fell et al. 2018).

Although experimental pulse flows in 2017 produced average migration conditions, the addition of 2017 data to both the egg-to-fry and adult-to-fry models supported the hypothesis that more variability in flows during the adult migration period increases productivity. In the 10-year synthesis of egg-to-fry stock recruitment, the top-ranked model included a negative effect of increased discharge (>60 m^3s^{-1}) during the incubation period (Fell et al. 2018). Although this remained a top model with the addition of 2017 data, the top-ranked model included a positive effect of discharge days >25<80 m^3s^{-1} during the peak adult migration period (the two top-ranked models in 2017 had equal support according to DIC). These model results suggested that more days with high discharge during egg incubation can negatively affect egg-to-fry survival, while more days with discharge between 25 and 80 m^3s^{-1} during adult incubation can positively affect egg-to-fry survival. We found discharge pulses (that generally increase the number of days between 25 and 80 m^3s^{-1}) appear to increase side-channel usage by adults. As egg-to-fry survival is known to be higher in side channels, the increase in side-channel spawning may explain why more days with discharge between 25 and 80 m^3s^{-1} may increase egg-to-fry survival.

Adding further support to the hypothesis that more variability in flows during the adult migration period increases productivity were results from the adult-to-fry stock recruitment analysis for 2017. We observed a strong positive effect of increasing the number of days during the peak adult migration period with discharge >25 and <80 m^3s^{-1} on adult-to-fry recruitment. This agrees with the results of the egg-to-fry modelling and suggests that greater discharge variability (above base flows) during the adult migration likely increases side-channel use and reduces spawner densities in mainstem habitats, thereby reducing density-dependent mortality and increasing overall juvenile productivity.

Both egg-to-fry and adult-to-fry SR models indicate that regulating discharge during incubation and adult migration could be used as a management tool to increase Chum Salmon productivity in the Cheakamus River; however, Chum Salmon are a long-lived species with highly variable abundances, and inferences drawn from stock-recruitment relationships with small sample sizes (i.e. years of monitoring) could be biased or inaccurate (Korman and Higgins 1997; Babcock et al. 2010; Fell et al. 2018). While results from experimental discharge pulses add more confidence to inferences from stock-recruitment relationships, we recommend a precautionary approach to any management decision made based on these results. BC Hydro has initiated an additional monitoring program for fall 2018 that will be characterized by an increased number of experimental discharge pulses during the adult migration period; however, the 2019 juvenile Chum Salmon monitoring (CMSMON1a) will only be completed if there is sufficient discharge variability >25<80 m^3s^{-1} during fall 2018. Without juvenile data, stock-recruitment modeling cannot be completed, as these data are not mutually exclusive, and the long-term data set of Chum Salmon productivity in the Cheakamus River would be compromised. Complete and accurate stock-recruit relationships are critical to understanding whether annual fluctuations in egg-to-fry and adult-to-fry recruitment are related to adult escapement or characteristics of the WUP discharge regime (i.e., fall discharge pulses) (Bradford et al. 2005). Data from both adult and juvenile Chum Salmon in the Cheakamus River are required to improve the robustness of stock-recruitment analyses and predictions discussed above, and ensure that management decisions are made considering the most complete information possible.

Not only is it important to increase sample size to improve the accuracy of the stock-recruitment models, but it would also be remiss to attribute the predicted juvenile productivity increases solely to the effects of discharge as there are a number of additional factors beyond the scope of this monitoring program that could influence this outcome. For example, juvenile productivity can also vary with overall watershed productivity, predation, or the physiological condition of juveniles and spawning adults. However, despite not accounting for these factors, the effects of discharge in this analysis have been identified as predictors of juvenile abundance and salmonid productivity and are biologically related to mechanisms known to affect different salmonid life-history stages (Arthaud et al. 2014; Zeug et al. 2014; Rebenack et al. 2015; Zimmerman et al. 2015). Discharge variability is known to influence the upstream migration behaviour, distribution, and spawning success of numerous species of salmonids, including Chum Salmon (Hunter 1959; Telzlaff et al. 2005; Taylor and Cooke 2012). In the Cheakamus River, a positive linear relationship appears to exist between increasing minimum flows (15-25 m^3s^{-1}) during peak spawning and the proportion of adult Chum Salmon utilizing side-channel habitats. Analysis of radio-tagged fish in this study also found that adults that experienced a greater number of discharge days ≥ 25 m^3s^{-1} and ≤ 80 m^3s^{-1} may be more likely to move into potential spawning habitat in the 'upper river' near the Bailey Bridge. In all these cases, greater discharge variability above base flows during the adult migration likely increases juvenile productivity by increasing adult distribution throughout suitable spawning habitat and reducing density dependent juvenile mortality.

4.3 MQ 2 & 3: Modelled effective spawning area as an accurate representation of spawning site selection and availability of spawning habitat

The mainstem reaches of the Cheakamus River upstream of the Bailey Bridge (RK 7.0) were modelled as effective Chum Salmon spawning habitat during the WUP consultative process based on depth, velocity, and substrate, and the assumptions that more habitat would increase productivity and that discharge was the most important habitat metric (BC Hydro 2007). However, results from this study refute these core assumptions and highlight the limitations of the habitat suitability modelling approaches used during the WUP consultative process. During the 10 years of monitoring, adult Chum Salmon have rarely been observed in high densities upstream of the Bailey Bridge apart from 2012. In this year, overall adult abundance was high, suggesting spawning above the Bailey Bridge is likely related to density dependent movement rather than spawning habitat suitability. Moreover, published literature and the results of this monitor suggest the primary factor in adult Chum Salmon spawning site selection is strong groundwater upwelling, which is more prevalent in the lower river relative to upstream of the Bailey Bridge. Thus, the models developed during the WUP consultative process do not provide an accurate representation of available Chum Salmon spawning habitat because they did not include groundwater upwelling. Ongoing temperature monitoring in confirmed and suspected redd sites upstream of the Bailey Bridge will help refine answers to MQ's 2 and 3.

5.0 Conclusion

During the 10-year synthesis for CMSMON1b we identified a number of remaining uncertainties with respect to the effects of the WUP discharge regime on adult distribution, groundwater-influenced incubation conditions, and stock-recruitment (Fell et al. 2018). Monitoring of adult Chum Salmon in 2017 was earmarked by three periods of experimental pulse flows during the fall migration ($>25<80$ m^3s^{-1}) designed to address these uncertainties and add more confidence to conclusions made regarding the guiding management questions and hypotheses of this monitor.

Results from 2017 and the previous 10-year synthesis indicate that the habitat downstream of the Bailey Bridge (RK 7.0) is critical to Chum Salmon productivity, particularly the artificial side-channels and spawning sites with dominant groundwater inflows. Despite pulsed flows in 2017, 0% of radio tagged adults were distributed above the Bailey Bridge, further supporting the hypothesis that usage of this modeled ‘effective habitat’ is density dependent rather than related to variability in fall discharge. However, discharge pulses do likely lead to more side-channel usage as the daily number of entries into these habitats increased with increasing discharge during the fall migration. Thus, increasing side channel usage through flow management may increase productivity, as side-channels are characterized by higher egg-to-fry survival.

Observations from redd temperature monitoring suggest groundwater inflows are an important component to determining effective Chum Salmon spawning habitat. In the 10-year synthesis, groundwater data were often scarce or incomplete, and the groundwater relationship with discharge was inconclusive, thus we expanded monitoring in 2017 to address this uncertainty. We continued to observe strong evidence of groundwater in spawning sites below the Bailey Bridge and also found that groundwater exists in many locations in the upper river, although the strength of upwelling was highly variable between sites. We also observed a high degree of heterogeneity in the amount of groundwater both within and between known and potential spawning sites, and in the relationships between groundwater and discharge at these sites. More refined groundwater monitoring throughout the 2018 – 2019 fall migration and juvenile incubation period will better capture variably in upwelling and lend further inference into the groundwater-discharge relationship. This coupled with surveys of locations of spawning adults during experimental pulse flows will highlight more of the patterns associated with site selection, groundwater, and discharge.

Results from egg-to-fry and adult-to-fry stock recruitment modelling in 2017 support the hypothesis that fall discharge variability has a positive effect on recruitment. These results highlight the utility of maintaining a variable Cheakamus River hydrograph above the current WUP base flow regime as a potential management tool to increase Chum Salmon productivity. However, with only 11 years of data we reiterate the need for a precautionary approach to any management decision made based on these results and recommend additional years of monitoring both adult and juvenile Chum Salmon escapement.

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7.0 Appendix 1

Table 8. Index of discharge covariates used in egg-to-fry and adult-to-fry stock-recruitment analyses calculated for distinct adult migration and juvenile incubation time periods.

Covariate number	Discharge covariate	Time Period
1	Spawning season minimum discharge	Entire Spawning Season: October 15 - December 15
2	Spawning season maximum discharge	Entire Spawning Season: October 15 - December 15
3	Spawning season median discharge	Entire Spawning Season: October 15 - December 15
4	Spawning season average discharge	Entire Spawning Season: October 15 - December 15
5	Spawning season discharge std. dev.	Entire Spawning Season: October 15 - December 15
6	Spawning season discharge variance	Entire Spawning Season: October 15 - December 15
7	Upstream migration minimum discharge	Upstream Migration: October 15 - November 7
8	Upstream migration maximum discharge	Upstream Migration: October 15 - November 7
9	Upstream migration median discharge	Upstream Migration: October 15 - November 7
10	Upstream migration average discharge	Upstream Migration: October 15 - November 7
11	Upstream migration discharge std. dev.	Upstream Migration: October 15 - November 7
12	Upstream migration discharge variance	Upstream Migration: October 15 - November 7
13	Peak spawning minimum discharge	Peak Spawning: November 1-15
14	Peak spawning maximum discharge	Peak Spawning: November 1-15
15	Peak spawning median discharge	Peak Spawning: November 1-15
16	Peak spawning average discharge	Peak Spawning: November 1-15
17	Peak spawning discharge std. dev	Peak Spawning: November 1-15
18	Peak spawning discharge variance	Peak Spawning: November 1-15
19	Incubation period minimum discharge	Incubation period: December 1 - March 31
20	Incubation period maximum discharge	Incubation period: December 1 - March 31
21	Incubation period median discharge	Incubation period: December 1 - March 31
22	Incubation period average discharge	Incubation period: December 1 - March 31
23	Incubation period discharge std. dev.	Incubation period: December 1 - March 31

24	Incubation period discharge variance	Incubation period: December 1 - March 31
25	Peak migration discharge days >25<80 m^3s^{-1}	Peak Upstream Migration: October 25 - November 7

All tables presented hereafter are of DIC model ranking statistics and coefficient estimates for Ricker models with covariate effects of different discharge metrics on Chum Salmon egg-to-fry and adult-to-fry recruitment (specified) in the Cheakamus River across different habitat types (combined mainstem and side-channels, or individual side-channels). Models are compared to a base Ricker model with no covariate effect and ranked by ΔDIC – the difference between model-specific DIC values indicate the level of empirical support for each model; prob. $\gamma > 0$ is the probability that the coefficient effect is greater than 0 and used is to evaluate the importance of the covariate; R^2 is an estimate of the proportion of variance explained by each model. Each covariate index number corresponds with a different discharge metric presented in Table 1.

Egg-to-fry recruitment models

Table 9. Effects of discharge on Chum Salmon egg-to-fry recruitment across *all habitat types* (combined mainstem and side-channels).

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	*0.53*	*23.48*	*4.86*	*4*
25	0.36	0.09	0.66	99.4	0.71	18.62	0.00	1
20	-0.28	-0.55	-0.01	2.2	0.75	19.46	0.83	2
23	-0.25	-0.52	0.06	4.4	0.72	22.48	3.86	3
24	-0.25	-0.53	0.05	4	0.71	23.53	4.91	5
21	-0.21	-0.50	0.11	8.8	0.67	24.43	5.81	6
22	-0.24	-0.53	0.06	4.9	0.70	24.46	5.83	7
9	-0.17	-0.59	0.20	16.9	0.49	25.43	6.81	8
3	-0.06	-0.51	0.33	39.2	0.49	25.74	7.12	9
6	-0.17	-0.55	0.21	14.9	0.55	25.87	7.24	10
1	0.13	-0.26	0.47	78	0.61	25.89	7.26	11
15	-0.07	-0.51	0.38	38.8	0.49	25.97	7.35	12
7	0.08	-0.36	0.44	67.6	0.58	26.02	7.40	13
4	-0.12	-0.49	0.23	23.2	0.53	26.22	7.60	14
10	-0.13	-0.53	0.23	22.8	0.52	26.27	7.65	15
12	-0.17	-0.50	0.17	14.4	0.60	26.33	7.70	16
5	-0.13	-0.49	0.23	21.1	0.56	26.42	7.79	17
18	-0.14	-0.52	0.23	21.1	0.48	26.48	7.86	18
17	-0.05	-0.43	0.31	40.2	0.52	26.51	7.88	19
2	-0.14	-0.49	0.24	20.9	0.56	26.98	8.36	20
13	0.04	-0.40	0.44	61.3	0.56	26.98	8.36	21
16	-0.05	-0.52	0.37	42.5	0.50	27.36	8.74	22

11	-0.10	-0.49	0.27	26.7	0.54	27.41	8.79	23
8	-0.09	-0.48	0.27	29.9	0.53	27.46	8.83	24
14	-0.08	-0.48	0.32	34.1	0.50	28.97	10.34	25
19	-0.08	-0.54	0.32	33.5	0.51	41.81	23.18	26

Table 10. Effects of discharge on Chum Salmon egg-to-fry recruitment in the *mainstem* Cheakamus River.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.39	41.25	4.52	15
9	-0.99	-1.74	-0.24	0.5	0.52	36.72	0.00	1
18	-0.96	-1.71	-0.21	1	0.52	37.86	1.14	2
14	-0.88	-1.72	-0.05	2.1	0.41	38.54	1.81	3
25	0.87	0.04	1.68	97.7	0.43	38.72	2.00	4
15	-0.85	-1.70	-0.01	2.5	0.40	38.93	2.21	5
10	-0.89	-1.73	-0.06	2	0.46	39.06	2.34	6
16	-0.83	-1.70	0.04	3	0.37	39.20	2.47	7
17	-0.79	-1.65	0.08	3.6	0.35	39.78	3.05	8
6	-0.80	-1.62	0.12	4.1	0.36	40.04	3.32	9
11	-0.79	-1.66	0.10	3.7	0.36	40.29	3.57	10
3	-0.72	-1.60	0.17	5.5	0.29	40.37	3.64	11
8	-0.69	-1.53	0.20	6.2	0.31	40.64	3.92	12
13	-0.66	-1.53	0.26	7.8	0.27	40.64	3.92	13
4	-0.72	-1.67	0.18	5	0.31	40.94	4.21	14
5	-0.69	-1.65	0.23	6.3	0.31	41.25	4.53	16
12	-0.84	-1.70	-0.02	2.4	0.44	41.38	4.65	17
7	-0.59	-1.50	0.39	10.1	0.20	41.40	4.68	18
20	-0.61	-1.55	0.31	9.5	0.24	41.46	4.73	19

2	-0.66	-1.57	0.27	7.3	0.27	41.50	4.78	20
21	-0.56	-1.49	0.41	11.3	0.26	43.26	6.54	21
19	-0.15	-1.17	0.89	37.5	0.12	43.48	6.76	22
1	-0.16	-1.19	0.87	38	0.13	43.61	6.88	23
23	-0.69	-1.59	0.23	5.9	0.39	44.02	7.29	24
22	-0.75	-1.64	0.15	4.2	0.42	44.07	7.35	25
24	-0.73	-1.62	0.17	5.1	0.41	44.81	8.09	26

Table 11. Effects of discharge on Chum Salmon egg-to-fry recruitment in the *Cheakamus Centre side channels*.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* $\gamma > 0$	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.30	7.75	2.96	5
25	0.18	0.00	0.35	97.6	0.45	4.79	0.00	1
7	0.19	0.04	0.33	99.3	0.74	6.18	1.39	2
13	0.19	0.04	0.32	99	0.72	6.66	1.87	3
19	-0.14	-0.33	0.05	6.4	0.34	6.69	1.90	4
16	0.17	0.01	0.32	97.90	0.67	8.01	3.22	6
20	-0.11	-0.31	0.08	11.10	0.31	8.59	3.80	7
1	0.14	-0.04	0.32	94.90	0.53	8.77	3.98	8
17	0.13	-0.05	0.31	92.20	0.44	9.17	4.38	9
18	0.09	-0.10	0.29	84.30	0.38	9.32	4.53	10
3	0.17	0.01	0.32	98.20	0.68	9.40	4.61	11
14	0.14	-0.05	0.30	94.60	0.51	9.50	4.71	12
21	-0.09	-0.28	0.10	16.20	0.34	9.54	4.75	13
10	0.08	-0.11	0.28	80.70	0.32	9.87	5.08	14
22	-0.06	-0.26	0.16	26.10	0.28	9.91	5.12	15
4	0.08	-0.13	0.28	81.90	0.31	9.97	5.18	16

15	0.17	-0.01	0.33	96.70	0.66	10.01	5.22	17
9	0.08	-0.12	0.28	80.10	0.35	10.03	5.24	18
24	-0.06	-0.25	0.16	28.30	0.28	10.22	5.43	19
23	-0.06	-0.26	0.15	24.00	0.23	10.34	5.55	20
8	0.07	-0.14	0.27	77.40	0.28	10.38	5.58	21
5	0.06	-0.15	0.26	72.10	0.26	10.44	5.65	22
11	0.06	-0.14	0.27	75.20	0.28	10.52	5.72	23
2	0.07	-0.14	0.28	74.70	0.27	10.58	5.79	24
12	0.01	-0.20	0.23	53.80	0.30	10.62	5.83	25
6	0.02	-0.18	0.23	57.70	0.30	10.66	5.87	26

Table 12. Effects of discharge on Chum Salmon egg-to-fry recruitment in the *BC Rail side channels*.

Covariate index (Base Ricker +)	**Coefficient estimate (γ)**	**Lower 95% CI**	**Upper 95% CI**	***prob.* γ > 0**	R^2	**DIC**	**ΔDIC**	**Model Rank**
Base Ricker	-	-	-	-	*0.09*	*27.76*	*1.88*	*10*
17	0.43	0.00	0.85	97.50	0.37	25.89	0.00	1
9	0.39	-0.04	0.85	96.10	0.32	26.58	0.70	2
18	0.38	-0.06	0.84	96.10	0.31	26.77	0.89	3
14	0.39	-0.05	0.85	95.80	0.33	26.79	0.90	4
5	0.36	-0.12	0.83	93.80	0.28	27.28	1.39	5
2	0.35	-0.12	0.82	93.90	0.27	27.42	1.54	6
6	0.33	-0.13	0.80	92.50	0.24	27.47	1.58	7
11	0.35	-0.12	0.84	94.00	0.25	27.64	1.75	8
10	0.36	-0.10	0.84	94.70	0.28	27.68	1.79	9
4	0.31	-0.17	0.78	90.30	0.23	27.88	2.00	11
12	0.32	-0.17	0.80	91.10	0.23	28.19	2.30	12
8	0.31	-0.19	0.79	89.90	0.22	28.31	2.43	13

16	0.31	-0.18	0.78	90.50	0.21	28.50	2.61	14
24	0.26	-0.24	0.75	86.40	0.16	28.81	2.93	15
22	0.22	-0.28	0.72	82.60	0.12	28.96	3.08	16
23	0.22	-0.30	0.71	81.50	0.15	29.29	3.40	17
19	-0.17	-0.69	0.37	24.90	0.08	29.43	3.54	18
15	0.25	-0.26	0.77	85.50	0.16	29.64	3.75	19
7	0.20	-0.32	0.70	79.40	0.10	29.73	3.85	20
1	-0.21	-0.70	0.31	19.60	0.11	30.08	4.19	21
13	0.16	-0.38	0.69	75.00	0.09	30.12	4.24	22
25	0.06	-0.50	0.62	59.10	0.06	30.37	4.49	23
20	0.10	-0.45	0.64	65.90	0.09	30.45	4.56	24
21	0.00	-0.53	0.55	49.50	0.08	30.71	4.82	25
3	0.26	-0.26	0.79	86.30	0.18	30.83	4.95	26

Adult-to-fry recruitment

Table 6. Effects of discharge on Chum Salmon adult-to-fry recruitment across all habitat types (combined mainstem and side-channels).

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.54	23.09	6.79	7
25	0.39	0.13	0.68	99.50	0.74	16.30	0.00	1
23	-0.26	-0.51	0.01	2.80	0.74	20.18	3.88	2
22	-0.26	-0.52	0.01	2.70	0.75	21.07	4.77	3
21	-0.25	-0.54	0.03	3.60	0.72	21.27	4.97	4
20	-0.28	-0.54	-0.02	2.00	0.76	21.51	5.21	5
24	-0.26	-0.52	0.01	2.70	0.75	22.09	5.79	6
9	-0.20	-0.58	0.15	13.90	0.49	23.80	7.50	8
6	-0.19	-0.52	0.12	9.80	0.63	24.02	7.72	9
12	-0.20	-0.52	0.11	9.30	0.63	24.67	8.37	10
18	-0.15	-0.54	0.23	19.30	0.52	24.89	8.59	11
15	-0.09	-0.53	0.33	34.90	0.48	25.09	8.79	12
1	0.14	-0.25	0.47	80.70	0.63	25.12	8.82	13
14	-0.10	-0.50	0.28	29.70	0.49	25.23	8.93	14
10	-0.15	-0.54	0.21	17.40	0.53	25.44	9.14	15
16	-0.07	-0.50	0.35	38.30	0.49	25.49	9.19	16
4	-0.13	-0.50	0.22	22.20	0.54	25.55	9.24	17
5	-0.15	-0.52	0.20	16.80	0.57	25.60	9.30	18
17	-0.07	-0.46	0.33	36.10	0.52	25.72	9.42	19
3	-0.07	-0.51	0.34	40.10	0.49	25.83	9.53	20
8	-0.11	-0.48	0.23	24.70	0.55	26.12	9.82	21
11	-0.13	-0.51	0.21	20.40	0.55	26.15	9.85	22

13	0.02	-0.42	0.42	56.90	0.55	26.21	9.91	23
2	-0.14	-0.49	0.19	18.20	0.56	26.24	9.94	24
19	-0.10	-0.51	0.29	28.80	0.50	26.27	9.97	25
7	0.06	-0.39	0.46	63.70	0.58	26.38	10.08	26

Table 7. Effects of discharge on Chum Salmon adult-to-fry recruitment in the mainstem Cheakamus River.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.41	43.29	5.11	15
9	-0.96	-1.71	-0.21	1.00	0.58	38.19	0.00	1
18	-0.93	-1.64	-0.26	0.70	0.63	38.41	0.22	2
25	0.80	0.01	1.60	97.60	0.52	39.00	0.81	3
12	-0.85	-1.47	-0.23	0.70	0.75	40.23	2.04	4
16	-0.79	-1.62	0.03	3.00	0.44	40.26	2.07	5
14	-0.83	-1.63	-0.01	2.30	0.51	40.45	2.27	6
15	-0.82	-1.73	0.07	3.40	0.44	40.64	2.45	7
10	-0.88	-1.66	-0.09	1.60	0.58	40.94	2.75	8
24	-0.85	-1.46	-0.17	1.30	0.77	41.58	3.39	9
17	-0.76	-1.58	0.02	2.70	0.53	41.92	3.73	10
6	-0.80	-1.51	-0.10	1.60	0.69	42.60	4.41	11
13	-0.62	-1.54	0.33	7.90	0.35	42.99	4.80	12
4	-0.70	-1.55	0.11	4.00	0.49	43.20	5.02	13
22	-0.81	-1.45	-0.14	1.20	0.72	43.21	5.02	14
11	-0.78	-1.58	-0.04	2.00	0.62	43.37	5.18	16
3	-0.67	-1.58	0.29	7.70	0.36	43.51	5.32	17
7	-0.50	-1.48	0.51	15.00	0.31	43.54	5.35	18
8	-0.71	-1.55	0.13	4.40	0.53	44.15	5.96	19

5	-0.69	-1.54	0.09	3.80	0.58	44.57	6.38	20
2	-0.66	-1.53	0.16	5.30	0.52	44.82	6.63	21
23	-0.74	-1.49	0.02	2.70	0.67	45.03	6.84	22
20	-0.63	-1.50	0.24	6.40	0.54	45.24	7.05	23
21	-0.69	-1.48	0.10	3.90	0.63	45.85	7.66	24
1	-0.07	-1.12	0.95	44.90	0.38	47.18	8.99	25
19	-0.11	-1.24	0.93	42.50	0.36	53.17	14.98	26

Table 8. Effects of discharge on Chum Salmon adult-to-fry recruitment in the Cheakamus Centre side-channels.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* $\gamma > 0$	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.26	10.24	2.40	*3*
25	0.21	0.00	0.41	97.70	0.42	7.84	0.00	1
19	-0.17	-0.37	0.05	5.70	0.32	9.23	1.40	2
21	-0.15	-0.37	0.08	8.40	0.32	11.01	3.18	4
20	-0.13	-0.36	0.09	12.20	0.23	11.09	3.26	5
1	0.14	-0.07	0.36	92.10	0.41	11.87	4.04	6
9	0.08	-0.16	0.30	75.80	0.32	12.13	4.29	7
7	0.16	-0.04	0.36	94.80	0.51	12.15	4.32	8
13	0.15	-0.07	0.36	92.60	0.47	12.19	4.35	9
22	-0.10	-0.34	0.13	17.60	0.21	12.41	4.57	10
23	-0.08	-0.32	0.16	21.60	0.20	12.50	4.67	11
24	-0.08	-0.32	0.15	21.20	0.23	12.57	4.74	12
14	0.12	-0.12	0.35	85.40	0.29	12.72	4.88	13
17	0.09	-0.14	0.32	80.30	0.24	12.78	4.94	14
4	0.07	-0.17	0.29	74.20	0.26	12.85	5.02	15

16	0.14	-0.08	0.36	91.20	0.45	12.94	5.11	16
8	0.03	-0.21	0.29	61.50	0.24	13.01	5.17	17
6	-0.01	-0.25	0.23	46.60	0.24	13.04	5.21	18
11	0.03	-0.22	0.28	59.40	0.25	13.06	5.22	19
3	0.17	-0.06	0.36	94.20	0.52	13.13	5.29	20
5	0.03	-0.21	0.27	61.40	0.22	13.13	5.29	21
18	0.06	-0.19	0.29	70.60	0.26	13.27	5.43	22
2	0.05	-0.19	0.30	66.00	0.21	13.29	5.45	23
10	0.05	-0.20	0.29	67.80	0.25	13.64	5.80	24
15	0.14	-0.09	0.36	89.20	0.44	13.70	5.86	25
12	-0.03	-0.28	0.22	40.60	0.20	13.80	5.96	26

Table 9. Effects of discharge on Chum Salmon adult-to-fry recruitment in all habitat types the BC Rail side-channels.

Covariate index (Base Ricker +)	**Coefficient estimate (γ)**	**Lower 95% CI**	**Upper 95% CI**	***prob.* γ > 0**	R^2	**DIC**	**ΔDIC**	**Model Rank**
Base Ricker	-	-	-	-	0.11	28.96	0.44	*2*
17	0.40	-0.10	0.90	94.80	0.30	28.51	0.00	1
9	0.37	-0.14	0.87	93.80	0.27	28.98	0.46	3
18	0.36	-0.16	0.87	92.50	0.25	29.02	0.51	4
14	0.37	-0.14	0.87	93.10	0.26	29.21	0.70	5
5	0.34	-0.19	0.84	90.50	0.23	29.53	1.02	6
2	0.33	-0.19	0.86	91.10	0.21	29.67	1.16	7
11	0.31	-0.21	0.83	89.40	0.19	29.78	1.27	8
10	0.34	-0.18	0.87	91.80	0.22	29.95	1.44	9
16	0.29	-0.23	0.85	87.60	0.18	30.28	1.77	10
4	0.30	-0.22	0.84	88.80	0.19	30.32	1.81	11
6	0.31	-0.23	0.83	88.70	0.19	30.38	1.87	12

3	0.26	-0.27	0.80	84.10	0.15	30.61	2.10	13
12	0.29	-0.25	0.83	86.70	0.17	30.67	2.16	14
8	0.28	-0.28	0.85	85.80	0.16	30.73	2.22	15
1	-0.22	-0.77	0.32	20.30	0.11	31.12	2.61	16
19	-0.20	-0.75	0.39	23.20	0.08	31.24	2.73	17
24	0.23	-0.31	0.79	81.50	0.15	31.29	2.78	18
7	0.18	-0.39	0.75	75.60	0.09	31.37	2.86	19
15	0.24	-0.33	0.81	82.20	0.14	31.37	2.86	20
23	0.21	-0.37	0.78	78.80	0.12	31.46	2.95	21
25	0.10	-0.51	0.68	63.50	0.05	31.53	3.02	22
22	0.19	-0.36	0.80	74.90	0.11	31.71	3.20	23
20	0.09	-0.46	0.70	63.60	0.14	31.86	3.35	24
13	0.13	-0.48	0.72	69.50	0.07	32.14	3.63	25
21	-0.06	-0.62	0.51	41.80	0.05	32.30	3.79	26

Egg-to-fry recruitment models with interaction

Table 10. Ranking and output statistics for models of interaction between discharge days >25<80m^3s^{-1} and escapement on Chum Salmon egg-to-fry recruitment across all habitat types (combined mainstem and side-channels).

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.53	24.24	6.40	5
23	-0.80	-1.38	-0.16	1.00	0.03	17.83	0.00	1
24	-0.80	-1.46	0.22	4.20	0.06	18.06	0.22	2
20	-0.67	-1.26	-0.06	1.70	0.01	20.17	2.34	3
25	0.40	-0.21	1.02	91.60	0.70	23.61	5.78	4
22	-0.60	-1.35	0.08	4.10	0.00	25.60	7.77	6

1	0.38	-0.25	1.04	89.40	0.44	26.21	8.38	7
6	-0.39	-0.89	0.14	6.30	0.24	29.19	11.35	8
5	-0.37	-0.87	0.17	6.90	0.22	29.60	11.76	9
10	-0.33	-0.86	0.24	9.80	0.34	29.99	12.15	10
8	-0.33	-0.87	0.21	9.60	0.16	30.34	12.50	11
9	-0.38	-0.94	0.17	7.30	0.37	30.35	12.52	12
21	-0.16	-1.03	0.58	33.10	0.67	30.37	12.53	13
11	-0.32	-0.84	0.24	10.20	0.21	30.39	12.56	14
16	-0.34	-1.46	0.86	25.20	0.25	30.42	12.58	15
13	0.26	-0.91	1.58	66.80	0.41	30.70	12.86	16
4	-0.33	-0.88	0.23	9.70	0.28	30.85	13.02	17
14	-0.34	-1.03	0.41	15.70	0.28	30.99	13.15	18
18	-0.32	-0.89	0.30	12.80	0.35	30.99	13.16	19
12	-0.42	-1.02	0.23	7.10	0.08	31.17	13.34	20
15	-0.78	-2.50	0.69	13.00	0.12	31.20	13.37	21
3	-0.44	-1.39	0.49	16.30	0.20	31.21	13.38	22
7	0.09	-0.87	0.99	58.90	0.58	31.24	13.41	23
19	0.00	-0.78	0.72	51.40	0.53	31.46	13.62	24
17	-0.23	-0.85	0.41	19.80	0.32	32.50	14.66	25
2	-0.42	-0.93	0.15	6.10	0.21	33.55	15.72	26

Table 11. Ranking and output statistics for models of interaction between discharge days >25<80m^3s^{-1} and escapement on Chum Salmon egg-to-fry recruitment in the mainstem Cheakamus River.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.39	40.94	5.40	9
15	-3.52	-5.84	-1.07	0.50	0.27	35.54	0.00	1

20	-1.87	-3.12	-0.63	0.40	0.00	37.32	1.78	2
23	-1.93	-3.24	-0.54	0.50	0.00	38.50	2.96	3
9	-1.25	-2.53	0.01	2.60	0.44	39.04	3.50	4
16	-2.25	-4.44	0.02	2.70	0.25	39.83	4.29	5
18	-1.23	-2.55	0.11	3.30	0.42	40.63	5.09	6
14	-1.59	-3.24	0.09	3.10	0.30	40.91	5.37	7
25	0.89	-0.78	2.60	86.50	0.43	40.92	5.37	8
3	-1.65	-3.73	0.53	6.40	0.19	41.63	6.09	10
22	-1.47	-3.16	0.27	4.10	0.01	41.72	6.18	11
10	-1.06	-2.44	0.34	5.80	0.37	41.94	6.40	12
24	-1.76	-3.20	0.92	6.50	0.01	42.23	6.69	13
17	-1.08	-2.68	0.52	7.90	0.25	42.81	7.26	14
13	-1.08	-3.99	1.68	20.10	0.20	43.40	7.86	15
11	-0.93	-2.39	0.52	9.30	0.25	43.47	7.92	16
1	0.81	-0.79	2.40	85.80	0.15	43.48	7.94	17
4	-0.92	-2.35	0.58	9.40	0.21	43.50	7.96	18
5	-0.87	-2.29	0.65	11.10	0.20	43.85	8.30	19
12	-0.79	-2.42	0.83	14.00	0.48	44.08	8.53	20
8	-1.02	-2.50	0.44	7.80	0.12	44.13	8.59	21
2	-0.97	-2.56	0.61	10.00	0.14	44.38	8.84	22
7	-0.59	-2.84	1.68	28.90	0.21	44.38	8.84	23
6	-0.80	-2.27	0.58	11.70	0.44	44.80	9.26	24
21	-0.94	-2.93	1.14	15.90	0.04	45.47	9.93	25
19	-0.59	-2.52	1.40	24.60	0.04	45.93	10.39	26

Table 12. Ranking and output statistics for models of interaction between discharge days >25<80m^{3}s^{-1} and escapement on Chum Salmon egg-to-fry recruitment in the Cheakamus Centre side channel.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	*0.31*	*7.80*	*10.30*	*15*
12	-0.84	-1.23	-0.40	0.10	0.12	-2.50	0.00	1
11	-0.49	-0.81	-0.17	0.50	0.24	-0.25	2.25	2
6	-0.59	-0.92	-0.23	0.40	0.13	0.08	2.57	3
5	-0.44	-0.74	-0.13	0.80	0.20	0.34	2.83	4
2	-0.43	-0.71	-0.14	0.80	0.22	0.41	2.91	5
4	-0.38	-0.70	-0.05	1.60	0.29	1.90	4.40	6
8	-0.42	-0.77	-0.06	1.50	0.24	2.38	4.88	7
10	-0.44	-0.79	-0.11	0.70	0.26	3.10	5.59	8
17	-0.27	-0.62	0.07	5.50	0.41	5.44	7.94	9
9	-0.42	-0.82	-0.05	1.40	0.24	6.02	8.52	10
18	-0.39	-0.79	0.00	2.50	0.28	6.15	8.65	11
14	-0.26	-0.74	0.18	11.00	0.38	6.84	9.34	12
15	-0.36	-1.23	0.46	19.60	0.36	7.30	9.79	13
3	-0.19	-0.73	0.30	22.60	0.39	7.69	10.19	14
22	-0.50	-1.02	0.04	3.50	0.01	7.95	10.44	16
19	0.06	-0.32	0.42	64.20	0.15	8.04	10.53	17
25	0.15	-0.28	0.55	79.00	0.44	8.48	10.98	18
23	-0.44	-0.99	0.15	5.60	0.00	9.12	11.62	19
16	-0.23	-0.84	0.38	21.30	0.41	9.20	11.69	20
24	-0.40	-1.09	0.41	13.30	0.01	9.90	12.40	21
20	-0.19	-0.77	0.43	24.80	0.16	11.05	13.55	22
7	-0.06	-0.56	0.41	38.10	0.02	11.73	14.22	23

1	0.17	-0.31	0.65	76.50	0.52	12.10	14.59	24
13	0.04	-0.58	0.66	56.90	0.68	12.10	14.59	25
21	-0.16	-0.71	0.40	27.80	0.13	12.26	14.76	26

Table 13. Ranking and output statistics for models of interaction between discharge days >25<80m^{3}s^{-1} and escapement on Chum Salmon egg-to-fry recruitment in the BC Rail side channel.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.09	27.68	1.86	7
17	0.35	-0.27	0.96	86.90	0.33	25.82	0.00	1
9	0.36	-0.22	0.98	88.20	0.32	26.21	0.39	2
14	0.34	-0.31	0.98	85.40	0.30	26.90	1.08	3
18	0.32	-0.28	0.94	85.30	0.30	26.93	1.12	4
10	0.31	-0.31	0.94	83.40	0.27	27.27	1.45	5
2	0.29	-0.31	0.93	83.80	0.22	27.56	1.74	6
5	0.27	-0.33	0.88	81.30	0.22	27.83	2.01	8
6	0.27	-0.30	0.88	82.10	0.21	28.04	2.22	9
12	0.27	-0.35	0.89	80.90	0.19	28.38	2.56	10
16	0.26	-0.41	0.97	77.40	0.22	28.40	2.58	11
4	0.26	-0.34	0.89	79.80	0.20	28.54	2.72	12
11	0.30	-0.30	0.89	84.50	0.24	28.75	2.93	13
8	0.30	-0.33	0.94	83.20	0.22	28.79	2.97	14
3	0.21	-0.48	0.93	71.90	0.14	28.87	3.05	15
24	0.25	-0.38	0.88	79.70	0.15	29.05	3.23	16
15	0.20	-0.51	0.93	71.30	0.14	29.06	3.24	17
23	0.24	-0.40	0.89	77.80	0.15	29.28	3.46	18
1	-0.26	-0.95	0.43	21.60	0.12	29.48	3.66	19

22	0.16	-0.47	0.80	70.10	0.08	29.49	3.68	20
7	0.10	-0.62	0.85	61.40	0.08	29.83	4.01	21
13	0.05	-0.65	0.82	55.30	0.02	30.28	4.46	22
20	0.20	-0.48	0.87	72.70	0.10	30.58	4.77	23
19	0.13	-0.58	0.76	67.50	0.03	30.59	4.77	24
25	-0.06	-0.74	0.66	42.70	0.03	30.67	4.85	25
21	-0.05	-0.72	0.63	43.40	0.00	30.87	5.05	26

Adult-to-fry recruitment models with interaction

Table 14. Ranking and output statistics for models of interaction between discharge days >25<80m^{3}s^{-1} and escapement on Chum Salmon adult-to-fry recruitment across all habitat types (combined mainstem and side-channels).

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.54	22.74	8.86	6
23	-0.85	-1.31	-0.27	0.40	0.02	13.88	0.00	1
24	-0.80	-1.33	-0.02	2.30	0.02	15.18	1.30	2
20	-0.65	-1.22	-0.02	2.30	0.04	18.94	5.06	3
25	0.38	-0.17	0.96	92.40	0.72	19.92	6.04	4
22	-0.60	-1.21	-0.04	2.00	0.04	21.59	7.71	5
1	0.37	-0.23	0.98	88.90	0.46	24.27	10.39	7
2	-0.44	-0.90	0.06	3.70	0.26	26.01	12.13	8
6	-0.41	-0.84	0.08	4.60	0.32	26.17	12.29	9
12	-0.45	-0.97	0.11	5.00	0.18	26.43	12.55	10
21	-0.19	-0.93	0.39	28.80	0.72	26.65	12.77	11
8	-0.36	-0.83	0.16	6.80	0.21	27.00	13.12	12
11	-0.36	-0.84	0.19	7.30	0.27	27.58	13.70	13
15	-0.77	-2.12	0.59	10.90	0.17	27.71	13.83	14
10	-0.36	-0.87	0.17	7.40	0.38	27.92	14.04	15
5	-0.39	-0.84	0.09	4.50	0.25	28.77	14.89	16
4	-0.35	-0.83	0.20	8.30	0.32	28.85	14.97	17
14	-0.35	-1.07	0.38	13.90	0.25	28.90	15.02	18
18	-0.36	-0.90	0.24	8.80	0.38	29.29	15.41	19
13	0.14	-0.99	1.34	58.70	0.54	29.33	15.45	20
19	0.00	-0.70	0.65	51.40	0.54	29.44	15.56	21

17	-0.26	-0.84	0.36	16.10	0.33	29.67	15.80	22
3	-0.37	-1.30	0.55	18.50	0.24	29.75	15.88	23
7	0.08	-0.76	0.97	57.40	0.58	29.82	15.94	24
16	-0.38	-1.41	0.68	20.80	0.26	29.85	15.97	25
9	-0.40	-0.95	0.16	6.40	0.38	30.56	16.68	26

Table 15. Ranking and output statistics for models of interaction between discharge days >25<80m^3s^{-1} and escapement on Chum Salmon adult-to-fry recruitment in the mainstem Cheakamus River.

Covariate index (Base Ricker +)	**Coefficient estimate (γ)**	**Lower 95% CI**	**Upper 95% CI**	***prob.* γ > 0**	R^2	**DIC**	**ΔDIC**	**Model Rank**
Base Ricker	-	-	-	-	0.41	43.28	4.91	10
24	-1.29	-2.29	-0.20	1.10	0.20	38.38	0.00	1
15	-2.67	-4.73	-0.27	1.50	0.32	40.20	1.83	2
20	-1.23	-2.30	0.01	2.60	0.04	41.15	2.78	3
23	-1.26	-2.32	-0.14	1.70	0.11	41.17	2.79	4
9	-1.14	-2.25	0.01	2.60	0.57	41.94	3.56	5
22	-1.02	-2.02	0.00	2.40	0.51	42.06	3.69	6
25	0.70	-0.75	2.20	83.30	0.42	42.38	4.00	7
16	-1.81	-3.56	0.19	3.60	0.34	42.62	4.25	8
1	0.63	-0.71	1.88	83.70	0.23	43.04	4.66	9
10	-1.01	-2.05	0.14	3.90	0.55	43.35	4.97	4.97
14	-1.43	-2.77	-0.02	2.40	0.44	43.81	5.43	5.43
18	-1.23	-2.29	-0.13	1.80	0.59	44.25	5.87	5.87
12	-0.92	-1.95	0.12	3.90	0.70	44.80	6.43	6.43
6	-0.87	-1.83	0.18	4.30	0.65	44.87	6.50	6.50
7	-0.38	-2.47	1.54	34.10	0.36	45.09	6.71	6.71
21	-0.73	-1.90	0.38	9.60	0.59	45.20	6.83	6.83

13	-0.82	-3.08	1.47	22.80	0.31	45.37	7.00	7.00
4	-0.83	-2.07	0.46	9.50	0.44	46.18	7.80	7.80
8	-0.97	-2.02	0.21	4.80	0.39	46.29	7.92	7.92
17	-1.08	-2.31	0.17	4.60	0.44	46.42	8.04	8.04
11	-0.97	-1.99	0.08	3.40	0.51	46.84	8.47	8.47
2	-0.92	-2.10	0.31	6.40	0.41	47.02	8.65	8.65
5	-0.90	-2.03	0.30	5.70	0.44	49.26	10.88	10.88
3	-1.13	-3.22	0.91	12.30	0.29	50.09	11.72	11.72
19	-0.24	-1.76	1.22	37.10	0.17	51.39	13.02	13.02

Table 16. Ranking and output statistics for models of interaction between discharge days >25<80m^3s^{-1} and escapement on Chum Salmon adult-to-fry recruitment in the Cheakamus Centre side channel.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* $\gamma > 0$	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.26	10.40	2.64	3
25	0.19	-0.07	0.44	93	0.42	7.76	0	1
19	-0.15	-0.39	0.10	10.3	0.33	9.34	1.58	2
21	-0.16	-0.40	0.08	9.10	0.28	10.86	3.10	4
20	-0.12	-0.38	0.13	16.70	0.24	11.56	3.79	5
23	-0.10	-0.35	0.17	21.40	0.16	12.09	4.33	6
24	-0.10	-0.36	0.16	21.70	0.18	12.32	4.56	7
1	0.15	-0.10	0.39	87.80	0.39	12.37	4.60	8
14	0.08	-0.19	0.36	71.80	0.39	12.40	4.64	9
13	0.13	-0.16	0.41	82.10	0.46	12.52	4.76	10
3	0.14	-0.13	0.43	85.30	0.54	12.63	4.86	11
22	-0.12	-0.37	0.16	18.30	0.15	12.80	5.04	12
16	0.10	-0.18	0.38	77.60	0.47	12.82	5.06	13

4	0.02	-0.24	0.29	57.20	0.28	12.88	5.12	14
7	0.14	-0.14	0.42	85.00	0.53	12.94	5.17	15
5	-0.01	-0.28	0.26	44.90	0.11	13.03	5.27	16
8	0.00	-0.27	0.27	47.60	0.22	13.10	5.34	17
17	0.05	-0.20	0.32	63.60	0.28	13.16	5.40	18
2	-0.01	-0.28	0.27	47.60	0.11	13.17	5.41	19
6	-0.04	-0.31	0.24	36.80	0.06	13.20	5.44	20
12	-0.05	-0.32	0.21	36.00	0.12	13.30	5.54	21
9	0.03	-0.24	0.32	59.00	0.34	13.39	5.63	22
18	0.02	-0.25	0.30	55.30	0.32	13.46	5.70	23
11	-0.01	-0.28	0.27	45.40	0.19	13.46	5.70	24
10	0.01	-0.26	0.28	52.90	0.31	13.53	5.76	25
15	0.10	-0.20	0.42	74.10	0.48	14.26	6.50	26

Table 17. Ranking and output statistics for models of interaction between discharge days >25<80m^3s^{-1} and escapement on Chum Salmon adult-to-fry recruitment in the BC Rail side channel.

Covariate index (Base Ricker +)	**Coefficient estimate (γ)**	**Lower 95% CI**	**Upper 95% CI**	***prob.* γ > 0**	R^2	**DIC**	**ΔDIC**	**Model Rank**
Base Ricker	-	-	-	-	0.11	29.40	0.82	5
17	0.40	-0.11	0.88	94.70	0.29	28.58	0.00	1
14	0.36	-0.15	0.87	92.90	0.26	28.83	0.25	2
9	0.38	-0.12	0.87	93.60	0.26	28.98	0.40	3
2	0.33	-0.20	0.84	90.90	0.22	29.31	0.73	4
18	0.35	-0.20	0.88	91.00	0.24	29.47	0.89	6
4	0.30	-0.22	0.85	87.50	0.18	29.88	1.30	7
10	0.34	-0.17	0.87	91.60	0.23	30.00	1.41	8
6	0.30	-0.24	0.81	88.20	0.20	30.10	1.52	9

16	0.27	-0.26	0.80	86.10	0.18	30.23	1.65	10
5	0.34	-0.20	0.85	91.30	0.22	30.27	1.69	11
12	0.29	-0.25	0.86	86.70	0.18	30.37	1.79	12
11	0.32	-0.20	0.87	89.50	0.20	30.43	1.85	13
3	0.25	-0.30	0.78	84.20	0.15	30.54	1.96	14
1	-0.20	-0.77	0.34	21.80	0.11	30.72	2.14	15
24	0.23	-0.31	0.79	81.50	0.13	30.72	2.14	16
8	0.27	-0.27	0.82	86.30	0.17	30.87	2.29	17
15	0.23	-0.33	0.81	80.40	0.13	30.99	2.41	18
23	0.20	-0.35	0.80	76.60	0.10	31.17	2.59	19
7	0.17	-0.40	0.75	73.20	0.09	31.36	2.78	20
25	0.09	-0.52	0.65	63.80	0.05	31.44	2.86	21
19	-0.17	-0.78	0.49	25.50	0.09	31.50	2.92	22
21	-0.04	-0.64	0.55	44.10	0.06	31.54	2.96	23
22	0.17	-0.42	0.74	74.50	0.10	31.78	3.20	24
13	0.14	-0.42	0.75	70.50	0.07	31.88	3.29	25
20	0.08	-0.51	0.67	61.00	0.12	32.44	3.86	26

Egg-to-fry recruitment models with interaction

Table 138. Ranking and output statistics for models of interaction between discharge days >25<80m^{3}s^{-1} and escapement on Chum Salmon egg-to-fry recruitment across all habitat types (combined mainstem and side-channels).

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.53	24.24	6.40	5
23	-0.80	-1.38	-0.16	1.00	0.03	17.83	0.00	1
24	-0.80	-1.46	0.22	4.20	0.06	18.06	0.22	2
20	-0.67	-1.26	-0.06	1.70	0.01	20.17	2.34	3
25	0.40	-0.21	1.02	91.60	0.70	23.61	5.78	4
22	-0.60	-1.35	0.08	4.10	0.00	25.60	7.77	6
1	0.38	-0.25	1.04	89.40	0.44	26.21	8.38	7
6	-0.39	-0.89	0.14	6.30	0.24	29.19	11.35	8
5	-0.37	-0.87	0.17	6.90	0.22	29.60	11.76	9
10	-0.33	-0.86	0.24	9.80	0.34	29.99	12.15	10
8	-0.33	-0.87	0.21	9.60	0.16	30.34	12.50	11
9	-0.38	-0.94	0.17	7.30	0.37	30.35	12.52	12
21	-0.16	-1.03	0.58	33.10	0.67	30.37	12.53	13
11	-0.32	-0.84	0.24	10.20	0.21	30.39	12.56	14
16	-0.34	-1.46	0.86	25.20	0.25	30.42	12.58	15
13	0.26	-0.91	1.58	66.80	0.41	30.70	12.86	16
4	-0.33	-0.88	0.23	9.70	0.28	30.85	13.02	17
14	-0.34	-1.03	0.41	15.70	0.28	30.99	13.15	18
18	-0.32	-0.89	0.30	12.80	0.35	30.99	13.16	19
12	-0.42	-1.02	0.23	7.10	0.08	31.17	13.34	20
15	-0.78	-2.50	0.69	13.00	0.12	31.20	13.37	21

3	-0.44	-1.39	0.49	16.30	0.20	31.21	13.38	22
7	0.09	-0.87	0.99	58.90	0.58	31.24	13.41	23
19	0.00	-0.78	0.72	51.40	0.53	31.46	13.62	24
17	-0.23	-0.85	0.41	19.80	0.32	32.50	14.66	25
2	-0.42	-0.93	0.15	6.10	0.21	33.55	15.72	26

Table 149. Ranking and output statistics for models of interaction between discharge days >25<80m^3s^{-1} and escapement on Chum Salmon egg-to-fry recruitment in the mainstem Cheakamus River.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.39	40.94	5.40	9
15	-3.52	-5.84	-1.07	0.50	0.27	35.54	0.00	1
20	-1.87	-3.12	-0.63	0.40	0.00	37.32	1.78	2
23	-1.93	-3.24	-0.54	0.50	0.00	38.50	2.96	3
9	-1.25	-2.53	0.01	2.60	0.44	39.04	3.50	4
16	-2.25	-4.44	0.02	2.70	0.25	39.83	4.29	5
18	-1.23	-2.55	0.11	3.30	0.42	40.63	5.09	6
14	-1.59	-3.24	0.09	3.10	0.30	40.91	5.37	7
25	0.89	-0.78	2.60	86.50	0.43	40.92	5.37	8
3	-1.65	-3.73	0.53	6.40	0.19	41.63	6.09	10
22	-1.47	-3.16	0.27	4.10	0.01	41.72	6.18	11
10	-1.06	-2.44	0.34	5.80	0.37	41.94	6.40	12
24	-1.76	-3.20	0.92	6.50	0.01	42.23	6.69	13
17	-1.08	-2.68	0.52	7.90	0.25	42.81	7.26	14
13	-1.08	-3.99	1.68	20.10	0.20	43.40	7.86	15
11	-0.93	-2.39	0.52	9.30	0.25	43.47	7.92	16
1	0.81	-0.79	2.40	85.80	0.15	43.48	7.94	17

4	-0.92	-2.35	0.58	9.40	0.21	43.50	7.96	18
5	-0.87	-2.29	0.65	11.10	0.20	43.85	8.30	19
12	-0.79	-2.42	0.83	14.00	0.48	44.08	8.53	20
8	-1.02	-2.50	0.44	7.80	0.12	44.13	8.59	21
2	-0.97	-2.56	0.61	10.00	0.14	44.38	8.84	22
7	-0.59	-2.84	1.68	28.90	0.21	44.38	8.84	23
6	-0.80	-2.27	0.58	11.70	0.44	44.80	9.26	24
21	-0.94	-2.93	1.14	15.90	0.04	45.47	9.93	25
19	-0.59	-2.52	1.40	24.60	0.04	45.93	10.39	26

Table 20. Ranking and output statistics for models of interaction between discharge days >25<80m^{3}s^{-1} and escapement on Chum Salmon egg-to-fry recruitment in the Cheakamus Centre side-channel.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.31	7.80	10.30	15
12	-0.84	-1.23	-0.40	0.10	0.12	-2.50	0.00	1
11	-0.49	-0.81	-0.17	0.50	0.24	-0.25	2.25	2
6	-0.59	-0.92	-0.23	0.40	0.13	0.08	2.57	3
5	-0.44	-0.74	-0.13	0.80	0.20	0.34	2.83	4
2	-0.43	-0.71	-0.14	0.80	0.22	0.41	2.91	5
4	-0.38	-0.70	-0.05	1.60	0.29	1.90	4.40	6
8	-0.42	-0.77	-0.06	1.50	0.24	2.38	4.88	7
10	-0.44	-0.79	-0.11	0.70	0.26	3.10	5.59	8
17	-0.27	-0.62	0.07	5.50	0.41	5.44	7.94	9
9	-0.42	-0.82	-0.05	1.40	0.24	6.02	8.52	10
18	-0.39	-0.79	0.00	2.50	0.28	6.15	8.65	11

14	-0.26	-0.74	0.18	11.00	0.38	6.84	9.34	12
15	-0.36	-1.23	0.46	19.60	0.36	7.30	9.79	13
3	-0.19	-0.73	0.30	22.60	0.39	7.69	10.19	14
22	-0.50	-1.02	0.04	3.50	0.01	7.95	10.44	16
19	0.06	-0.32	0.42	64.20	0.15	8.04	10.53	17
25	0.15	-0.28	0.55	79.00	0.44	8.48	10.98	18
23	-0.44	-0.99	0.15	5.60	0.00	9.12	11.62	19
16	-0.23	-0.84	0.38	21.30	0.41	9.20	11.69	20
24	-0.40	-1.09	0.41	13.30	0.01	9.90	12.40	21
20	-0.19	-0.77	0.43	24.80	0.16	11.05	13.55	22
7	-0.06	-0.56	0.41	38.10	0.02	11.73	14.22	23
1	0.17	-0.31	0.65	76.50	0.52	12.10	14.59	24
13	0.04	-0.58	0.66	56.90	0.68	12.10	14.59	25
21	-0.16	-0.71	0.40	27.80	0.13	12.26	14.76	26

Table 21. Ranking and output statistics for models of interaction between discharge days >25<80m^3s^{-1} and escapement on Chum Salmon egg-to-fry recruitment in the BC Rail side-channel.

Covariate index (Base Ricker +)	Coefficient estimate (γ)	Lower 95% CI	Upper 95% CI	*prob.* γ > 0	R^2	DIC	ΔDIC	Model Rank
Base Ricker	-	-	-	-	0.09	27.68	1.86	7
17	0.35	-0.27	0.96	86.90	0.33	25.82	0.00	1
9	0.36	-0.22	0.98	88.20	0.32	26.21	0.39	2
14	0.34	-0.31	0.98	85.40	0.30	26.90	1.08	3
18	0.32	-0.28	0.94	85.30	0.30	26.93	1.12	4
10	0.31	-0.31	0.94	83.40	0.27	27.27	1.45	5
2	0.29	-0.31	0.93	83.80	0.22	27.56	1.74	6
5	0.27	-0.33	0.88	81.30	0.22	27.83	2.01	8

6	0.27	-0.30	0.88	82.10	0.21	28.04	2.22	9
12	0.27	-0.35	0.89	80.90	0.19	28.38	2.56	10
16	0.26	-0.41	0.97	77.40	0.22	28.40	2.58	11
4	0.26	-0.34	0.89	79.80	0.20	28.54	2.72	12
11	0.30	-0.30	0.89	84.50	0.24	28.75	2.93	13
8	0.30	-0.33	0.94	83.20	0.22	28.79	2.97	14
3	0.21	-0.48	0.93	71.90	0.14	28.87	3.05	15
24	0.25	-0.38	0.88	79.70	0.15	29.05	3.23	16
15	0.20	-0.51	0.93	71.30	0.14	29.06	3.24	17
23	0.24	-0.40	0.89	77.80	0.15	29.28	3.46	18
1	-0.26	-0.95	0.43	21.60	0.12	29.48	3.66	19
22	0.16	-0.47	0.80	70.10	0.08	29.49	3.68	20
7	0.10	-0.62	0.85	61.40	0.08	29.83	4.01	21
13	0.05	-0.65	0.82	55.30	0.02	30.28	4.46	22
20	0.20	-0.48	0.87	72.70	0.10	30.58	4.77	23
19	0.13	-0.58	0.76	67.50	0.03	30.59	4.77	24
25	-0.06	-0.74	0.66	42.70	0.03	30.67	4.85	25
21	-0.05	-0.72	0.63	43.40	0.00	30.87	5.05	26