Stave River Project Water Use Plan

Limited Block Loading as Deterrent to Spawning Monitor

Implementation Year 10

Reference: SFLMON-4

SFLMON-4: Limited Block Loading as Deterrent to Spawning Monitor Escapement Analysis

Study Period: October 2005 – November 2014

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SFLMON-4 Limited Block Load as Deterrent to Spawning

Stave River, BC

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Executive Summary

This report consists of the final installment of the analysis of limited block loading as a deterrent to spawning of Chum Salmon adults in the lower Stave River below Ruskin Dam. Expanding upon earlier limited block loading observations which explored detailed sets of hypotheses surrounding spawning deterrence at high elevation redd locations (Troffe and Ladell 2007), we collated annual Inch Creek Hatchery - Fisheries and Oceans Canada Lower Stave River Chum Salmon spawner escapement as a relative index of spawner abundance. We evaluated the hypothesis that Chum Salmon escapement has not changed since the introduction of the fall limited block loading strategy as a part of the Lower Stave Water Use Plan in 2004. The ability of the partial peaking strategy to assist in sustaining a healthy Chum Salmon population was investigated. A new area under the curve method was used to calculate annual abundance and its associated variance. Overall Chum Salmon escapement has been in decline since 2000 and escapement trends in the Lower Stave River mirror those seen in other Lower Fraser River watersheds. We were unable to find convincing evidence that operational parameters (discharge, tailrace elevation, etc.) are strongly linked to Chum escapement. Our results provide evidence that the limited block loading strategy implemented over the past 10 years may be providing some mitigation to reduce high elevation spawning and its associated detrimental effects on Chum escapement. However, there are too many other factors and uncertainty to definitively determine if fine scale changes to operations significantly affect escapement.

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Peter Troffe – Triton Environmental; Darin Nishi - BC Hydro; Dave Hunter - BC; James Bruce - BC Hydro (Ret.); Kim Meidal - BC Hydro; Lynne Campo - Water Survey Canada; Stu Barnetson - Fisheries and Oceans Canada - Inch Creek Hatchery; Glen Dixon - Fisheries and Oceans Canada - Inch Creek Hatchery; Mike Landiak – Fisheries and Oceans Canada; Peter van Will – Fisheries and Oceans Canada.

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Ladell, J., and A. Putt. 2015*. Lower Stave River Limited Block Load as Deterrent to Spawning Monitor – Escapement Reporting (1999-2014), Technical report for BC Hydro – Environmental Risk Management. 52 p.*

1.0 INTRODUCTION

1.1 Background

Since 1980, a number of initiatives have been undertaken to improve the escapement of lower Stave River Chum Salmon adults downstream of Ruskin Dam. The number of adult salmon returning to the river has experienced a 7-fold increase from its 1960-1984 average of just 44,000 individuals (Figure 2). These initiatives have included a hatchery release program to supplement smolt out-migration, a Fraser River exploitation reduction program, and a habitat restoration program which more than doubled the area of spawning habitat in the lower river. Since 1990, Fisheries and Oceans Canada with BC Hydro and other partners have worked to rehabilitate ~60,000 square metres of salmon spawning habitat by recontouring and re-grading the gravel beds below Ruskin Dam (Mike Landiak – DFO, pers. comm.).

In addition to these activities, a flow regime was implemented by BC Hydro that restricted the fluctuation of downstream water levels during the chum spawning and incubation periods (Bailey 2002). The objective of the regime was to minimize the risk of adult and redd stranding. However, these restrictions implemented in 1999 were costly in a power generation capacity as they removed considerable flexibility in plant operations which was previously used to match periods of peak power demand.

During the WUP process, an alternate plant operating strategy was proposed. This strategy was designed to take advantage of the initial test digging behaviour and subsequent egg laying patterns of Chum Salmon and utilize this to minimize the risk of redd stranding. This in turn reintroduced some flexibility in power generation during the spawning and incubation periods. The underlying premise of the strategy was to maintain a relatively high base water level during the spawning and incubation periods such that most of the available spawning habitat was continuously usable and relatively free from the risk of future stranding during the incubation period.

Hydraulic simulation modeling found that a constant release of 100 m^3/s was sufficient for this purpose as it allowed most of the spawning habitat to be underwater by at least 10 cm and was sustainable during the spawning and incubation periods in most years. Above the 100 m^3/s base release, all restrictions to generation were removed, allowing plant releases to vary as needed to meet power demands and manage the supply reservoir levels. Because of the contoured banks of the river, a direct result of habitat restoration efforts, the Consultative Committee (CC) accepted the notion that such variable flows would not severely impact the spawning population. Stave River hydraulic modeling indicated that the vast majority of the spawning habitat was located below the 100 m^3/s watermark, and field observations indicated that the variability in velocities would be within tolerance limits of the population.

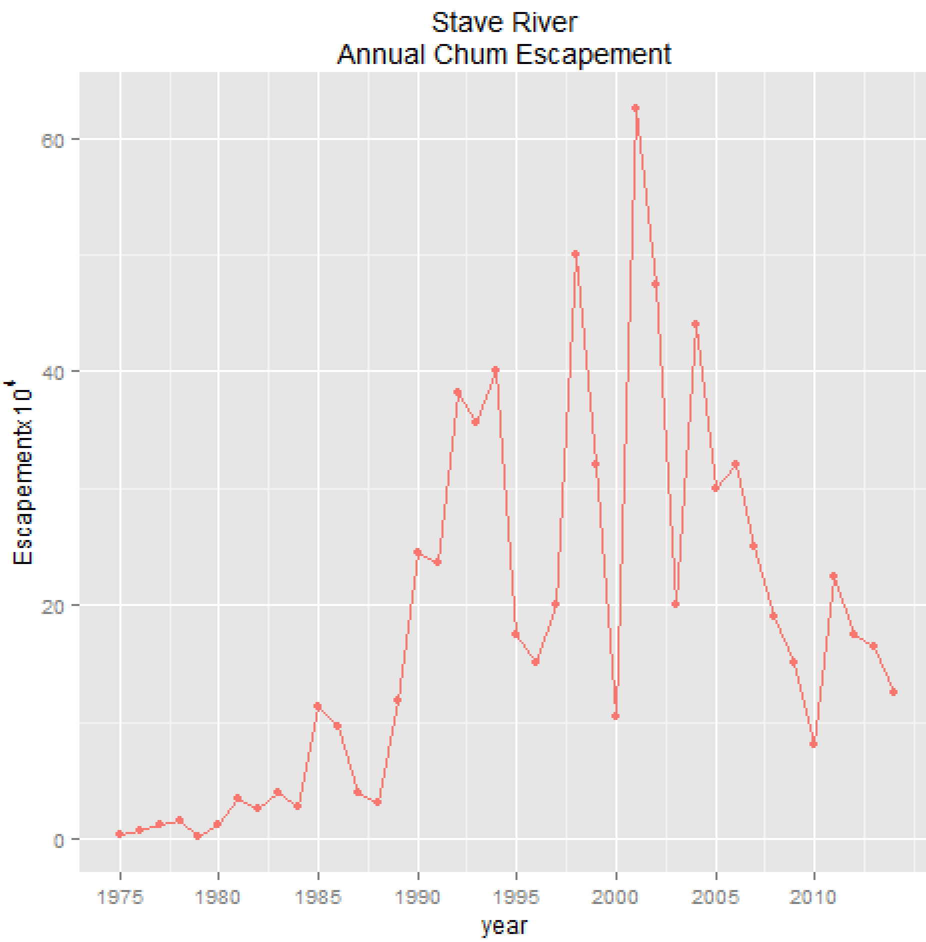

Figure 1. Inch Creek Hatchery (Fisheries and Oceans Canada) adult Chum Salmon spawning escapement estimates for the lower Stave River, 1975 through to 2014. Annual counts are based on weekly aerial surveys conducted during the late September through early December spawning period.

In fact, the CC adopted the view that variability in flows above 100 m^3/s would in the long run be beneficial to fish production, the rationale being that pulsed flows would deter Chum Salmon from spawning in habitats that are susceptible to dewatering during incubation (Failing 1999).

Studies that support the assertion that peaking flows (in this case flows between 100 m^3/s and 325 m3/s for periods of 4 or more hours) can deter spawning appear limited but are documented. Of three publications referenced, two were reported from the Columbia River (Bauersfeld 1978, Chapman et al. 1986), and the other in New Zealand (Hawke 1978). All of these studies were concerned with Chinook Salmon spawning. At the time of project inception, whether these results could be extended to other Pacific salmonids was unknown. In the absence of data to the contrary for WUP purposes it was assumed that this was indeed the case and the concept of ‘partial peaking’ was adopted as part of the Combo 6 WUP operating strategy recommended by the CC, provided that a monitor was carried out to verify results.

1.2 Management Questions

The intention of this monitor is to determine whether the limited block loading strategy adopted in the WUP process has been successful in maintaining healthy Chum Salmon populations relative to the pre-WUP ‘full’ block loading strategy. Historic escapement estimates for Stave River Chum Salmon suggest that the system has the potential to reach its full carrying capacity of 220,000 spawners (Bailey 2002). An increase in average escapement under post-WUP operations is not expected, largely due to the limiting effects of redd super-imposition on potential fry yield. Instead, a more appropriate indicator of success would be non-declining average adult spawner escapement (allowing for external influences including exploitation and marine survival) and non-declining juvenile fry production.

Operating conditions similar to limited block loading operations were imposed immediately after 1999 WUP discussions; however, a number of periods of unrestricted fall peaking and spilling (>100 m^3/s for >12 hrs) occurred from 1999 to 2001 during the spawning period and during a portion of 2006 and 2009 (Table 1). From 2004 to present (excluding 2006 and 2009 spills), fall limited block loading operations have been implemented without unrestricted fall peaking operations. Given the historic age structure of the Stave River spawner population (22.7% Ocean 3, 68.2% Ocean 4, and 8.9% Ocean 5 spawners; data on file: Inch Creek Hatchery), the first of the dominant Ocean 4 cohort of spawners from the 1999-2003 broods returned during fall 2004 to 2008 (Table 2). Post-WUP (mostly partial block loading influenced) Ocean-4 returns would have returned to the lower Stave River after 2007.

Limited block loading operations have the potential to directly impact spawning Chum Salmon by causing nest abandonment and altered redd site selection (Harnish et al. 2013). Daily flow manipulations can result in the loss or persistent relocation of quality spawning habitat, resulting in spawning occurring in more marginal areas. In addition, flow manipulations affect local water depth and velocity, possibly resulting in hydraulic conditions outside tolerance limits of spawning Chum Salmon. The effect of unsuitable hydraulic conditions on spawning is very difficult to determine due to the potential for both acute effects and cumulative effects of multiple flow alterations across the spawning period. While considering the limited block load strategy during the WUP process, the consultative committee assumed that hydraulic conditions in mid-channel spawning grounds and key gravel bars would remain within acceptable tolerance limits; however, this assumption was not verified and was based primarily on anecdotal information. If the impact of high flows is severe and detrimental to spawning in these key areas, the partial block loading operating strategy may actually have a detrimental effect on Stave River Chum Salmon populations.

Another effect of flow manipulations on Chum Salmon is the potential for stranding of both adult fish prior to spawning and juvenile salmon during the rearing period (Harnish et al. 2013). Rapid depth fluctuations can isolate adults and juveniles in changing stream margins and side channels, and can result in mortality if flow is not restored within an appropriate time frame. Repeated flow fluctuations may also affect rearing juvenile salmon due to indirect effects on food availability, diversity, and density. These effects fall outside the scope of this monitor; however, adult stranding is reported (SFLMON-5 Risk of Adult Stranding) separately by Troffe and Ladell (2007) and juvenile stranding (SFLMON-6 Risk of Fry Stranding) by Troffe and McCubbing (2009).

Table 1. List identifying the pre- (prior to 2004) and post- (2004 to present) water use plan operation schedules for BC Hydro's Ruskin facility during the Fall Block Loading period (15 October – 30 November) and concurrent Chum Salmon incubation period.

Ruskin WUP Operation (2004 – 2014)
(1.1) Fall Block Loading (15 Oct – 30 Nov) - min tailwater of 1.8 m (~70 100 m^3/s) (1.1.1) Discharges from RUS less than or equal to 100 m^3/s To avoid impacting habitat for spawning salmon, discharge from RUS GS may be held constant or increased during the period 15 October – 30 November. Once flows are increased, they may not be decreased while discharge is less than 100 m^3/s. An increase may be initiated only once every 7 days or more and must be conducted over a period of 4 hours or less. (1.1.2) Discharges from RUS greater than 100 m^3/s To keep salmon from spawning in habitat above 100 m^3/s, discharge from RUS GS must be reduced to 100 m^3/s every 12 hours or less. The duration of the flow reduction must be 1 hour or greater and may include ramp down time. Ramp down rates are restricted to 113 m^3/s or less every 30 minutes.
Ruskin Pre-WUP Operation (prior to 2004)
(i) At all times maintain a minimum tailwater elevation of 1.57 m immediately downstream of Ruskin Powerhouse. (ii) During the salmon spawning period, between 15 October and 30 November, discharges from RUS must be blocked (no load factoring) on a weekly basis. During this period the block release can be changed once a week and must remain at that loading for the duration of the week unless an agreement can be reached with DFO and MELP or an emergency is encountered. Between 15 October and 31 October RUS can be block loaded between 10 MW (~50 m^3/s) and 40 MW (~140 m^3/s) and for the month of November RUS can be block loaded between 20 MW (85 m^3/s) and 40 MW. DFO and MELP have to be notified prior to setting block loads between 40 MW and 60 MW (200 m^3/s) during the spawning period (15 Oct - 30 Nov). Loads above 60 MW must be negotiated with DFO and MELP before implementation. (iii) During the fish incubation period from 1 December to 15 May, for one hour every day, a flushing flow equal to or higher than the maximum blocked release during the spawning period has to be provided.

Table 2. The years with spawners from pre-WUP broods (yellow), and those years post-WUP (green) with spawner broods which experienced block loading conditions during both spawning and incubation.

Spawning Year	Adult Return Year (Adult Return Age 3)	Adult Return Year (Adult Return Age 4)
1999	2002	2003
2000	2003	2004
2001	2004	2005
2002	2005	2006
2003	2006	2007
2004	2007	2008
2005	2008	2009
2006	2009	2010
2007	2010	2011
2008	2011	2012
2009	2012	2013
2010	2013	2014
2011	2014	2015
2012	2015	2016
2013	2016	2017
2014	2017	2018

1.3 Impact Hypothesis

This monitor will focus on determining the success of the post-WUP partial block loading strategy in sustaining annual escapements of Chum Salmon through the following hypothesis:

H_0: Chum Salmon escapement at the lower Stave River does not change following introduction of the partial block loading strategy during the spawning period.

1.4 Key Water Use Decisions Affected

The key water use decision affected by this monitor is whether to continue, modify, or abandon the limited block loading strategy. This operating strategy has not previously been applied in British Columbia, and its use has been limited to a small number of systems in the Pacific Northwest (Bauersfeld 1978). If partial block loading is found to successfully maintain adult yields of Stave River Chum Salmon, it may be continued in the Stave River and potentially expanded to other systems in British Columbia. Conversely, if this monitor finds evidence that the reproductive success of Chum Salmon has been negatively impacted by partial block loading, the operating regime may be modified or abandoned in the Stave River system.

2.0 Methods

2.1 Stave River Escapement Estimates

Observed and estimated spawning Chum Salmon numbers were obtained from weekly Fisheries and Oceans Canada helicopter surveys of the Lower Stave River system and used in AUC estimation. We assumed that DFO used a standard trapezoidal area-under-the-curve (AUC) method to calculate escapement for a Chum. Residence time and observer efficiency are key components in the AUC estimate of escapement.

We were not able to determine the values of observer efficiency and survey life used by DFO to model Chum Salmon escapement in the Stave River. Currently, DFO assumes 100% observer efficiency for most counting flights (Trouton 2004) and survey life was 7 days (Grant et al. 2007) for all years of estimation. Given the lack of detail in the escapement information provided by DFO and the critical importance of Chum Salmon escapement to this monitor we calculated our own escapement estimates using current methods

Chum Salmon escapement in the Stave River (1998 to 2014) was estimated using an Area Under the Curve (AUC) model, where escapement is modelled as a quasi-Poisson distribution with normally distributed arrival timing (Miller et al. 2011). The number of observed spawners at time *t* (C_t) is estimated as

1) $$C_t = a\ exp\left[-\frac{(t-m_s)^2}{2\tau_s^2}\right]$$

where *a* is the maximum height of the spawner curve, m_s is the time of peak spawners, and t_s is the standard distribution of the arrival timing curve.

Because the normal density function integrates to unity, the exponent term in equation 1 becomes $\sqrt{2\pi\tau_s}$ and equation 1 can be simplified to

2) $$C_t = a\sqrt{2\pi\tau_s}$$

The final estimate of escapement (*E*) is obtained by applying observer efficiency (*v)* and survey life (*l*) to the estimated number of observed spawners

3) $$\hat{E} = \frac{\hat{C}_t}{l * v}$$

E in equation 3 is estimated via maximum likelihood, where $\hat{a}$ and $\hat{\tau}$ are the ML estimates of *a* and *t* in equation 2.

The AUC model in equation 1 can be re-expressed as a linear model, allowing the estimation to be performed as simple log-linear equation with an over-dispersion correction factor. The over-dispersion correction accounts for instances where the variance of the observations exceeds the expected value. The log-linear model is computationally simple and can be completed using standard generalized linear modelling software, making it appropriate for use in this monitor.

2.2 Escapement Comparisons among Fraser River Chum Populations

The difference in average Stave River spawner escapement before and after 2008 (i.e., the first cohort affected by post-WUP partial block loading) was evaluated using a Welch's two-sample t-test. Time series' of escapement for other Fraser River Chum Salmon populations were obtained from Fisheries and Oceans Canada. Fraser River stocks selected for comparison were those with escapement greater than 5,000 spawners and less than 4 years of missing escapement estimates. Welch's t-test's were performed on Fraser River stocks to determine if stocks throughout the Fraser River experienced parallel changes in escapement before and after 2008. Variables used in parametric tests were assessed for normality and equal variances. Because a majority of variables used for testing were characterized by heterogeneous variances, the Welch's t-test (robust to unequal variances) was used to compare sample means.

The correlation between escapement in Stave River and other Fraser River stocks was assessed using linear regression. Regressions were performed on the entire time series (1999-2014) and on the two pre- and post-WUP time series (2003-2007 and 2008-2014, respectively). Pre- and post-WUP regressions may indicate whether escapement trends in the Stave River system diverged from those of stocks throughout the Fraser River following the partial block loading implementation. Post-WUP data is limited to 7 years of escapement estimates and regression analyses during this time period may therefore be limited.

2.3 Modelling Stave River Environmental Variables and Adult Returns

Environmental variables were compiled for the Stave River system to determine if adult returns of Chum Salmon are associated with parallel changes in physical conditions and/or dam operations. The variables identified as potential model inputs are described in Table 3. Welch's two-sample t-tests were performed on each of the environmental variables to compare mean values before and after changes to WUP operation (i.e., 1999-2003 and 2004-2014).

A Pearson's correlation matrix (Bonferonni-corrected) was used to identify correlated environmental variables and select variables for multiple linear regression modelling. In the case of correlated variables, the variable explaining the greatest amount of variation in brood year escapement was used in the regression modelling. Individual linear regressions were used to determine whether changes in escapement were associated with changes in each of the selected variables. A multiple regression analysis was then used to examine the range of influences river variables and brood year escapement may have on future Ocean age-4 spawner escapement.

A regression tree analysis was also used to determine which of the environmental variables had the greatest ability to predict return escapement of Stave River Chum Salmon. Regression trees recursively partition data into groups based on explanatory variables. At each node, the data are split into two homogeneous groups based on rules related to the explanatory variables (e.g., mean discharge greater or less than 100 m3/s). The splitting process continues until further branching fails to produce statistically significant groupings in the response variable. We fit a regression tree to the Stave River data using the rpart package in R Project (Therneau et al. 2015), which partitions data based on the value of the explanatory variable that results in the greatest between-group sum of squares in ANOVA testing.

Table 3. Environmental variables and operational variables identified as potential inputs for multiple linear regression of adult returns of Stave River Chum Salmon. All variables are calculated for October 15 to November 30.

Variable	Variable description	Data Source	Spario-Wilk (p)
esc	Stave River spawner escapement (brood year assuming 4-year life cycle)	Estimated in this report	0.18
Log(RQ.u)	Mean turbine discharge from Ruskin Dam. Represents an index of total power generation. Log transformed to reduce heteroscedasticity of residuals.	BC Hydro	0.07
RQ.sd	Standard deviation (variation) in Ruskin Dam discharge. Represents an index of variability of discharge.	BC Hydro	0.98
RQ.cv	Coefficient of variation (variation scaled by mean) of Ruskin Dam discharges	BC Hydro	0.74
TE.u	Mean elevation of Ruskin Dam tailrace	BC Hydro	0.87
TE.sd	Standard deviation (variation) of Ruskin Dam tailrace elevation	BC Hydro	0.67
TE.cv	Coefficient of variation (variation scaled by mean) of Ruskin Dam tailrace elevation	BC Hydro	0.67
FRQ.u	Mean discharge of Fraser River at Hope	Water Survey of Canada	0.72
FRQ.sd	Standard deviation (variation) of Fraser River discharge at Hope	Water Survey of Canada	0.76
FRQ.cv	Coefficient of variation (variation scaled by mean) of Fraser River discharge at Hope	Water Survey of Canada	0.37
RQ.100	Count of the number of days with discharge greater than 100 cms	Calculated using BC Hydro discharge	0.003*

3.0 Results

3.1 Stave River Escapement Estimates

Hatchery supplementation to the lower Stave River by Inch Creek Hatchery (DFO), started in 1982, was terminated after the 1997 brood year. It is estimated that 1999-2003 returns received between 30,000 to 65,000 hatchery raised returns distributed among the Ocean 3 to Ocean 5 cohorts (Bailey 2002, Stu Barnetson pers comm.).

Stave River Chum Salmon escapement was estimated for the years 1999 to 2014 by both InStream Fisheries using the methods described in this monitor, and by DFO (Figure 2). Stave River escapement estimates suggest escapement has been highly variable over the past 15 years, ranging from ~60,000 spawners in 2010 to over 450,000 spawners in 2001. Average escapement from 1999 to 2014 was ~209,000 spawners, with a standard deviation of ~118,000 spawners. DFO estimates the carrying capacity of the Stave River to be 220,000 spawners (Bailey et al. 2005).

According to escapement estimates, carrying capacity was exceeded in the Stave River system in 1999 and from 2001 to 2006, but there has been an overall decline in Stave River Chum Salmon escapement since the early 2000's. Average Chum Salmon spawner escapement for adult progeny of the post-WUP broods (i.e. 2008-2014 escapement; 119,559 spawners) was significantly less (Welch's t-test, p=0.002) than for adult returns affected by the full block loading operations (2003 – 2007 escapement; 275,521 spawners).

Stave River escapement estimated by InStream Fisheries in this report and as reported by the DFO were significantly correlated (R^2=0.734, p=9.0e^{-05}). DFO estimates were, on average, higher than those estimated by IFR (Figure 2); however, mean DFO escapement was not significantly greater than IFR estimates (Welch's t-test, p=0.180).

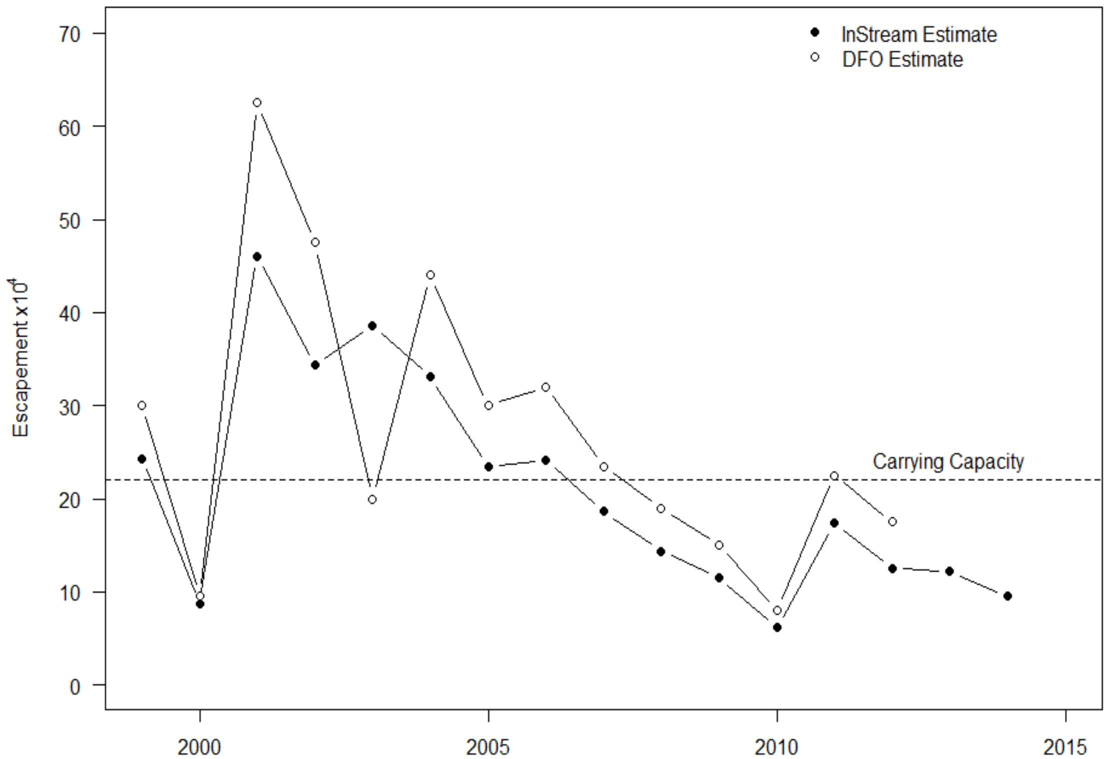

Figure 2. Chum Salmon escapement (1999-2014) in the Stave River estimated by InStream Fisheries Inc. and DFO.

3.1 Escapement Comparisons among Fraser River Chum Populations

Estimated escapement for Chum Salmon stocks in the Lower Fraser Area has been highly variable from 1999 to 2012 (Figure 3). The coefficient of variability (*cv*, the standard deviation scaled by the mean escapement) of Stave River escapement (estimated in this report) was 56% from 1999 to 2014. Similar variability in Chum Salmon escapement occurred in other Fraser River stocks: the *cv* for Chilliwack River Chum Salmon (1999-2012) was 52%, Inch Creek was 45%, and Harrison River was 58%. Historic coast-wide total commercial Chum Salmon catches from British Columbia as reported by DFO were also highly variable during the same time period (*cv* 69%) (DFO Commercial catch statistics 2011; McCubbing et al. 2012; Troffe et al. 2007-2009).

Stave River Chum Salmon escapement was significantly correlated with escapement from Chilliwack River, Harrison River and Inch Creek, as well as with coast-wide commercial catch estimates (Figure 4 & Table 4). Average escapement from 2003-2007 was significantly higher than 2008 to 2012 for all stocks listed in Table 4 (with the exception of Harrison River, $p=0.064$), further suggesting that all Fraser River stocks have been declining in parallel with the Stave River stock (Figure 5). Correlations were also examined between Stave River escapement and Fraser River escapement separated into pre- and post-WUP time periods (Table 4). According to linear modelling results, the change in correlation strength for pre- and post-WUP analyses were not consistent amongst stocks.

Table 4. Correlations between Stave River Chum Salmon escapement and escapement from Fraser River stocks over three time periods: all years, pre-WUP, and post-WUP.

		All Years (1999-2012)		Pre-WUP (2003-2007)		Post-WUP (2008-2012)	
Stock	**Pearson's Corr p (Bonferroni adj)**	R^2	**p**	R^2	**p**	R^2	**p**
Chilliwack River	0.399	0.407	0.019	0.088	0.627	0.641	0.200
Harrison River	0.012	0.642	0.001	0.338	0.304	0.110	0.586
Inch Creek	0.001	0.761	0.000	0.519	0.170	0.824	0.033
DFO Commercial Catch	0.093	0.504	0.004	0.739	0.062	0.673	0.089

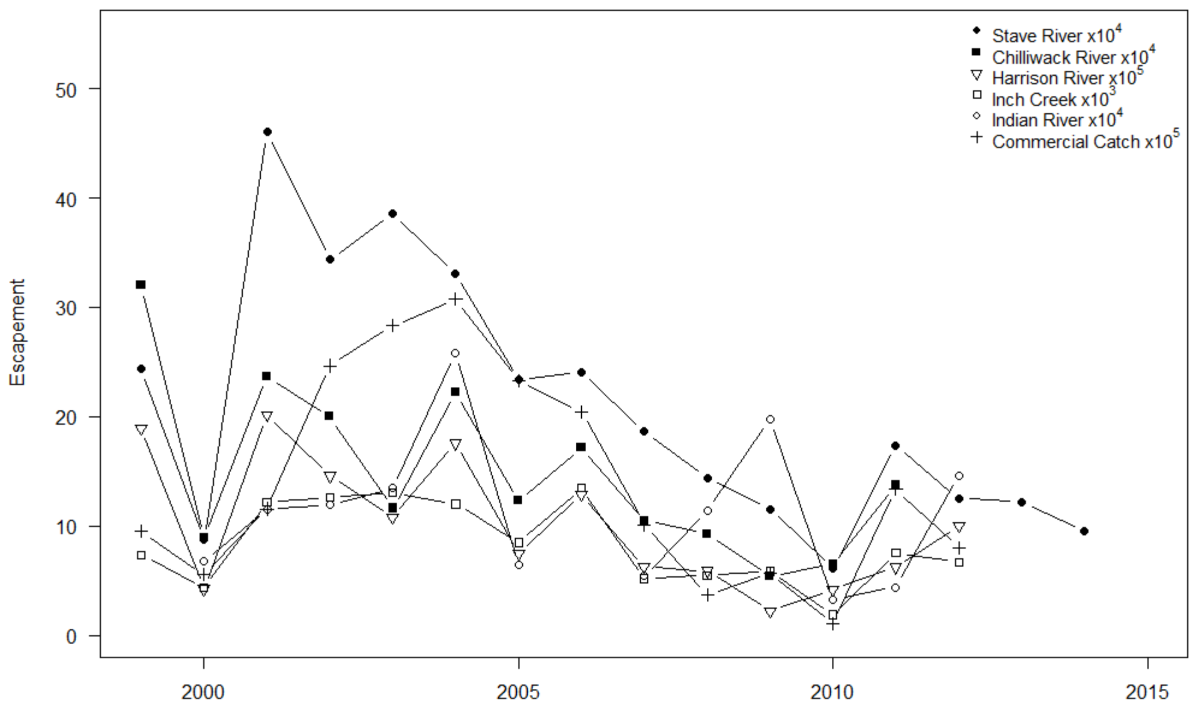

Figure 3. Regional escapement (1999-2014) for Lower Fraser River Chum Salmon and DFO commercial catch.

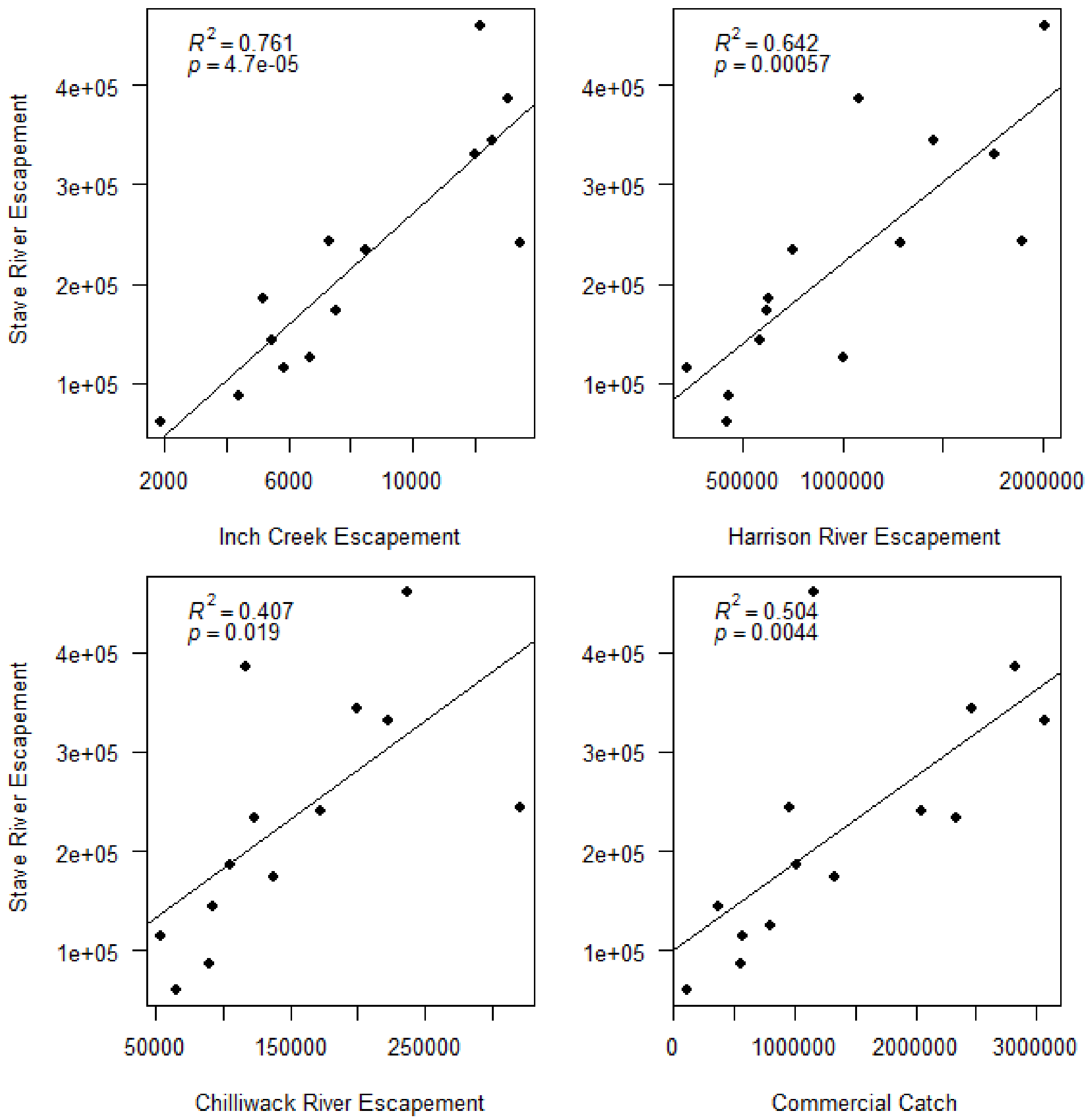

Figure 4. Linear model correlations between Stave River escapement and escapement of Fraser River stocks from 1999 to 2012.

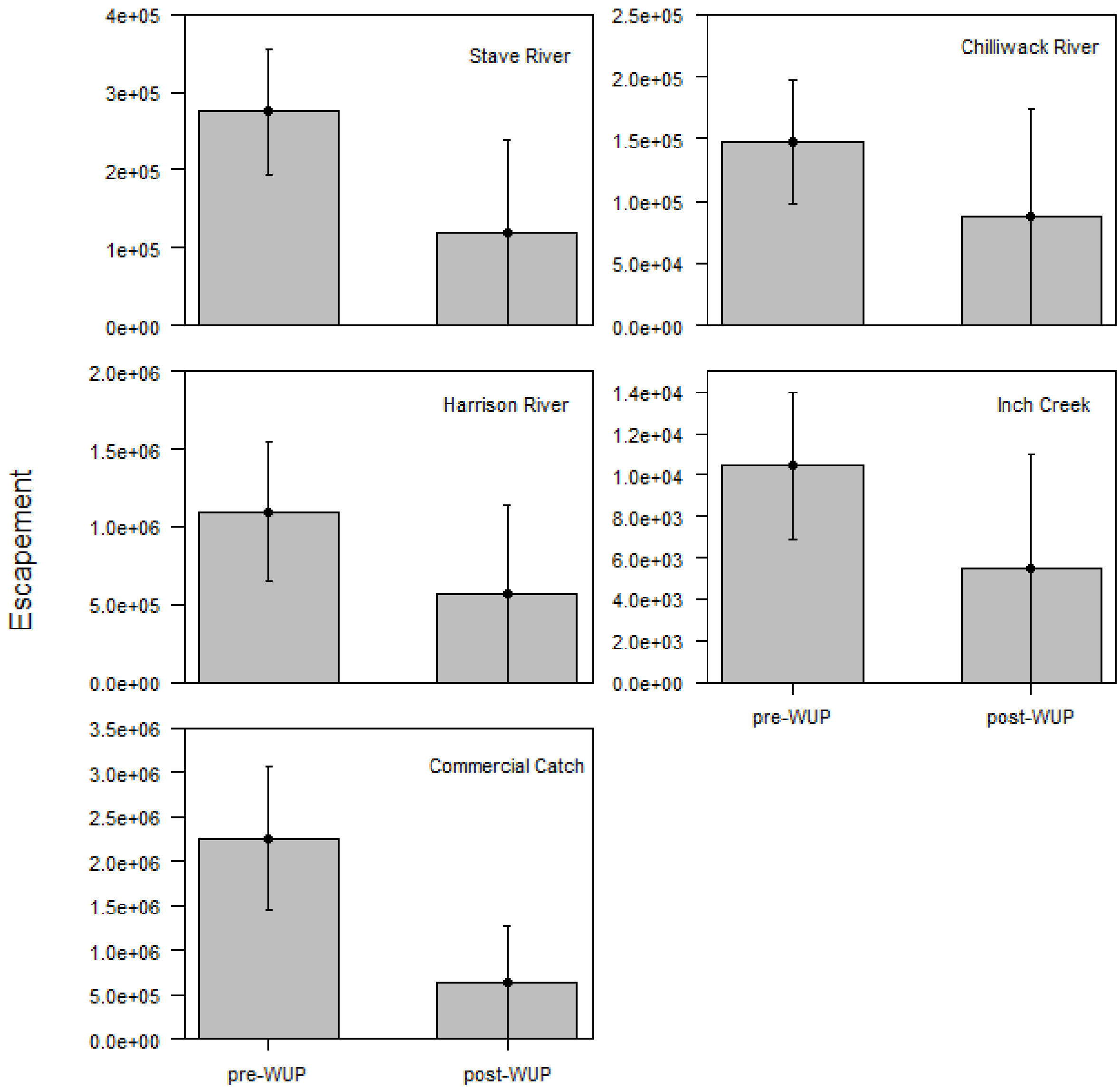

Figure 5. Pre-WUP (2003-2007) and post-WUP (2008-2012) mean escapements for Fraser River Chum Salmon stocks.

3.2 Stave River Environmental Variables

3.2.1 Ruskin Dam Turbine Discharge

Profiles of Ruskin Dam turbine discharge (Figure 6 & Figure 7) show daily fluctuations in discharge during the spawning period (October 15 to November 30). Pre- and post-WUP conditions are not entirely consistent between years due to anomalies in operating procedures. Operating conditions similar to block loading were imposed in 1999 immediately after the WUP discussions; however, some periods of unrestricted fall peaking and spilling (>100 m^3/s for >12 hrs) occurred during the spawning period in 1999-2003, and spilling also occurred during a portion of 2006 and 2009. For spawning periods from 2004-2014 (excluding short spill periods in some years), fall block loading operations were fully implemented without unrestricted fall peaking operations.

A significant difference was found between average pre- and post-WUP Ruskin Dam turbine discharge in previous monitor reports (Ladell and McCubbing 2013); however, with the addition of 2013 and 2014 data (Figure 8) there was no significant difference between mean discharge in the two time periods (Welch's two-sample p=0.830) (Figure 9). There was also no statistical difference in the average standard deviation of turbine discharge, the average coefficient of variation of turbine discharge, and the total number of days with discharge >100 m^3/s between the two time periods (p=0.590, p=0.327, and 0.907, respectively).

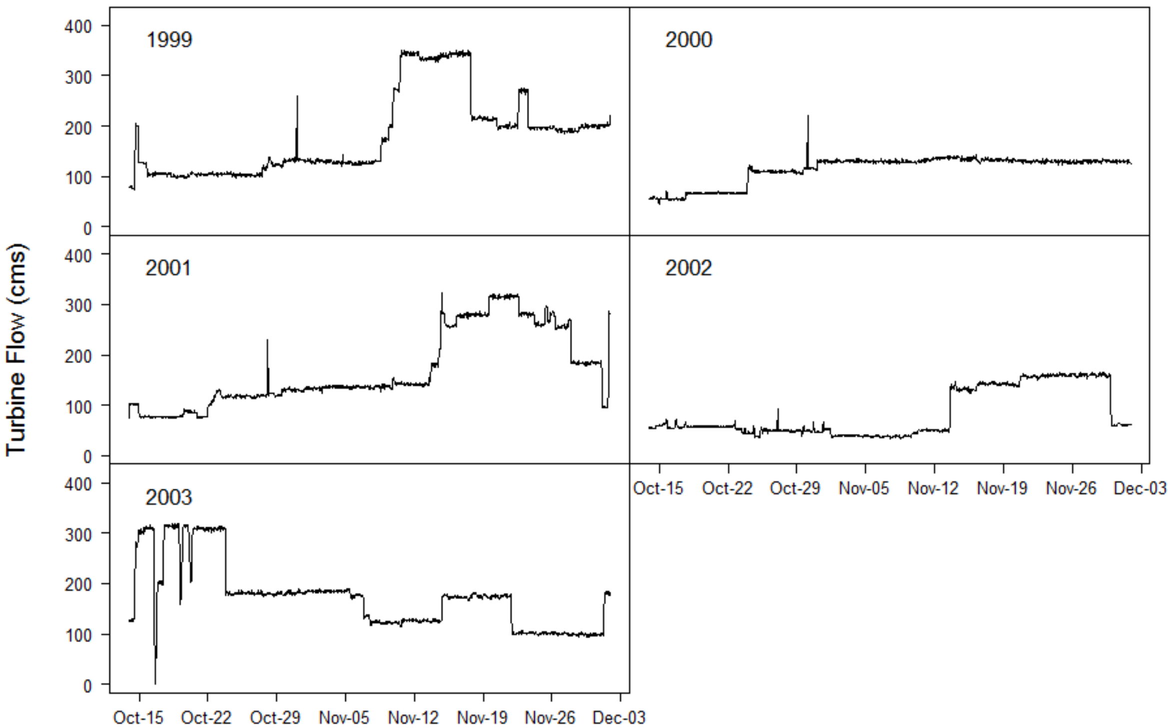

Figure 6. Hourly Ruskin discharge (m^3/s) profile during Chum Salmon spawning season (October 15 – November 30) for years 1999 – 2003 (pre-WUP operations)

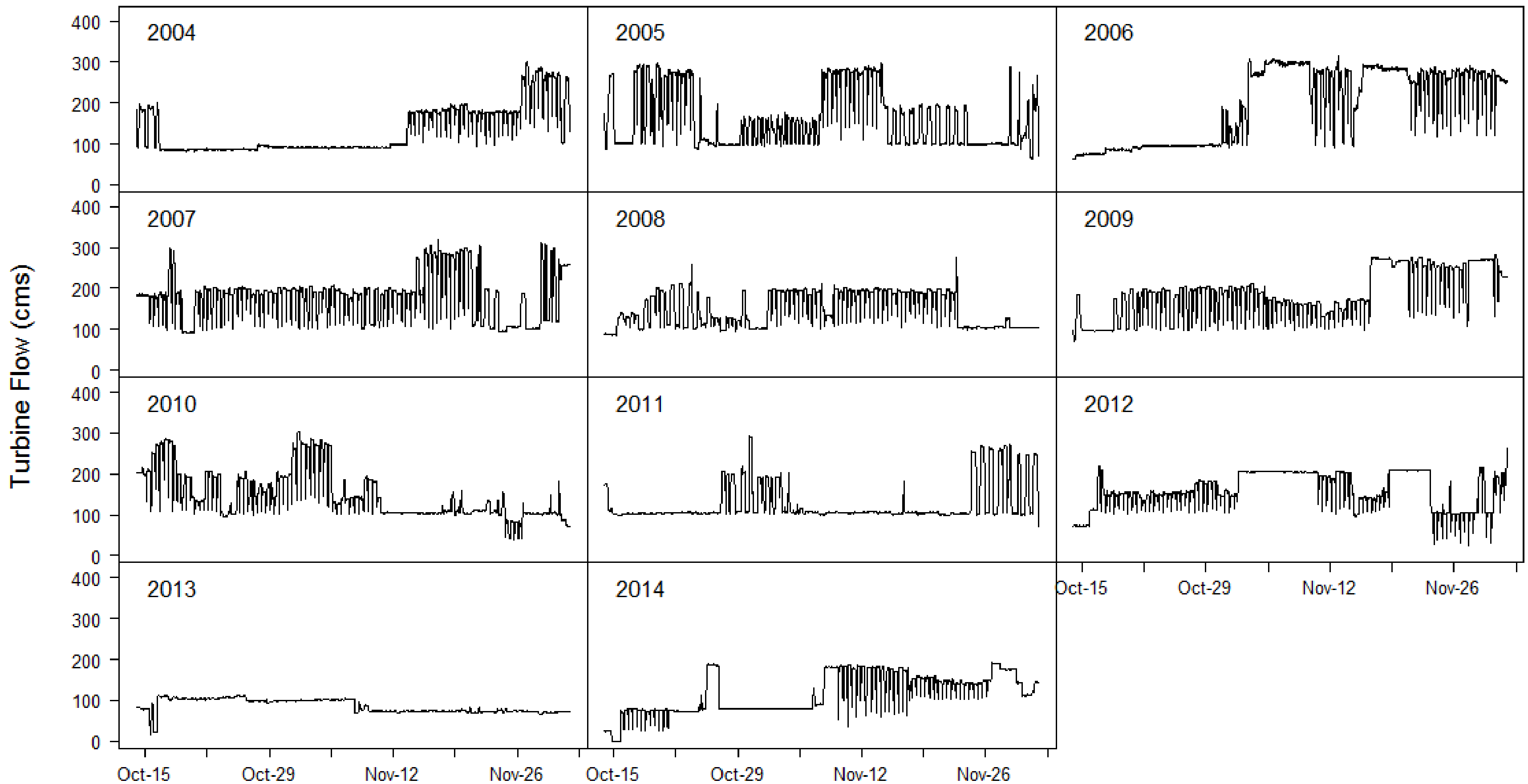

Figure 7. Hourly Ruskin discharge (m^3/s) profile during Chum Salmon spawning season (October 15 – November 30) for years 2004 – 2014 (post-WUP operations)

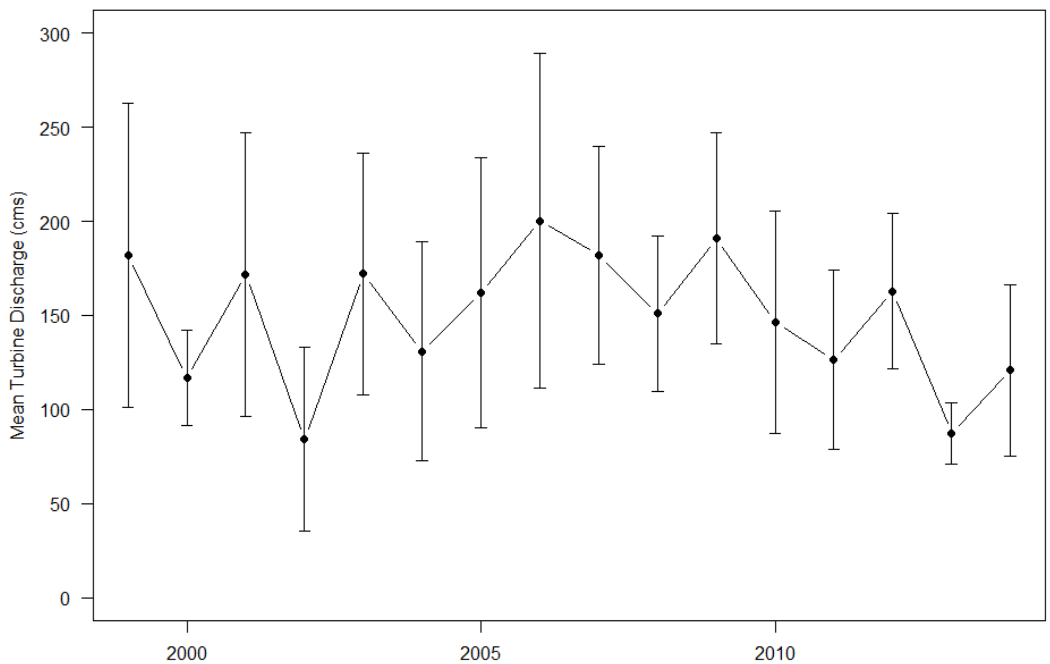

Figure 8. Average yearly (±S.D.) Ruskin discharge profile during Chum Salmon spawning season (October 15 – November 30) for years 1999-2014

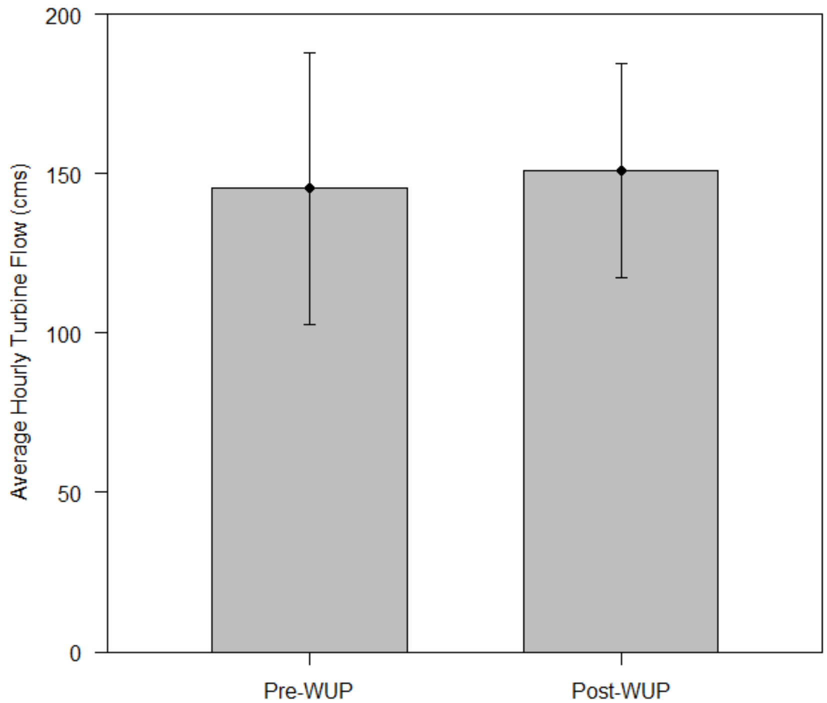

Figure 9. Average yearly (±S.D.) Ruskin discharge during Chum Salmon spawning season (October 15 – November 30) for years pre-WUP (1999-2003) and post-WUP (2004-2014)

3.2.2 Ruskin Dam Tailrace Elevation

Profiles of tailrace elevation below the Ruskin Dam (Figure 10 & Figure 11) show daily fluctuations in elevation during the spawning period (October 15 to November 30) from 2001 to 2014. There was no significant difference between mean elevation for 2001 to 2004 and 2005 to 2014 (Welch's two-sample t-test p=0.613; Figure 12Figure 12 & Figure 13). There was also no statistical difference in the average standard deviation of tailrace elevation and the coefficient of variation of tailrace elevation (p=0.442 and p=0.180, respectively).

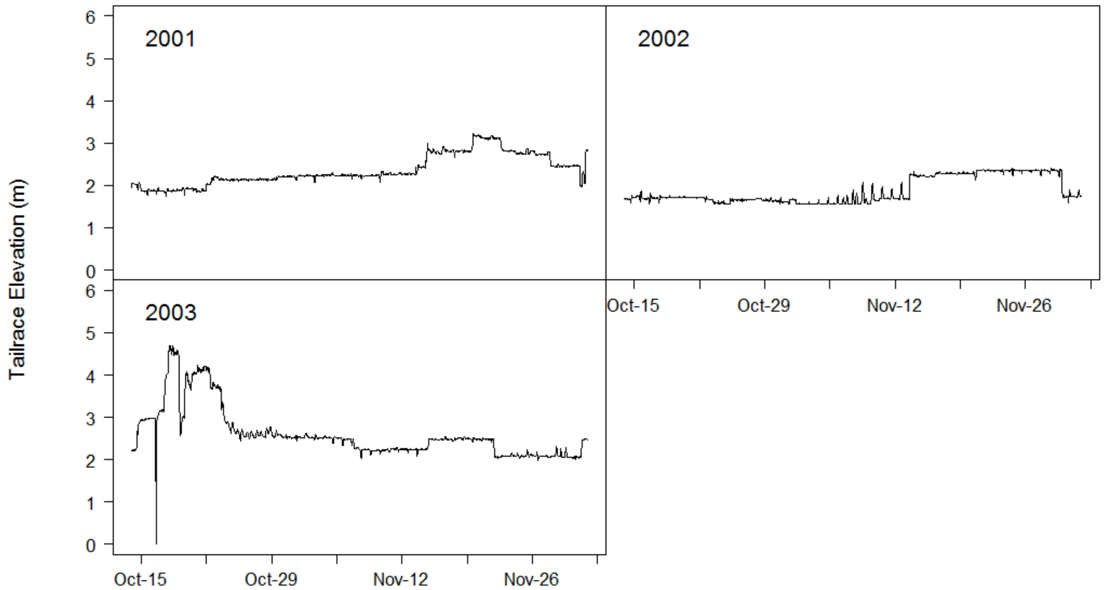

Figure 10. Hourly tailrace elevation (m) during Chum Salmon spawning season (October 15 – November 30) for years 2001 – 2003 (pre-WUP operations)

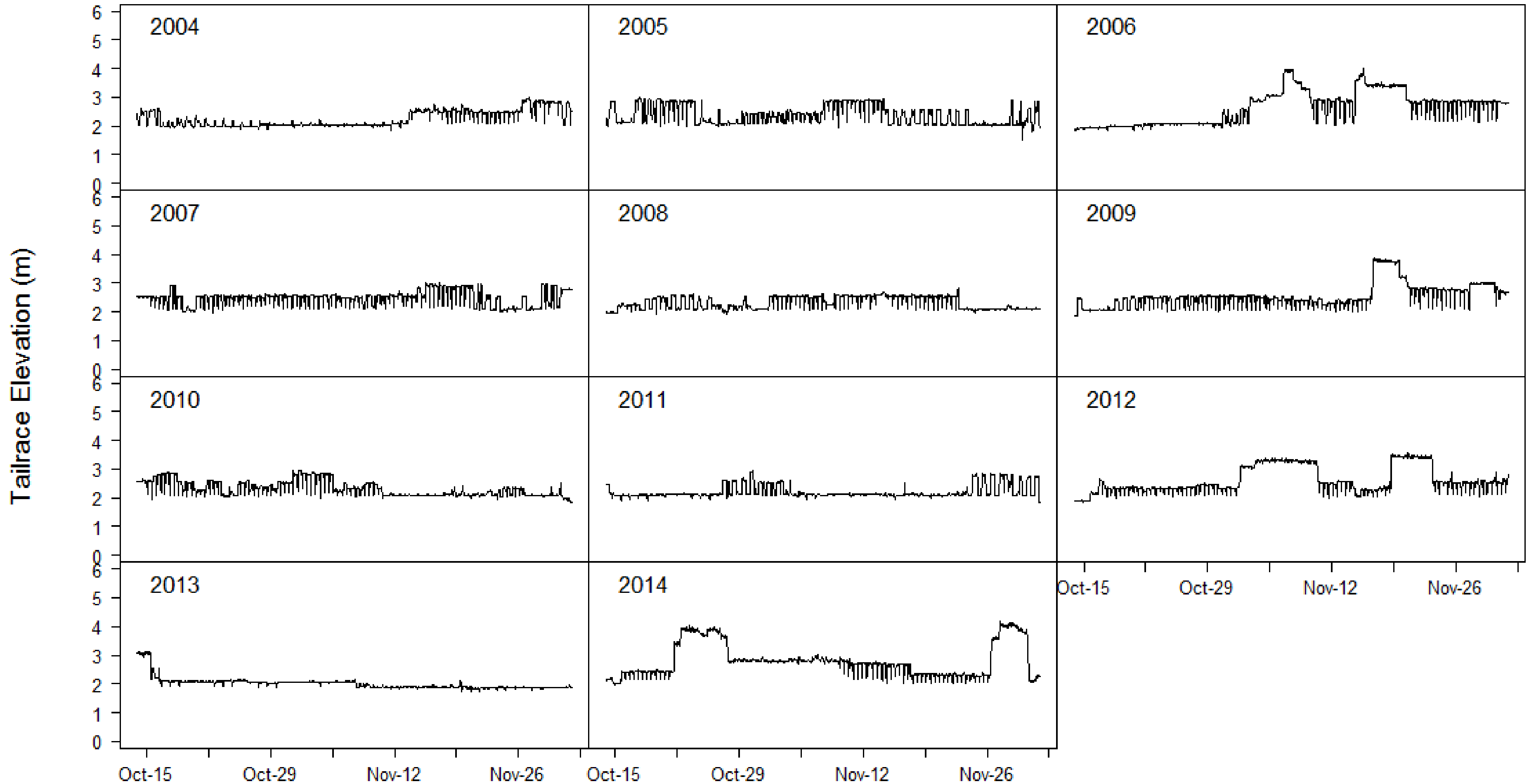

Figure 11. Hourly Ruskin tailrace elevation (m) during Chum Salmon spawning season (October 15 – November 30) for years 2004 – 2014 (post-WUP operations)

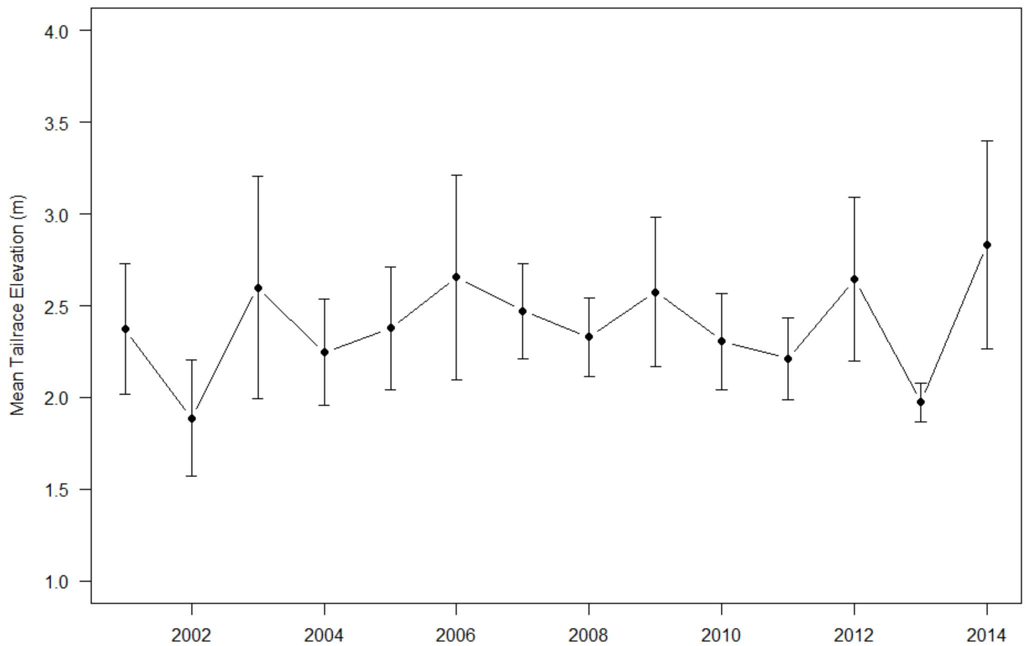

Figure 12. Average yearly (±S.D.) tailrace elevation during Chum Salmon spawning season (October 15 – November 30) for years 2001-2014

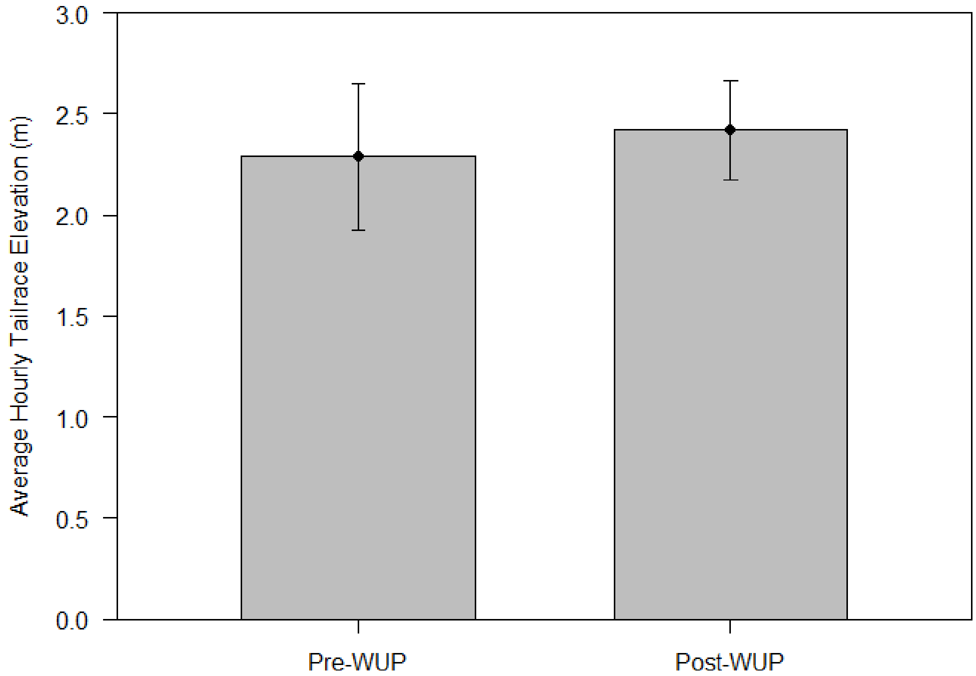

Figure 13. Average yearly (±S.D.) tailrace elevation during Chum Salmon spawning season (October 15 – November 30) for years pre-WUP (2001-2003) and post-WUP (2004-2014)

3.2.1 Fraser River Discharge at Hope

Profiles of Fraser River discharge at Hope (Figure 14 & Figure 15) show daily fluctuations in discharge during the spawning period (October 15 to November 30) from 1999 to 2012. There was no significant difference between mean discharge for 1999 to 2003 and 2004 to 2012 (Welch's two-sample p=0.050; Figure 16 & Figure 17). There was also no statistical difference in the average standard deviation of discharge and the coefficient of variation of discharge (p=0.214 and p=0.141, respectively).

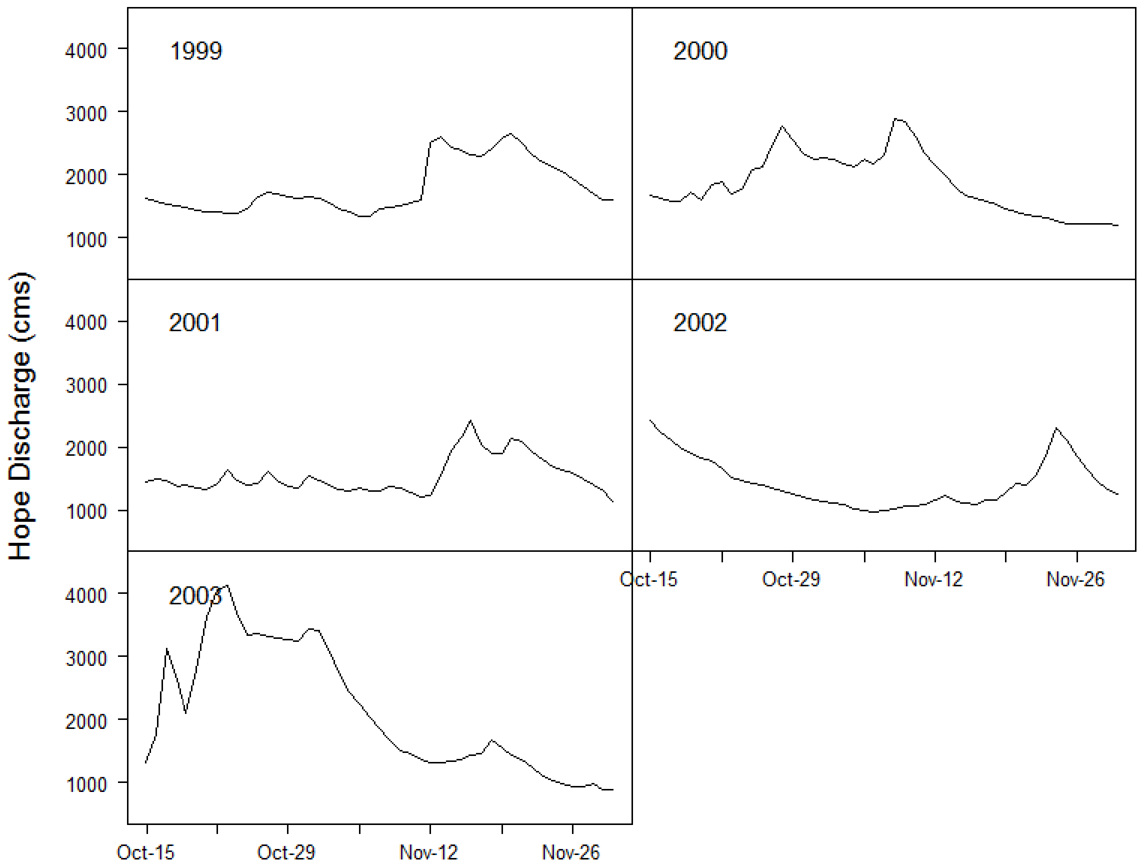

Figure 14. Daily Fraser River discharge at Hope (m^3/s) during Chum Salmon spawning season (October 15 – November 30) for years 1999 – 2003 (pre-WUP operations)

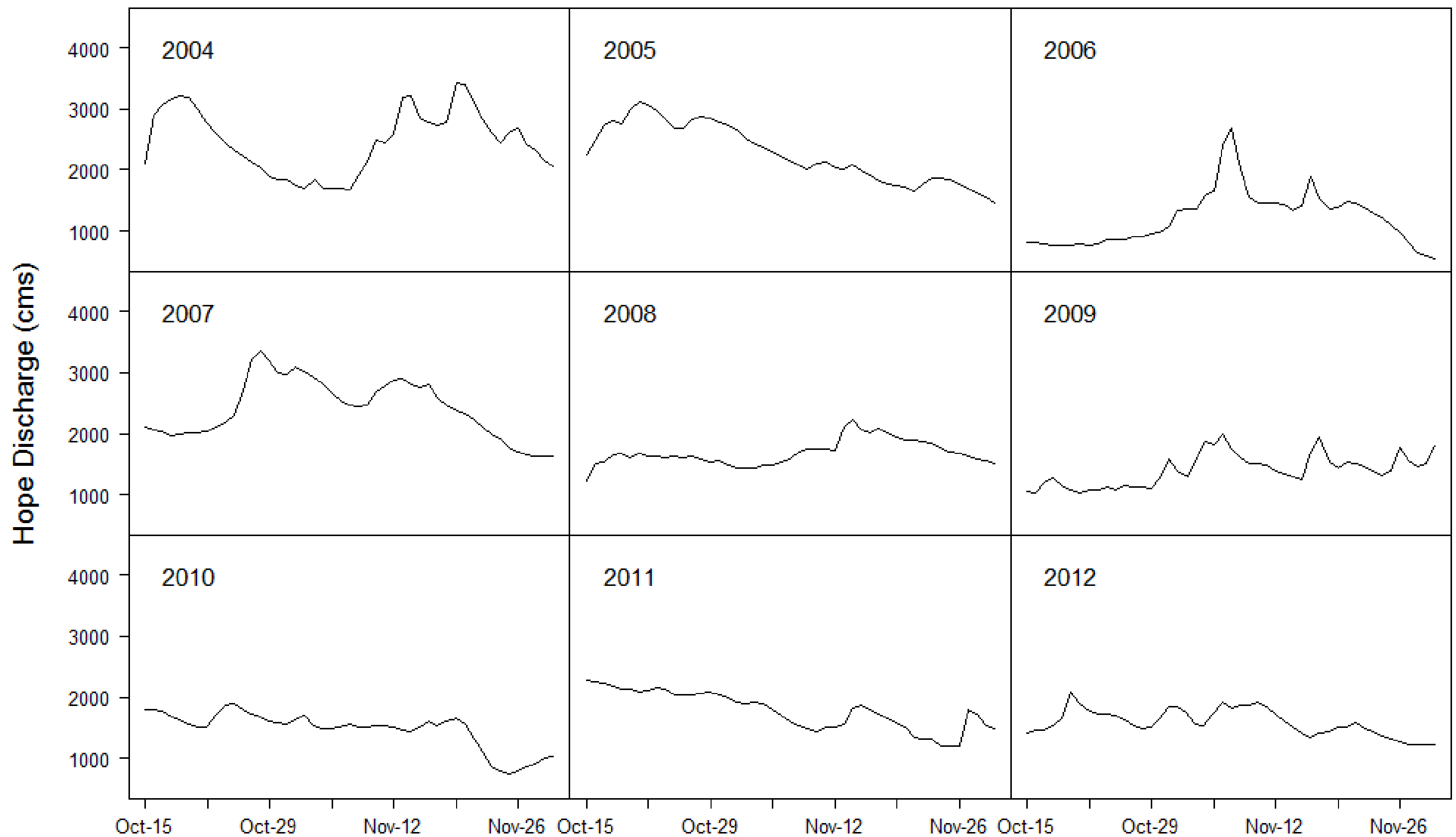

Figure 15. Daily Fraser River discharge at Hope (m^3/s) during Chum Salmon spawning season (October 15 – November 30) for years 2004 – 2012 (post-WUP operations)

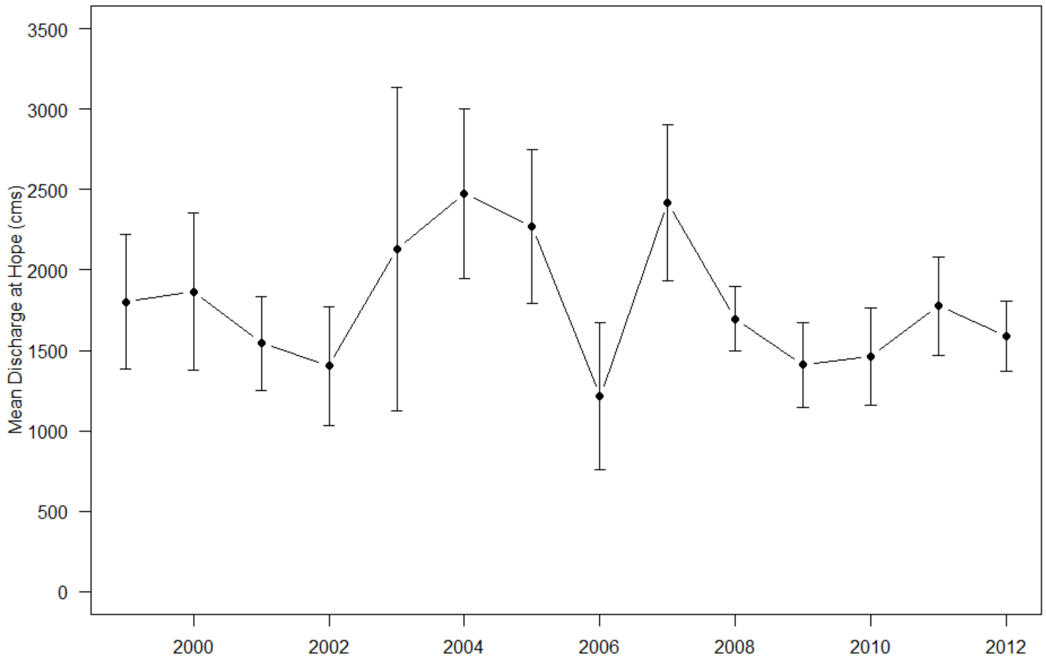

Figure 16. Average yearly (±S.D.) Fraser River discharge at Hope during Chum Salmon spawning season (October 15 – November 30) for years 1999-2012

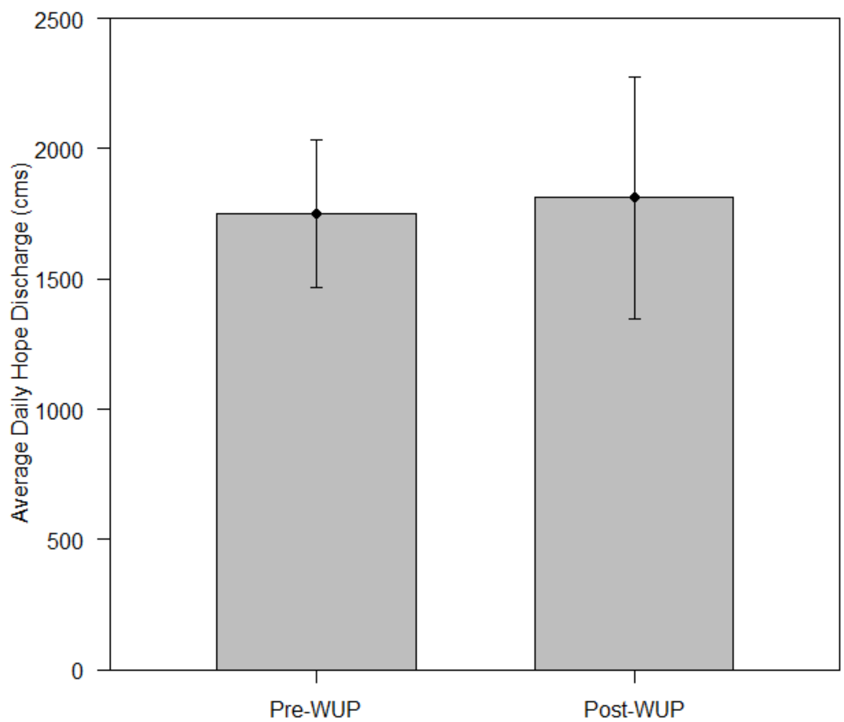

Figure 17. Average yearly (±S.D.) Fraser River discharge at Hope during Chum Salmon spawning season (October 15 – November 30) for years pre-WUP (1999-2003) and post-WUP (2004-2012)

3.3 Modelling Stave River Environmental Variables and Adult Returns

Decision and regression tree analysis, bivariate regression modelling, and multiple linear regression modelling were explored as methods to determine whether environmental variables and/or brood escapement are associated with return escapement of Stave River Chum Salmon.

3.3.1 Bivariate Regression Modelling

Linear regressions were performed between return escapement and the environmental variables listed in Table 3 (results in Table 5). All variables were assessed for normality and homogeneity of residuals. The only variable for which the slope of the relationship with return escapement was significantly different than zero was the logarithm of mean turbine flow (R^2 0.411, p-value=0.025; Figure 18).

Table 5. Linear regressions (multiple R^2 and p-value) of return escapement modelled against brood escapement and environmental variables

Variable	R-square	P-value
esc	0.027	0.611
Log(RQ.u)	0.411	0.025
RQ.sd	0.300	0.065
RQ.cv	0.043	0.516
TE.u	0.001	0.926
TE.sd	0.006	0.819
TE.cv	0.004	0.851
FRQ.u	0.132	0.273
FRQ.sd	0.000	0.983
FRQ.cv	0.010	0.774
RQ.100	0.235	0.110

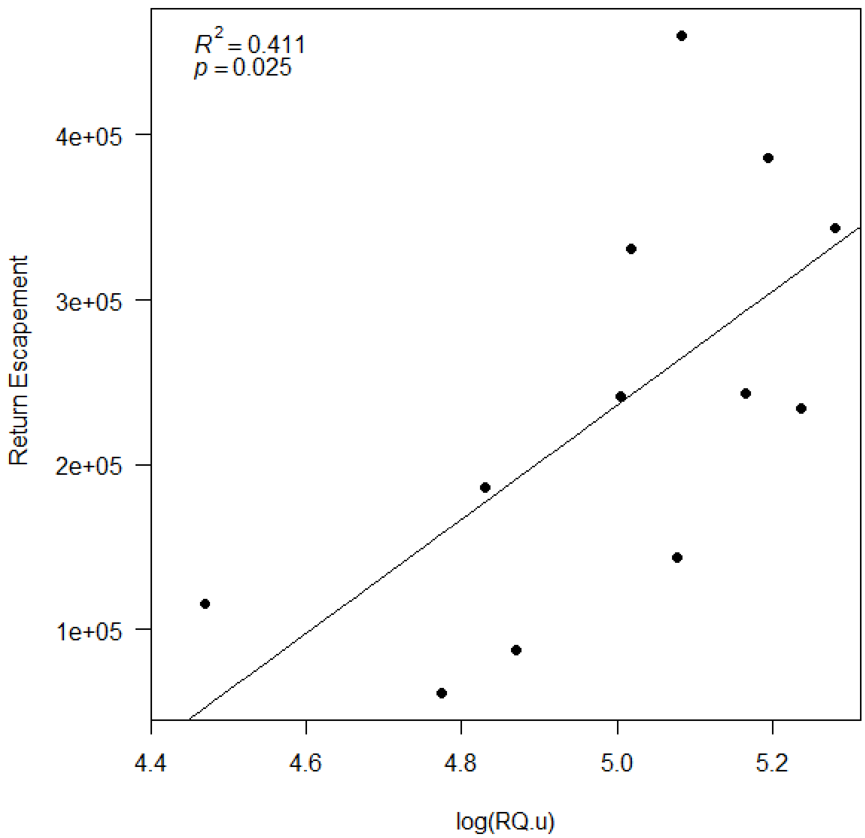

Figure 18. Linear model of return escapement and the logarithm of mean turbine discharge

3.3.2 Multiple Linear Regression Modelling

A Bonferroni-corrected correlation matrix was used to aid in variable selection for multiple linear modelling and regression tree analysis. A matrix of all variables in Table 3 identified potential correlations between Log(RQ.u) and RQ.sd (p=0.078), TE.u and TE.sd (p=0.059), TE.sd and TE.cv (p=4.04e-7), and FRQ.sd and FRQ.cv (1.07e-10). All potential correlations occurred between variations of a single environmental variable, and there were no potential correlations between separate environmental variations. In the case of correlations, the variable that explained the largest variation in return escapement was considered for the multiple linear regression analysis, with the final variables being:

- esc
- Log(RQ.u)
- RQ.cv
- TE.sd
- FRQ.u
- FRQ.cv
- RQ.100

A multiple linear model including the above suite of environmental variables resulted in an adjusted R^2 of 0.406 (i.e., adjusted for multiple variables). The F-statistic was 1.976 with 7 and 6 degrees of freedom (p-value 0.310) indicating that the model did not have significant capacity to predict return escapement. None of the individual variables were significant in the model including all variables. AIC model fitting was used to determine the best fit model by removing individual variables from the overall model. No interactions were tested during model fitting. The model with the lowest AIC value was a model including Log(RQ.u), TE.sd, FRQ.u, and the FRQ.cv. The adjusted R^2 for the final model was 0.645, the F-statistic was 5.36 (4 and 6 degrees of freedom), and the overall p-value for the ANOVA was 0.033. Significant variables in the model were Log(RQ.u), TE.sd, and FRQ.cv (Table 6).

Table 6. Multiple linear regression outputs for modelling return escapement of Stave River Chum Salmon

Variable	Coefficient	P-value
(Intercept)	1,976,475	0.6033
Log(RQ.u)	507,140	0.0221
TE.sd	-595,420	0.0372
FRQ.u	-3,499	0.1394
FRQ.cv	6,410,198	0.0299
F-stat: 5.536 on 4 and 6 DF; p-value: 0.0326		
Adjusted R-squared: 0.6447		

3.3.3 Regression Tree Analysis

Decision and regression tree analysis was used to further explore the relative importance of environmental variables for explaining variability in return escapement. Variables selected for multiple linear regression modelling were also used in the regression tree analysis (a regression tree model using all variables in Table 3 did not produce different results). According to the regression tree analysis, the variable that explained the largest variability in return escapement was Log(RQ.u) (the R^2 value of the single branching model was 0.533). Although the logarithm of turbine flow was the best explanatory variable in the regression tree analysis, this division was not an improvement over the root model, and cross validation suggested that any model with >0 branches is over-fit. The cross-validated error for a tree including Log(RQ.u) was 1.95; i.e., the misclassification rate of a tree with one branch is almost 2 times that of the tree with no branches. This suggests that although environmental variables are weakly associated with return escapement, associations are not statistically strong enough to confidently be used to predict return escapement.

4.0 Discussion

Fluctuations in river discharge can substantially affect overall aquatic productivity and fish populations in downstream systems. The degree to which discharge fluctuations affect salmon populations is dependent on the magnitude, timing, and duration of flow variations, with some salmon life stages being more sensitive to environmental variation than others (Harnish et al., 2013). Discharge fluctuations in natural rivers of the Pacific Northwest are gradual and generally occur at predictable intervals throughout the year as a result of meltwater and precipitation events. In contrast, discharge fluctuations below hydroelectric facilities can result in extreme daily fluctuations and unnatural seasonal flow patterns, and have been documented to have negative effects on spawning, incubation, and rearing of salmon populations (Malcom et al. 2012; Young et al. 2011). Potential negative effects include reduced habitat availability, redd dewatering, stranding, physiologically-unsuitable discharge and temperature conditions, and altered substrate composition (Harnish et al. 2013; Young et al. 2011).

Chum Salmon escapement in the Stave River below the Ruskin hydroelectric facility has generally been declining since the early 2000s (Figure 2). In recent decades, a number of changes have occurred to salmon management policies and environmental conditions in the Stave River system, including the end of hatchery supplementation (1998) and the use of a number of different discharge management strategies (i.e., full block loading prior to 2004 and partial block loading from 2004 to present). Over the same time period, salmon stocks throughout the Fraser Valley have been impacted by variable fishing pressures, altered ocean conditions, contaminants throughout migration routes, and a changing climate. This monitor was tasked with determining whether changing Stave River Chum Salmon escapement can be attributed to the partial block loading strategy implemented in 2004 at the Ruskin Dam or unmeasured variables in the Stave River and/or greater ocean environment.

This report did not find conclusive evidence linking Ruskin Dam operational parameters to Chum Salmon escapement in the Stave River system. There was a significant linear relationship between returning escapement and mean turbine discharge, and previous reports for this monitor have also found discharge variation to be significantly correlated with Chum Salmon escapement (Ladell and McCubbing 2013). In addition, a multiple linear regression model including mean turbine discharge, the standard deviation of tailrace elevation, and parameters related to Fraser River discharge at Hope was a significant predictor of return escapement. No clear patterns emerged during the analysis of available parameters and return escapement, and correlations between escapement and environmental variables were generally weak. Although the best-fit multiple regression model was a significant predictor of return escapement, the overall model fit and individual correlations were weak and the model significance may be partially due to random occurrence. A large amount of variation in Chum Salmon return escapement was not explained by the best-fit model, and there are likely other factors not included in this analysis that contributed to changes in Stave River Chum Salmon escapement.

Significant correlations between Stave River escapement and escapement of other Fraser River stocks provide further evidence that conditions outside of the Stave River system are affecting Chum Salmon escapement. All of the Fraser River stocks (and coast-wide commercial catch) examined in this report had significantly lower mean escapement from 2008-2012 (i.e., during the Stave River post-WUP period) compared to 2003-2007 (pre-WUP) (Figure 5), and Stave River escapement was correlated with escapement of other Chum Salmon populations in the Fraser River (Figure 4). These correlations strongly suggest that Chum Salmon stocks are being affected by regional climate conditions or characteristics of the ocean environment, rather than conditions in their local spawning grounds.

Although this monitor did not find conclusive evidence that hydroelectric operational parameters directly affect salmon escapement in the Stave River, significant effects of dam operations on downstream Chum Salmon populations are well documented. A study of Chum Salmon behaviour downstream of the Bonneville Dam in the Columbia River (Washington, USA) found reduced digging and eventual redd abandonment with increased velocity (Tiffan et al. 2010). At the Priest Rapids Dam (on the Columbia River upstream of the Bonneville Dam), dam operations in the 1970s resulted in redd dewatering and stranding mortality of spawning Chum Salmon (Harnish et al. 2013). An operating strategy that restricted the magnitude of discharge fluctuations was implemented in the 1980s, but effects to salmon still occur through juvenile stranding and entrapment during rearing periods. Similar findings resulted from research in the Skagit River Basin (Washington, USA), where changes to ramping procedures at the Skagit Hydroelectric Facility resulted in reduced fry stranding and redd dewatering (Connor and Pflug 2004). Similar effects have been documented in rivers throughout North America, a review of which can be found in Young et al. (2011).

A number of different modelling strategies have been used to examine the effects of hydroelectric facilities on downstream salmon populations. Linear and nonlinear bivariate regressions have been used in a number of studies to examine the effect of hydroelectric operations on salmon escapement and production. Connor and Pflug (2004) examined the linear relationships between escapement and minimum incubation flows in the upper Skagit River, Washington. The researchers performed a before-and-after impact comparison of pre- and post-flow management changes on spawner abundances using 27 years of Skagit River escapement data for Pink, Chum, and Chinook Salmon data. In the Columbia River, Harnish et al. (2013) used linear and non-linear regressions and regression tree analysis to determine how operation of the Bonneville Dam affects Chinook Salmon productivity. Over a 30-year time series, ten parameters were examined relating to spawn-timing discharges, post-hatch incubation discharges, and the cumulative area dewatered during post-hatch incubation. Both Connor and Pflug (2004) and Harnish et al. (2013) found weakly significant relationships between operational parameters and escapement, but cautioned that unmeasured factors such as ocean conditions may have contributed to changes in spawner abundance and overall salmon productivity in the study areas.

Previous WUP monitors in the Stave River system indicated that fry and adult stranding were difficult to tie solely to discharge and that the tidal influence from the Fraser River plays an important role (Troffe and Ladell 2007; Troffe and McCubbing 2009). Adult stranding during operational drawdown during normal block loading operations was low (~ 0.4%) but increased by a factor of two when spilling occurred. Fry stranding during the spring block loading period was not only related to discharge but also to the timing of Chum Salmon emergence and the frequency of operational drawdowns.

Chum Salmon abundance in the Stave River is undoubtedly affected by a variety of factors over and above brood escapement and discharge from the dam. Annual commercial exploitation rates, marine survival, homing rates and terminal losses due to angling activities in approach waters, FN catches, poaching and natural deaths are all parameters that have some influence on escapement. The results of this monitor do not necessarily indicate that dam operations have no effect on Chum Salmon in the Stave River. The lack of significance may be because time series' are not long enough to detect significance, operational parameters not available for this analysis, variation in escapement is explained by environmental factors outside of the Stave River system, or a combination of these possibilities.

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