Bridge River Project Water Use Plan

Effectiveness of Cayoosh Flow Dilution, Dam Operation, and Fishway Passage on Delay and Survival of Upstream Migration of Salmon in the Seton-Anderson Watershed

Implementation Year 4

Reference: BRGMON-14

2015 Data Report

Study Period: 2015

University of British Columbia
Instream Fisheries Research

Casselman, M.T., Burnett, N.J., Bett, N.N., Middleton, C.T., Martins, E.G., Braun, D.C., McCubbing, D., and Hinch, S.G. 2016. BRGMON-14 Effectiveness of Cayoosh Flow Dilution, Dam Operation, and Fishway Passage on Delay and Survival of Upstream Migration of Salmon in the Seton-Anderson Watershed. Annual Report – 2015. Report prepared for St'át'imc Government Services and BC Hydro. The University of British Columbia, Vancouver, BC. 66 p. + 2 Apps.

March 2016

March 2016

BRGMON-14

Effectiveness of Cayoosh Flow Dilution, Dam Operation, and Fishway Passage on Delay and Survival of Upstream Migration of Salmon in the Seton-Anderson Watershed

Annual Report - 2015

Prepared for:

St'át'imc Eco-Resources Ltd.
10 Scotchman Rd, PO Box 2218
Lillooet, BC V0K 1V0

BC Hydro
6911 Southpoint Drive
Burnaby, BC V3N 4X8

UBC

INSTREAM

Suggested Citation:

Casselman, M.T., C.T. Middleton, V. Minke-Martin, S.M. Drenner, N.N. Bett, N.J. Burnett, D.C. Braun and Hinch, S.G. 2016. BRGMON-14 Effectiveness of Cayoosh Flow Dilution, Dam Operation, and Fishway Passage on Delay and Survival of Upstream Migration of Salmon in the Seton-Anderson Watershed. Annual Report – 2015. Report prepared for St'át'imc Eco-Resources Ltd. and BC Hydro. The University of British Columbia, Vancouver, BC. 93 p. + 2 Apps.

Cover photo: Tagging a Gates Creek sockeye salmon at the Seton River fish fence site. Photos © University of British Columbia.

EXECUTIVE SUMMARY

Key BRGMON-14 monitoring program goals in 2015 were assessing in-river migratory behaviour of Gates Creek sockeye salmon at dilution ratios exceeding the 20% target ratio and to continue assessing of fish passage at Seton Dam. Additional analyses were completed for Gates Creek and Portage Creek migration behaviour and survival in 2013-2014.

As in previous years, fish were captured at the Seton River fish fence and a total of 860 Gates Creek sockeye salmon were tagged with radio or PIT tags throughout August 2015. Tagged fish were released from the fence or transported and released in the Fraser River downstream of the Seton Generating Station. Fence-released fish were used to monitor dam passage whereas downstream-released fish were used to monitor time spent at the Seton Generating Station and movements in the Fraser River. Modified operations at Walden North were used to increase the Seton River dilution ratio to above-target ratios for one week in August 2015, followed by a decrease in the dilution ratio to below-target ratios to act as a control. Telemetry arrays monitored Gates Creek sockeye salmon migration behaviour and success to Seton Dam. Arrays at Seton Dam and upstream on Gates Creek monitored dam passage and survival to spawning grounds, respectively.

Gates Creek sockeye salmon that experienced above-target dilution ratios in 2015 were found to have increased exploratory behaviour in the Fraser River and decreased survival to Seton Dam as compared with fish that experienced below-target dilution ratios. Survival to Seton Dam for fish released during the week of elevated dilution ratios was up to 25% lower than fish released in the following week. However, there was no difference in the time spent in the Seton Generating Station tailrace or in the time to reach Seton Dam. Analyses of 2013-2014 telemetry data found no effect of dilution on migration behaviour although the dilution ratio rarely exceeded the 20% target ratio in these years. Additional analyses will account for temporal variation in Gates Creek sockeye salmon condition and migration behaviour.

Passage success at Seton Dam remained high for Gates Creek sockeye salmon in 2015. An unanticipated decrease in Seton Dam discharge in late-July eliminated the need for the mid-August ramp-down, and only one flow condition was studied at Seton Dam in 2015. Of the Gates Creek sockeye salmon released at the fence in 2015, 97% of fish successfully located the Seton Dam fishway and passed Seton Dam. Similar passage success was observed in 2014 (98%) and the time fish spent in the Seton Dam tailrace was not different between 2014 and 2015. Post-passage survival in 2015 was equivalent to that during the alternative flow scenario in 2014; however, routine Seton Dam discharge was lower in 2015.

Gillnet injuries were observed on a large proportion of fish that entered the Seton River in early to mid-August 2015. Although measurements taken during tagging suggested many fish entering the Seton River at this time were strays, approximately 30% of Gates Creek sockeye salmon tagged during this period displayed gillnet injuries. Comparable proportions of deceased sockeye salmon recovered from the Seton River fish fence also displayed gillnet injuries. Fish condition – including injuries present on Gates Creek sockeye - will be taken into account in future survival analyses.

Challenges in 2015 included low returns of late-run Fraser River sockeye salmon that did not allow a Portage Creek tagging program to take place and difficulties recovering tags from Gates Creek sockeye salmon collected as part of a food fishery at Portage Creek. It is recommended that monitors are put in place at Portage Creek to estimate fishing effort and to improve future estimates of Gates Creek sockeye salmon in-lake survival.

BRGMON-14 STATUS of OBJECTIVES, MANAGEMENT QUESTIONS and HYPOTHESES after Year 4

Objectives	Management Questions	Management Hypotheses	Year 4 (2015) Status
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds. *And* To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh Creek dilution in the Seton River.	Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations? *And* How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?	H_{O1}: Gates Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution exceeds 20%.	Water preference tests in 2013-2014 indicated that Gates Creek sockeye could be expected to delay at dilution ratios >20%. A dilution trial in 2015 found increased wandering and decreased survival to Seton Dam when the dilution ratio was >20%. Delay was not affected; however, migration timing must still be taken into account. The current data set should be sufficient to address this question. Methods: 2.4, 2.5. Results: 3.5, 3.8. Discussion: 4.1.1.
		H_{O2}: Portage Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution exceeds 10%.	Water preference tests in 2014 indicated Portage Creek sockeye could be expected to delay at dilution ratios >10%. Telemetry results in 2014 indicated increased dilution had a significant effect on the number of forays and time fish spent in the Seton Generating Station tailrace. Further analysis is required, but the current data set should be sufficient to test this hypothesis. Methods: 2.4, 2.5. Results: 3.5, 3.8. Discussion: 4.1.1.
		H_{O3}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.	Migration data collected during dilution ratios <20% in 2014 and >20% in 2015 will be used to address this hypothesis as sufficient data has now been collected to determine if there is a relationship between delay and the dilution ratio However, changes in migration timing and behaviour during the migration period must be taken into account. Methods: 2.4. Results: 3.5. Discussion: 4.1.1.
		H_{O4}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.	Increases in the dilution ratio significantly increased Portage Creek sockeye forays and time spent at the Seton Generating Station. Further analysis is required to determine the relationship between the dilution ratio and time in the tailrace. Methods: 2.4. Results: 3.5. Discussion: 4.1.1.

Objectives	Management Questions	Management Hypotheses	Year 4 (2015) Status
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds. *And* To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh Creek dilution in the Seton River.	What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?	H_{O5}: There is significant delay of pink salmon at the Seton Powerhouse under the normal operating procedure.	Pink salmon did not show a preference for Seton River water. Migration data suggests pink salmon did not delay but further data analysis is required. Hypothesis cannot be rejected at this time. Methods: 2.4, 2.5. Results: 3.9.
		H_{O6}: There is significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure.	Hypothesis cannot be tested because no Chinook salmon have been collected for study. Methods: 2.4, 2.5.
		H_{O7}: There is significant delay of coho salmon at the Seton Powerhouse under the normal operating procedure.	Coho were captured in limited numbers in 2013 and 2014. Low abundance of this species in the Seton River may prevent hypothesis from being properly tested. Methods: 2.3, 2.4. Results: 3.3, 3.5.
To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds.	Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam? *And* What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?	H_{O8}: Operation of Seton Dam and fishway does not affect attraction to the fishway.	Attraction efficiency varies with environmental conditions but was significantly improved under an alternative discharge scenario indicating Seton Dam operations can impact attraction efficiency. The alternative scenario should be re-tested to confirm improvements in attraction efficiency with continued monitoring of post-passage survival. Methods: 2.2, 2.4. Results: 3.2, 3.6, 3.7. Discussion: 4.1.2.
		H_{O9}: Operation of the Seton Dam and fishway does not affect passage efficiency at the fishway.	Depending on tag type, fishway passage efficiency was 89-99% for Gates Creek sockeye in 2012-2015 and 95-100% for Portage Creek sockeye salmon in 2013-2014. The fishway does not appear to affect the passage efficiency of sockeye salmon. Methods: 2.4. Results: 3.4, 3.6.

Keywords: Pacific salmon, *Oncorhynchus* spp., Seton River, Seton Dam, migration, fish passage, olfaction, telemetry.

ACKNOWLEDGEMENTS

Funding and logistic support for the BRGMON-14 adult fish passage monitoring program was provided through St’át’imc Eco-Resources, BC Hydro, and the Natural Sciences and Engineering Research Council of Canada. Infrastructure and additional support was provided through the Ocean Tracking Network of Canada and Fisheries and Oceans Canada. The authors would like to thank the following individuals for their contributions to the program: Ahmed Gelchu, Dorian Turner, and Jeff Walker (BC Hydro); Wesley Payne, Jessica Hopkins, Roxx Ledoux, Allison James, Avaleen Adolph, and Bonnie Adolph (St’át’imc Eco-Resources); Don McCubbing, Jason Ladell, Doug Braun, and Stephanie Lingard (Instream Fisheries Research Ltd.); David Zhu, Wenming Zhang, and Yu Qian (University of Alberta); Jayme Hills, Karia Kaukinen, Shaorong Li, Kristi Miller, and David Patterson (Fisheries and Oceans Canada); Harry O'Donaghey, Leo O'Donaghey, Lance O’Donaghey, and Chris Fletcher (N'Quatqua First Nation); David Levy (St’át’imc Eco-Resources); Carson White, Melanie Kuzyk, and Andrew Lotto (The University of British Columbia).

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1.0 INTRODUCTION

The Bridge River Power Development Water Use Plan (WUP) was developed for BC Hydro's operations in the Bridge River Basin and includes the Seton Dam and associated infrastructure in the Seton-Anderson watershed (BC Hydro 2011). Five Pacific salmon (*Oncorhynchus* spp.) species migrate through the Seton-Anderson watershed including two genetically-distinct populations of sockeye salmon (*O. nerka*), coho salmon (*O. kisutch*), Chinook salmon (*O. tshawytscha*), pink salmon (*O. gorbuscha*), and steelhead trout (*O. mykiss*) (BC Hydro 2000). The primary spawning grounds for salmon, with the exception of pink salmon, are upstream of Seton Dam. To access spawning areas, adult salmon migrating up the Fraser River must pass the Seton Generating Station tailrace, enter the Seton River, negotiate the Seton Dam tailrace, and locate and ascend the Seton Dam fishway. Recommendations within the WUP by the Consultative Committee included the implementation of an adult fish passage monitoring program in the Seton-Anderson watershed to identify factors impeding the successful upstream migration of salmon through this migration route. Specifically, the Consultative Committee recommended the monitoring program address uncertainties in the effects of current Seton Dam and fishway operations on salmon passage and uncertainties in the effects of Seton River dilution by Cayoosh Creek on salmon migration.

Sockeye salmon passage through the Seton Dam fishway was recently examined in 2005 (Pon et al. 2006; Pon et al. 2009a, Pon et al. 2009b). A follow-up investigation in 2007 also monitored sockeye salmon fishway passage as well as migration from the Seton Generating Station tailrace to spawning grounds above Seton Dam (Roscoe and Hinch 2008; Roscoe et al. 2010; Roscoe et al. 2011). Several impediments to salmon migration were identified in these studies including high discharge in the Seton River that hindered upstream migration and complex flow fields in the Seton Dam tailrace that delayed migration and reduced fishway attraction efficiency. These impediments resulted in the majority of observed sockeye salmon migration failure downstream of Seton Dam (Roscoe and Hinch 2008). Upstream migratory failure was also observed as post-passage mortality in Seton Lake and Anderson Lake with physiological indicators in failed migrants suggestive of increased stress. Post-passage mortality was also significantly higher for females than males. Fishway passage efficiency was high in both study years.

Absent from previous investigations was a comprehensive analysis of the influence of discharge and tailrace flow fields on salmon passage success at Seton Dam. Although a fish counter has historically been operated at the exit of the Seton Dam fishway, the low efficiency of the counter has not allowed Seton Dam operating conditions to be correlated with fish passage success. The studies in 2005 and 2007 provided some insight, but salmon passage could only be examined under five operating conditions and detailed information on Seton Dam water release patterns and associated flow conditions was not collected. In addition, the 2005 and 2007 investigations also primarily focused on sockeye salmon. Needed is a multi-year investigation of Seton River and Seton Dam fish passage to capture a range of discharge and flow conditions associated with Seton Dam operations. In addition, fish counter enumeration efficiency must be improved and a thorough assessment of how discharge and flow fields at Seton Dam influence delay and fishway attraction for all salmon species is required. Operating conditions at Seton Dam can then be correlated with migration success, post-passage survival, and environmental variables to identify factors impeding salmon migration and formulate mitigation measures.

Target dilution ratios for Cayoosh Creek discharge to total Seton River discharge are a component of the current WUP. Current targets were adopted from findings of the International Pacific Salmon Fisheries Commission (IPSFC) on population-specific water preference behaviour exhibited by Gates Creek and Portage Creek sockeye salmon (Fretwell 1989). Dilution targets for the Seton River are <20% Cayoosh Creek flow from 20 July to 31 August for Gates Creek sockeye salmon and <10% Cayoosh Creek flow from 28 September to 15 November for Portage Creek sockeye salmon (BC Hydro 2011). Maintaining target dilutions during sockeye migration periods are intended to reduce sockeye delay in the Seton Generating Station tailrace and encourage upstream migration to the Seton River-Fraser River confluence. The target dilution ratios and the apparent reduction in migratory delay are based on behavioural experiments and telemetry performed in the early 1980's. Neither the water preference behaviour of sockeye salmon nor the effectiveness of current dilution targets have been fully evaluated since the adoption and implementation of the target ratios. Recent studies have shown a high level of sockeye migration failure can still occur at target dilution levels (Hinch and Roscoe 2008). Further, it is not fully known how target dilution ratios influence the behaviour of other salmon species, although pink salmon appear less sensitive to changes in the dilution ratio (Fretwell 1989). The target dilution ratios and their effect on salmon migration will be assessed in this monitoring program.

The current BRGMON-14 monitoring program is a 5-year investigation that will provide a comprehensive assessment of how Seton River dilution, Seton Dam operations, and environmental variables interact with the behaviour and physiology of salmon to affect upstream migration in the Seton-Anderson watershed. Data collected in this program will build upon previous studies while incorporating new technologies to enhance monitoring. The University of British Columbia (UBC) will carry out physical parameter monitoring, use telemetry to assess fish migration, conduct behavioural experiments, and collaborate with the University of Alberta to measure Seton Dam tailrace flow fields. Instream Fisheries Research Inc. will conduct fish passage enumeration at the Seton Dam fishway using an electronic fish counter and video monitoring. Ultimately, this program will make recommendations to St'át'imc Eco-Resources Ltd. and BC Hydro on operational modifications to the hydroelectric facilities within the Seton-Anderson watershed to improve salmon passage. This report summarizes the results from Year 1 to Year 4 of the BRGMON-14 monitoring program.

1.1 Scope and Objectives

The objectives of the BRGMON-14 monitoring program are:

1. To determine the effectiveness of current dam operations for ensuring uninterrupted migration into Seton River and past Seton Dam to spawning grounds.
2. To evaluate the sensitivity of the salmon populations to variations in the level of Cayoosh dilution in Seton River.
3. To identify operating strategies that will mitigate delays in upstream migration without conflicting with other water use goals for environmental protection, flood risk, and power production in the Bridge Seton generating system.

1.2 Management Questions

The management questions of this monitoring program will achieve the program objectives by addressing specific uncertainties in the current operational requirements at Seton Dam and how these operations impact all salmon species migrating in the Seton-Anderson watershed. Uncertainty within the WUP operational requirements exist because Seton River dilution ratios were derived from studies that were limited to sockeye salmon and have not been re-evaluated. Further, fish passage at Seton Dam requires more detailed investigation. Therefore, the management questions of this monitoring program are:

1.1 Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations?

1.2 How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

2.1 What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?

3.1 Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?

3.2 What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

1.3 Management Hypotheses

Although previous investigations indicate that the target dilution ratios are necessary to mitigate delay of upstream migrating Gates Creek and Portage Creek sockeye salmon populations, confirming this operation requirement is central to the BRGMON-14 monitoring program and will address Management Question 1.1. The null (no effect) hypotheses to be tested for the effect of Cayoosh Creek dilution on the two sockeye salmon populations are:

H_{O1}: Gates Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution rate exceeds 20%.

H_{O2}: Portage Creek sockeye upstream migration is not significantly delayed when the Cayoosh Creek dilution rate exceeds 10%.

Testing these hypotheses will require monitoring sockeye salmon migration at different dilution ratios. Operating conditions during the 5-year monitoring program period should provide sufficient variation in dilution levels to accept or reject these hypotheses.

Variations in the dilution ratio necessitate a secondary set of hypotheses to test the sensitivity of Gates Creek and Portage Creek sockeye migration behaviour and address Management Question 1.2. The null hypotheses are:

H_{O3}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Gates Creek sockeye.

H_{O4}: There is not a predictable relationship between flow dilution and the delay of upstream migrations of Portage Creek sockeye.

To date, investigations have focused on sockeye salmon because of their abundance in the Seton-Anderson watershed and high cultural and economic value. It has not been determined if discharge at the Seton Generating Station delay pink, Chinook, or coho salmon migrating to the Seton River. Management Question 2.1 will be addressed by testing the following hypotheses:

H_{O5}: There is significant delay of pink salmon at the Seton Powerhouse under the normal operating procedure.

H_{O6}: There is significant delay of Chinook salmon at the Seton Powerhouse under the normal operating procedure.

H_{O7}: There is significant delay of coho salmon at the Seton Powerhouse under the normal operating procedure.

The following hypotheses are related to Seton Dam and fishway operations and will address Management Questions 3.1 and 3.2:

H_{O8}: Operation of Seton Dam and fishway does not affect attraction to the fishway.

H_{O9}: Operation of the Seton Dam and fishway does not affect passage efficiency at the fishway.

Year 3 of the BRGMON-14 monitoring program investigated each of the management hypotheses.

1.4 Study Area

The study area for the BRGMON-14 monitoring program encompasses the entire salmon migration route within the Seton-Anderson watershed from downstream of the Seton Generating Station on the Fraser River to Gates Creek and the Gates Creek spawning channel upstream of Anderson Lake (Figure 1-1). Detailed study of salmon migration was carried out in the Seton River study area that included the Seton Generating Station, Fraser River, Seton River, Cayoosh Creek, and Seton Dam (Figure 1-2). In addition, the migratory success of salmon to spawning grounds at Gates Creek and Portage Creek was quantified.

Detailed examination of migration was also carried out at Seton Dam located 4.4 km upstream from the Fraser River (Figure 1-3). Seton Dam is a 76.5 m long by 13.7 m high concrete structure consisting of a radial gate, five siphons, a fish water release gate (FWRG), and fishway. In order to access Seton Lake and spawning grounds, migrating salmon must navigate the Seton Dam tailrace, locate the fishway entrance adjacent to the FWRG, and ascend the fishway. The fishway has a total length of 107 m, contains 32 pools separated by vertical baffles, and has an overall grade of 6.9%. The Seton Dam fish counter is located at the upstream end of the fishway in the exit basin. Migrating salmon must pass through the fish counter to enter Seton Lake.

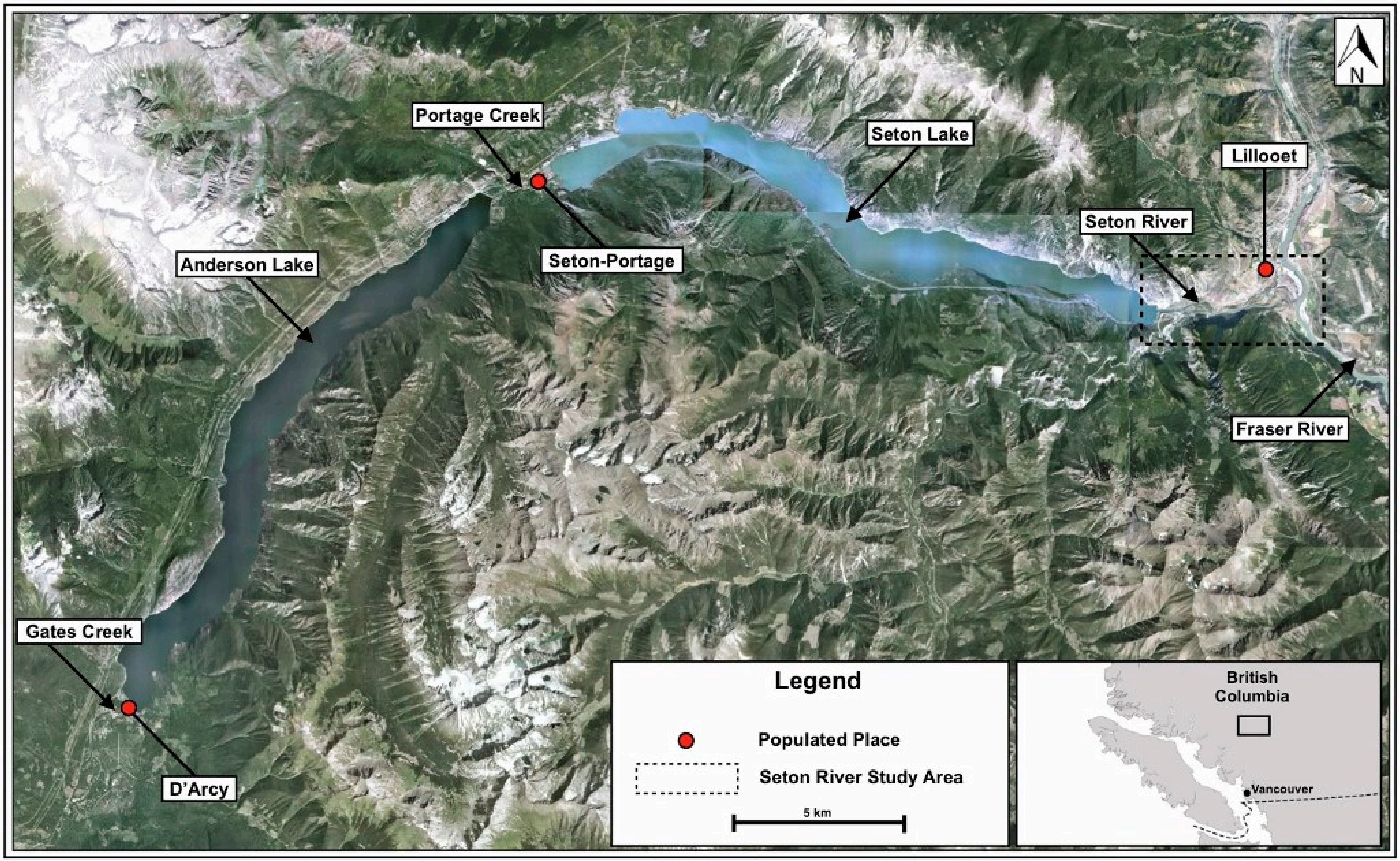

Figure 1-1: **Overview of the Seton-Anderson watershed and study area for the BRGMON-14 monitoring program**

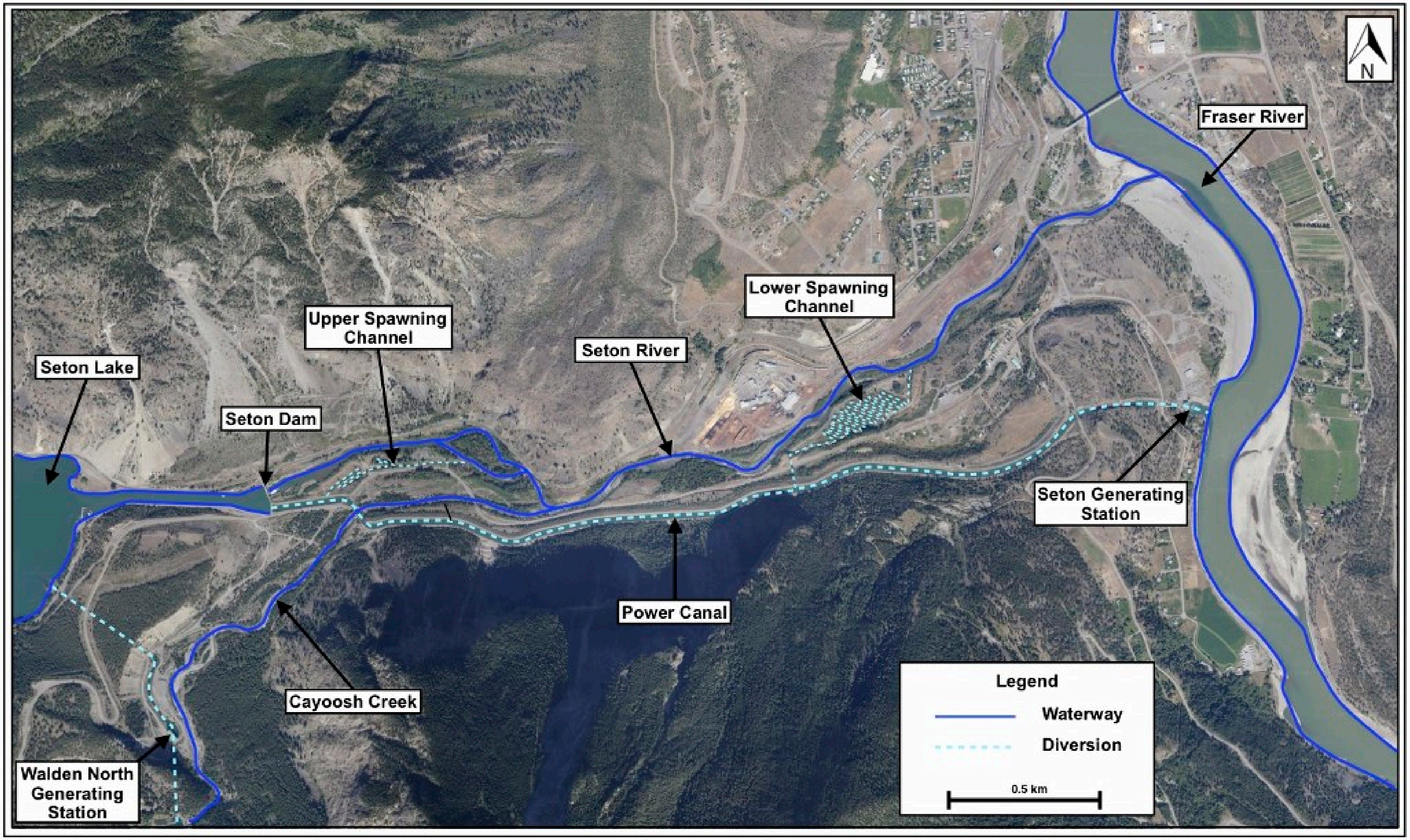

Figure 1-2: Waterways and diversion infrastructure within the Seton River study area

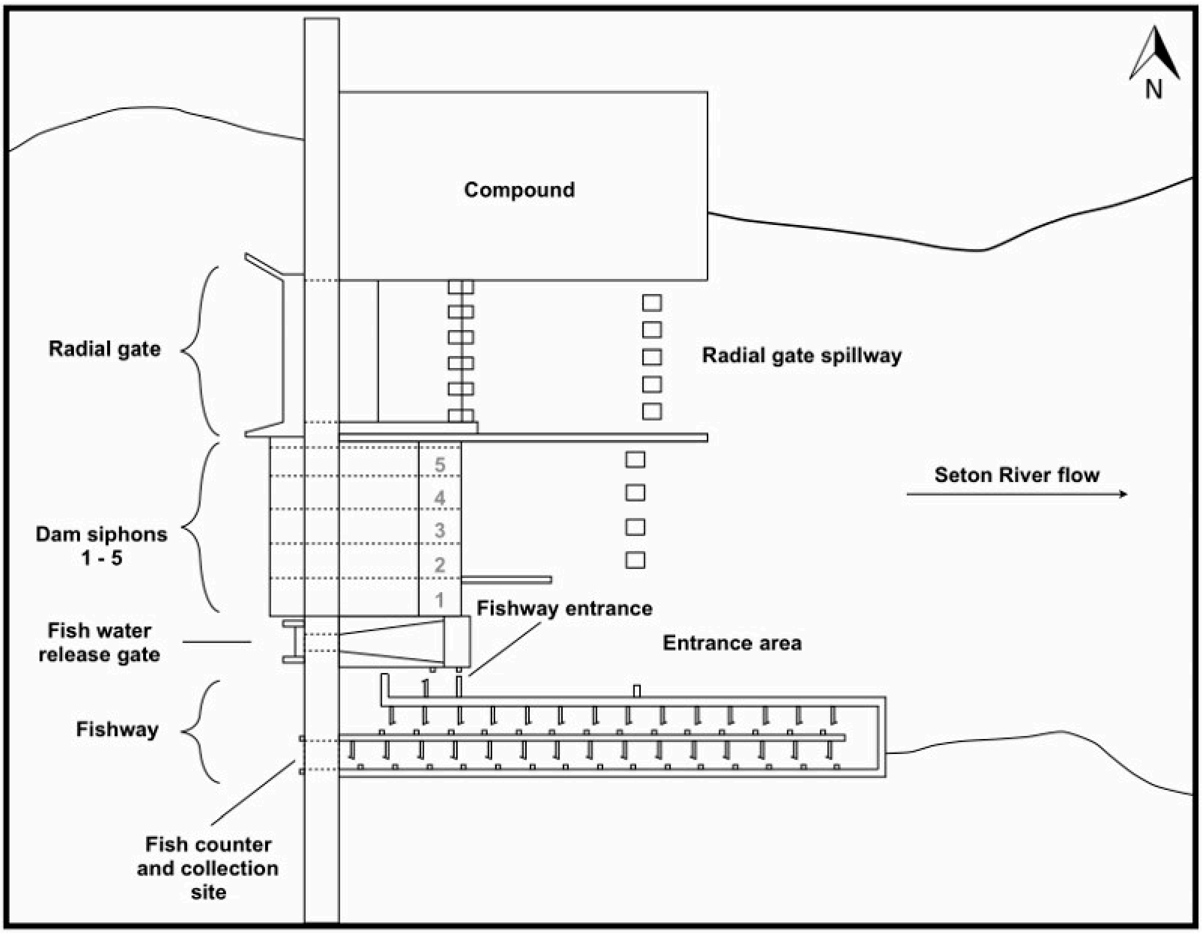

Figure 1-3: Schematic of Seton Dam showing water conveyance structures (left), fishway entrance are (bottom), and the radial gate spillway (top)

2.0 METHODS

2.1 Physical Parameter Monitoring

Monitoring of physical parameters important to salmon migration in the Seton-Anderson watershed began in 2012 and continued throughout the 2015 study period.

2.1.1 Discharge and Dilution Ratio

Discharge data for the upper Seton River and Cayoosh Creek were obtained from Water Survey Canada (WSC) and discharge data for Seton Dam, the Seton River spawning channels, and the Seton Generating Station were obtained from BC Hydro Power Records. Mean daily discharge for the upper Seton River and Cayoosh Creek was calculated from the hourly discharges recorded by WSC gauging stations 08ME003 (Seton River above Cayoosh Creek) and 08ME002 (Cayoosh Creek) (Figure 2-1). Mean daily discharge of individual conveyance structures at Seton Dam and the upper and lower spawning channels was calculated from the hourly discharge records provided by BC Hydro Power Records. Lower Seton River discharge was calculated as the sum of the discharge of the upper Seton River, Cayoosh Creek, and the spawning channels.

The mean daily dilution ratio for the Seton River was calculated by BC Hydro Power Records using the daily average discharge of each location in the following equation:

$$\text{Dilution Ratio (\%)} = \frac{\text{Cayoosh Creek}}{(\text{Cayoosh Creek} + \text{Seton River} + \text{Spawning Channels})}$$

2.1.2 Water Temperature

Water temperature data for 2012-2015 were collected at the water quality sites established in 2012-2014 (Figure 2-1; Table 2-1). TidbiT v2 water temperature loggers (±0.2°C accuracy) (Onset Computer Corporation Inc., Bourne, MA, USA) recorded hourly water temperature at all sites except at W07-SFW and W13-LGC where temperature was set to record at 15 min intervals starting in 2014. Duplicate temperature loggers were installed at most sites to ensure data security. In 2015, one logger at W04-LCC was lost during the spring freshet and was replaced 19 July 2015 (see Table 2-1).

Table 2-1: Locations of water quality sites and serial numbers for installed temperature loggers

Site	Description	UTM Coordinates	Serial #1	Serial #2
W01-LFR	Seton Generating Station	10 U 0576019 5613952	10206555	10170913
W02-UFR	Upper Fraser River	10 U 0575582 5615178	NA	NA
W03-LSR	Lower Seton River	10 U 0574397 5613831	10170909	10219612
W04-LCC	Lower Cayoosh Creek	10 U 0573069 5613554	10206558	10533125[b]
W05-USR	Upper Seton River	10 U 0572419 5613636	10219610	10170912
W07-SFW	Seton Dam Fishway	10 U 0572246 5613558	10206557	NA
W10-LPC	Lower Portage Creek	10 U 0550573 5617636	10219613	NA
W12-GSC	Gates Creek Channel	10 U 0536685 5599754	10219609	NA

W13-LGC	Lower Gates Creek	10 U 0537162 5599963	10219608 [a]	NA

[a] Installed 18 June 2014. [b] Logger 10206556 was lost during in early 2015 and was replaced.

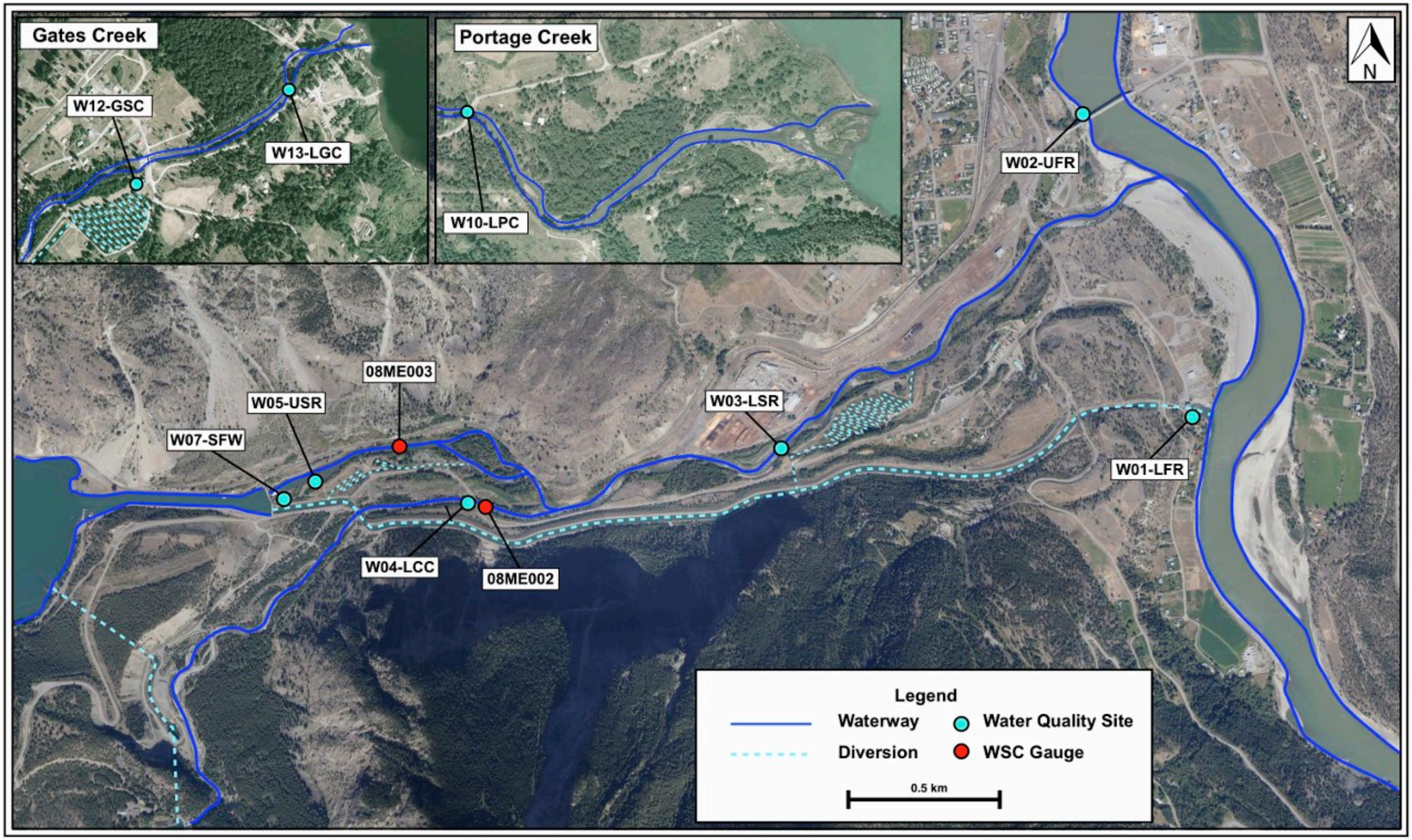

Figure 2-1: **Water quality sites in the Seton River (main map), Gates Creek spawning channel (insert, left), and Portage Creek (insert, right)**

Additional water temperature data were obtained for the Fraser River to estimate the thermal experience of salmon prior to entering the Seton River and temperature in the Fraser River between the Seton River and Seton Generating Station. Water temperature data were obtained from Fisheries and Oceans Canada for the Fraser River at Qualark Creek in 2012-2013 (UTM 10 U 613935 5488072) and from WSC station 08MF040 (Fraser River above Texas Creek) for 2013-2015 (Environment Canada – Water Survey Canada, 2015) as Qualark temperature monitoring was discontinued in 2014. For 2013-2015, the Fraser River temperature at Texas Ceek was used to represent the average thermal regime encountered by sockeye salmon during their upstream migration. Thermal experience was based on Fraser River entry dates and run duration reported in Hague and Patterson (2009), adjusted based on known migration rates to estimate run timing at Texas Creek for Gates Creek (10 July to 05 September) and Portage Creek (10 September to 06 October) sockeye salmon.

2.1.3 Water Chemistry

Specific conductivity measurements were collected to compare the water chemistry of the Seton River and Cayoosh Creek watersheds. As in 2013-2014, monitoring in 2015 was carried out at three sites: the lower Seton River (W03-LSR), lower Cayoosh Creek (W04-LCC), and the upper Seton River (W05-USR) above the Seton River-Cayoosh Creek confluence (Figure 2-1). Specific conductivity ($\mu S \cdot cm^{-1}$) measurements were taken using a hand-held YSI Pro30 conductivity meter (YSI Inc., Yellow Springs, OH, USA). Measurements were taken daily so long as personnel were available. Monitoring began on 01 August 2015 but was discontinued on 19 August 2015 due to a malfunctioning conductivity meter. A replacement conductivity meter could not be secured prior to the end of the Gates Creek sockeye salmon migration period.

2.2 Management Experiments

2.2.1 2014 Seton Dam Alternative Flow Scenario

In 2014, an alternative flow scenario was tested at Seton Dam to determine if using different conveyance structures to discharge water could reduce water velocities surrounding the fishway entrance and improve salmon passage. The University of Alberta was contracted to measure flow velocities and direction in the tailrace during the routine and alternate flow scenarios. Tagged fish were released during all flow scenarios. The alternative water flow scenario was implemented at Seton Dam between 08 and 19 August 2014. Prior to 08 August, BC Hydro operated Seton Dam according to routine operating procedures. On 08 August, discharge from the FWRG was reduced from 7.6 $m^3 \cdot s^{-1}$ to 1.9 $m^3 \cdot s^{-1}$ and discharge from the siphons changed from SSV1 to SSV4. On 19 August, BC Hydro returned Seton Dam to routine operating conditions during a scheduled ramp-down with FWRG flows increased to 2.5 $m^3 \cdot s^{-1}$ and siphon flows changed from SSV4 to SSV1.

A 2-dimensional ChannelMaster H-ADCP (Teledyne RD Instruments, Poway, CA, USA) was used to measure water velocity across 43 transects in the Seton Dam tailrace (Figure 2-2). The ADCP was either manually positioned from the river bank (S1 to S35) or lowered into the tailrace from the dam compound (S36 to S38) or fishway wall (X1 to X5) using a custom-built frame. Transects S1 to S38 were taken at a depth of 0.5 m, while transects X1 to X5 were taken every 0.5 m from 0.5 m below the water surface to 0.5 m above the river bed. Each transect was approximately 20 m long with water velocity measurements taken at 0.20 m to 0.25 m segments along the transect. Water velocity measurements were taken for a minimum of 5 min with a 5.5 s sampling interval. Particle tracking was used to estimate water velocities where the ADCP measurements were attenuated by highly turbulent and aerated water. Movements of test particles of known dimensions were recorded by digital video cameras recording at 120 frames per second and video analysis used to calculate surface water velocities.

River bathymetry was measured in October with a downward-facing 3.0 MHz RiverCat-ADP (SonTek, San Diego, CA, USA) mounted to aluminum hulls and towed across the tailrace. A total of 40 bathymetry transects were completed. The origin of each ADCP and bathymetry transect was measured using a RTK-GPS system (Trimble Navigation Limited, Sunnyvale, CA ,USA). ADCP and bathymetry data were post-processed using the software packages supplied by the ADCP manufacturers and imported to Microsoft Excel and Matlab for analysis.

Figure 2-2: **Acoustic Doppler Current Profiler measurement transects in the Seton Dam tailrace (S1-S38) and at the fishway entrance (X1-X5) in 2014**

2.2.2 2015 Experimental Dilution Ratio Increase

Walden North operations were modified in 2015 to increase dilution ratios in the Seton River and allow for study of the effect of above-target dilution ratios on the upstream migration behaviour of Gates Creek sockeye salmon.

On 07 August 2015, stop-logs were installed at the Seton Lake diversion tunnel, ceasing the diversion of Walden North discharge into Seton Lake and back-watering the Walden North tailrace. Culverts in the tailrace were opened to divert retained flows into Cayoosh Creek, increasing Cayoosh Creek discharge and the Seton River dilution ratio (see equation in Section 2.1.1). The modified flow regime was maintained until 14 August, at which time removal of the stop-logs was coordinated with closure of the diversion culverts to decrease Cayoosh Creek flows. Cayoosh Creek discharge was decreased over three days and was completed on 17 August. After 17 August, routine operations of Walden North occurred for the remainder of the 2015 study period.

2.3 Fish Passage Enumeration

A resistivity fish counter was operated at Seton Dam from 2012-2015 to estimate abundance and run timing for Gates Creek and Portage Creek sockeye salmon, coho salmon, Chinook salmon, and pink salmon in odd years. Operation of the counter has been consistent across years, with minor modifications each year to improve detection efficiency and validation capacity. Operations in 2015 are summarized below.

2.3.1 Resistivity Counter

On 29 July, the Seton Dam fish counter was reinstalled at the top of the Seton Dam fishway (Figure 2-3). The sensor unit consisted of eight independent sensor tubes connected to two Logie 2100c resistivity electronic fish counter (Aquantic Ltd., Scotland, UK). Each sensor tube was monitored by a single counter channel.

Detailed fish counter operation is summarized in the Year 1 report. Briefly, the counter operates by detecting a change in electrical resistance when fish swim through a sensor tube (Figure 2-3; Figure 2-4). The change in resistance is measured and an algorithm used to determine the direction of movement or if the fish entered the sensor unit but failed to pass. For detections meeting detection criteria, the date and time, conductivity, channel, direction (upstream or downstream), and peak signal size (PSS) are recorded. The PSS is a function of fish size, position in the sensor tube, electrode sensitivity, river conductivity, and bulk resistance (background resistance caused by flowing water). Minimum thresholds for detection were set (PSS of 40 out of 127) to eliminate resistance noise caused by air bubbles from the water surface or debris passing through the sensor tubes. Automatic re-calibrations of the sensor were programmed to occur every 30 min to compensate for changes in environmental conductivity. Detections were saved to one of eight channels on one of the two fish counters. Detection data was downloaded every 2-3 d during the study period.

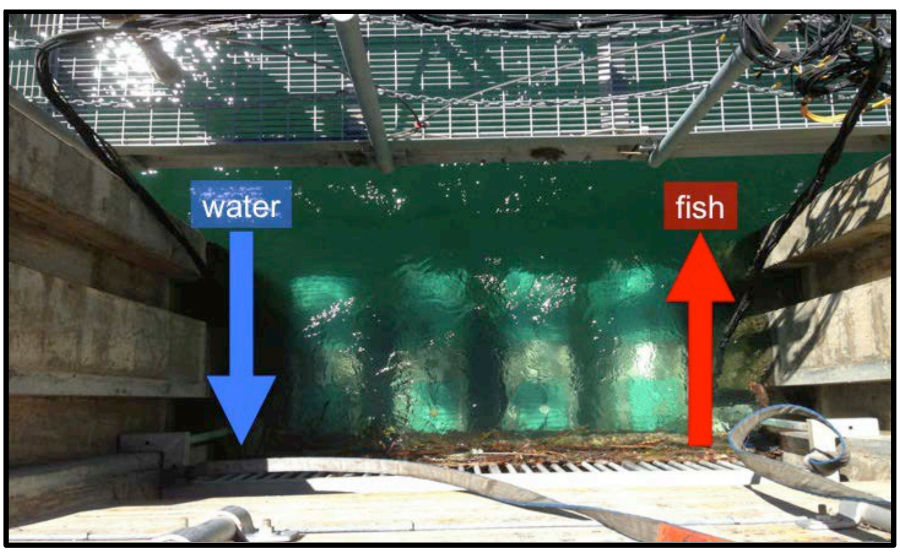

Figure 2-3: Overhead view of the resistivity counter sensor tubes installed at the exit of the Seton Dam fishway. Water flow and fish migration directions are indicated

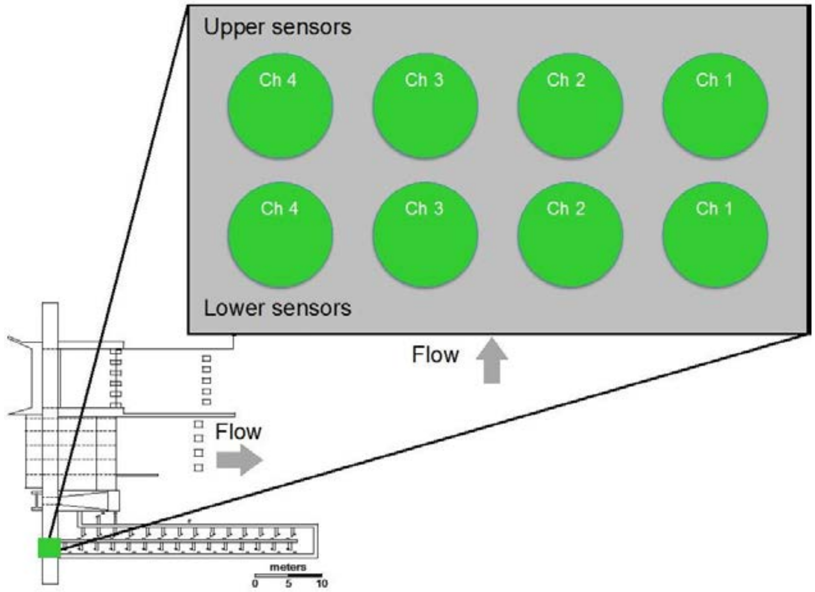

Figure 2-4: Schematic of the fish counter located at the exit of the Seton Dam fishway. The upper and lower sensors were monitored by two, four channel resistivity counters

2.3.2 Video Monitoring

Digital underwater video cameras were attached to the upstream end of each counter tube. This allowed for all eight tubes to be validated even when turbidity was high, an improvement from 2014 in which all eight tubes were validated but only when turbidity was low. Video was recorded from 12 August to 10 November and was saved to a digital-video recorder at 30 frames per second. Each camera has a light to aid nighttime viewing of fish, which allowed for species identification at night. Excessive algae growth in cameras prevented species identification of fish passing through two tubes during the day and night.

2.3.3 Data Analysis

For Gates Creek sockeye salmon, video recordings of fish passage were used to validate the counter detections and estimate the accuracy of each sensor tube. Recordings of fish passing through the counter were matched with the counter detections to determine the proportion of detections that were correctly recorded (accuracy). For each tube, 10 randomly–selected 10 min segments of video data were reviewed from every day between 20 August and 10 September. The number of fish validated was in proportion to the number of fish passing through each tube. Validation data was pooled for each sensor, resulting in a single accuracy for each sensor tube. The ratio of Gates Creek sockeye salmon to other species was estimated using video validation and incorporated into abundance estimates using the average ratio of Gates Creek sockeye salmon to other species for each tube. A similar approach was applied to Portage Creek sockeye salmon, pink salmon, and coho salmon but validation was conducted every second day for 5, 10-minute segments per day from 11 September to 23 October.

Abundance estimates for Gates Creek and Portage Creek sockeye salmon, pink salmon, and coho salmon were calculated by expanding the raw counter counts using up count accuracies and species ratios. Uncertainty in sensor accuracy methods and species ratios were incorporated into estimates of abundance in previous years using Monte Carlo simulations. The accuracy of upper sensor tube one was extremely low (<10%) due to debris caught in the sensor tube. To provide abundance estimates for this sensor tube, the daily number of fish recorded passing through the tube on the counter was correlated with the abundance of other sensor tubes.

Probability distributions for up count accuracy and species ratios were generated using a binomial beta distribution, which is a binomial distribution with a conjugate Beta prior:

$$\pi \sim \mathrm{B}(\alpha, \beta)$$

where π is the proportion of counts correctly classified, *B* is the binomial beta distribution, α and β are the alpha and beta parameters for the Beta distribution prior. Uniform priors were used in all simulations (i.e. the values of α and β were both 1).

The number of up counts for the target species was calculated as:

$$U_1^* = P_1^*(U - V_1) \qquad \text{equation 1}$$

where, U_1^* is the posterior distribution of the target species up count, and U is the up counts recorded by the counter for all species, P_1^* is the posterior distribution for the proportion of counts that are the target species, and V_1 is the number of target species up counts validated. Using the total up counts for the target species estimated in equation 1 the total abundance can be calculated by incorporating the uncertainty in sensor accuracy as follows:

$$S_1^* = \left[V_{U1} + \frac{U_1^*}{A_{U1}^*}\right] - \left[V_{D1} + \frac{U_1^*}{A_{D1}^*}\right] \qquad \text{equation 2}$$

where S_1^* is the posterior distribution for the abundance of the target species, V_{U1} and V_{D1} are the number of validated up and down counts for the target species, respectively. A_{U1}^* and A_{D1}^* are the posterior distributions for sensor accuracy for up and down counts for the target species, respectively. Downstream counts were ignored in abundance calculations because no sockeye salmon or coho salmon were observed moving downstream through the sensor tubes. For each Monte Carlo simulation 1,000 iterations were performed, which generated 1,000 abundance estimates. The mean abundance estimate 95% credible intervals are reported for Gates Creek and Portage Creek sockeye populations in 2013-2014 but could not be calculated in 2015 in time for the report deadline.

2.4 Telemetry

Telemetry studies were carried out on Gates Creek sockeye salmon exclusively in 2015. Portage Creek sockeye salmon were not targeted for telemetry studies in 2015 due to low forecasted abundance and overlap with pink salmon migration timing. Chinook and coho salmon, which were caught with low success in 2013 and 2014, were also not targeted for telemetry studies. Gates Creek sockeye salmon migration behaviour and success was monitored using radio and passive integrated transponder (PIT) telemetry in 2015. Radio transmitters were used to monitor fish migration from the Fraser River to spawning grounds. All radio-tagged fish received a PIT tag with additional Gates Creek sockeye salmon receiving only PIT tags. All methods involving animals were approved by the University of British Columbia Animal Care Committee.

2.4.1 Fish Collection

Fish tagged in 2015 were collected using a fully-spanning fish fence installed in the Seton River approximately 200 m downstream of Seton Dam (Figure 2-5). The installation location for the fence was the same as 2013 and 2014. Fence installation was completed on 30 July and the fence was removed on 28 September. Fence operation varied according to fish abundance and tagging efforts. During the majority of the Gates Creek sockeye salmon migration, the fence was closed (i.e. actively fishing) at approximately 06 00 h for five to eight hours each tagging day. Since sockeye primarily migrate at night, daytime closures minimized the likelihood of fence operations altering the behaviour of tagged salmon migrating through the system. Overall, limited recapture of tagged sockeye salmon occurred in 2015. When the fence was not operating, sections were removed to allow migration to continue unimpeded.

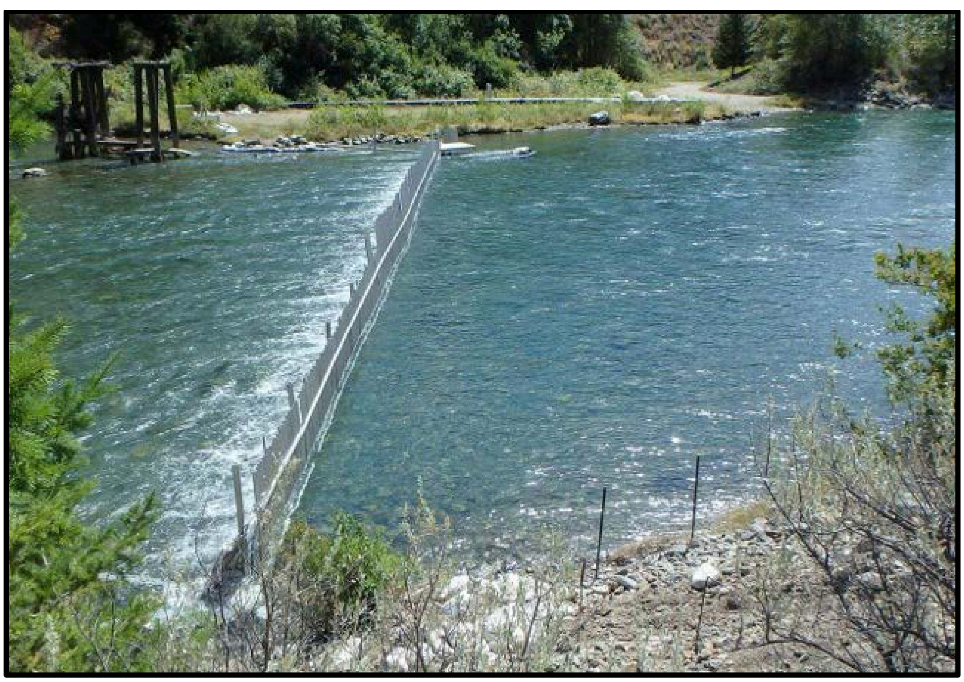

Figure 2-5: Full-spanning fish fence in the Seton River in 2015

2.4.2 Tagging and Sampling Protocol

Standardized protocols were used to tag and sample all fish. In 2015, fish received either a radio or PIT tag as a primary tag. No acoustic tags were deployed in 2015.

Tagging was performed at the site of the Seton River fish fence. Fish were transferred from holding pens to a V-shaped trough supplied with fresh water and manually restrained. An estimate of somatic lipid concentration was made using a fish Fatmeter (Distell, West Lothian, Scotland, UK) (Crossin and Hinch 2005). Based on 2013 and 2014 results, sockeye salmon collected during the Gates Creek migration period with an average Fatmeter reading greater than 2.7% were identified as strays and not tagged. Fork length was then measured to the nearest 0.5 cm and sex estimated.

All fish received a 32 mm HDX PIT tag (Oregon RFID, Portland, OR, USA) implanted in the dorsal musculature and a 12" spaghetti tag (Floy Tag & Mfg. Inc., Seattle, WA, USA) secured behind the dorsal fin. A subset of fish were radio-tagged with a Pisces5 radio transmitter (Sigma Eight Inc., Newmarket, ON, Canada) that was inserted into the stomach using a plastic plunger. Gates Creek sockeye salmon in 2013-2014 received an iButton DS1921Z or DS1922L temperature logger (Maxim Integrated, San Jose, CA, USA) with radio-tags but no iButtons were deployed in 2015. A DNA sample was taken from the adipose fin using a hole punch and stored on Whatman paper. Fish condition and injuries were then assessed and a photograph taken of the tagged fish. The average time to radio-tag a fish was approximately 3 min while the average time to PIT-tag a fish was approximately 2 min. Previously, all radio-and acoustic-tagged in 2013 and 2014 had 3 mL blood samples withdrawn using a caudal puncture (Houston 1990); however, no blood samples were collected in 2015. Blood samples were centrifuged and plasma withdrawn and frozen in liquid nitrogen before transfer to a -80°C freezer for storage.

A base level of injury assessment was applied to all fish in 2015. As in 2014, the severity of injuries was qualitatively assessed and, where possible, the origin of the injury was recorded (Table 2-2). Injury severity was assessed as either uninjured, minor (would not be expected to impair migration), moderate (could be expected to impair migration), or severe (expected to impair migration). Radio-tagged fish received a more-detailed injury assessment that was similar to that used in 2014 with new categories added to assess the extent of injury due to sea lice, classify the type of fin damage (if present), and classify the severity of gillnet damage. Some previously observed variables were not assessed (percent skin loss, gill condition) as these variables were either redundant (skin loss) or invasive to measure (gill condition).

Table 2-2: Injury monitoring protocol performed on radio-tagged fish in 2015

Injured?	Severity	Injuries Assessed	Injury Origin
Yes / No	Minor Moderate Severe	- Scale Loss (%), Fungus Cover (%), Sea Lice (%) - Wound Depth (1: Scales missing, skin visible; 2: Skin missing, muscle visible; 3: Missing muscle; 4: Organs, bones, cartilage visible) - Injured Eyes (0/1/2) - Fins Injured (0-7) - Fin Injury Type (exposed rays, split fin, portion missing, necrotic tissue, peripheral erosion, other)	Gillnet Sea Lice Hook Wound Predator Lamprey Unknown Other

	- Vent (Normal/Inflamed) - Old Wound (Presence/Absence)

2.4.3 Fish Releases

Fish tagged in 2015 were released either from the Upper Seton River fence site immediately after tagging or temporarily held post-tagging and then transported downstream to the Fraser River West site approximately 1 km downstream of the Seton Generating Station (Figure 2-6). Fish released at the Fraser River West site were transported in a 1,000 L aerated and oxygenated transport tank. Loading densities were approximately 50% of the maximum recommended loading density for adult salmon (Shepard and Bérézay 1987). Dissolved oxygen was maintained at 90-110% saturation and transport times from loading to released ranged from 25-35 min.

Releases from 2013 to 2015 are summarized in Table 2-3. Gates Creek sockeye salmon releases on the Fraser River in 2014 and 2015 occurred exclusively at the Fraser River West release site whereas releases in 2013 occurred at both the Fraser River West and East sites. Analysis of the 2013 telemetry data showed no effect of release site on survival to or passage of Seton Dam (see 2013 Annual Report – Appendix I); therefore, releases were pooled for analyses. The tag types deployed at each release site depended upon the suitability of each tag type for monitoring the upstream migration of fish. In 2015, radio- and PIT-tagged fish were released at the Fraser River West site with only PIT-tagged fish released at the Upper Seton River site. A total of 860 Gates Creek sockeye salmon were tagged and released in 2015.

Upstream capture and downstream release is a common method of studying salmon migration in regulated rivers (Thorstad et al. 2003; Naughton et al. 2005; Caudill et al. 2007) and there is little evidence to suggest that adult salmon have the ability to learn migration routes (Hansen and Jonsson 1994; Thorstad et al. 2003). Therefore, captured in the Seton River and released downstream in the Fraser River would be expected to behave the same as non-study fish.

Table 2-3: Summary of 2013, 2014 and 2015 releases of tagged fish

Species/ Stock	Tag Type	2013		2014		2015	
		Fraser River	Seton River	Fraser River	Seton River	Fraser River	Seton River
Gates Creek sockeye	Radio	168[a]	37[b]	166	-	206	-
	Acoustic	-	60[c]	-	45	-	-
	PIT	-	324[d]	191	565	197	457
Pink	Radio	58[e]	-	-	-	-	-
	PIT	-	280	-	-	-	-
Portage Creek sockeye	Acoustic	-	-	-	10	-	-
	Radio	24[f]	-	191	-	-	-
	PIT	-	14	193	241	-	-
Coho	Radio	-	-	7	-	-	-
	PIT	-	30	-	2	-	-
Chinook	PIT	-	1	-	-	-	-

[a] 2013 releases of Gates Creek sockeye occurred at the Fraser River West (*n*=81) and East site (*n*=87). [b] In 2013 only, radio-tagged Gates Creek sockeye were released in the Lower Seton River. [c] Acoustic releases

in 2013 were a combination of Upper (*n*=30) and Lower (*n*=30) Seton River releases. [d] PIT releases in 2013 were a combination of Upper (n=300) and Lower Seton River (*n*=24) releases. [e] Pink salmon were released at the Fraser River West (*n*=30) and East (*n*=28) sites. [f] Portage Creek sockeye were released at Fraser River West (*n*=12) and East (*n*=12) sites.

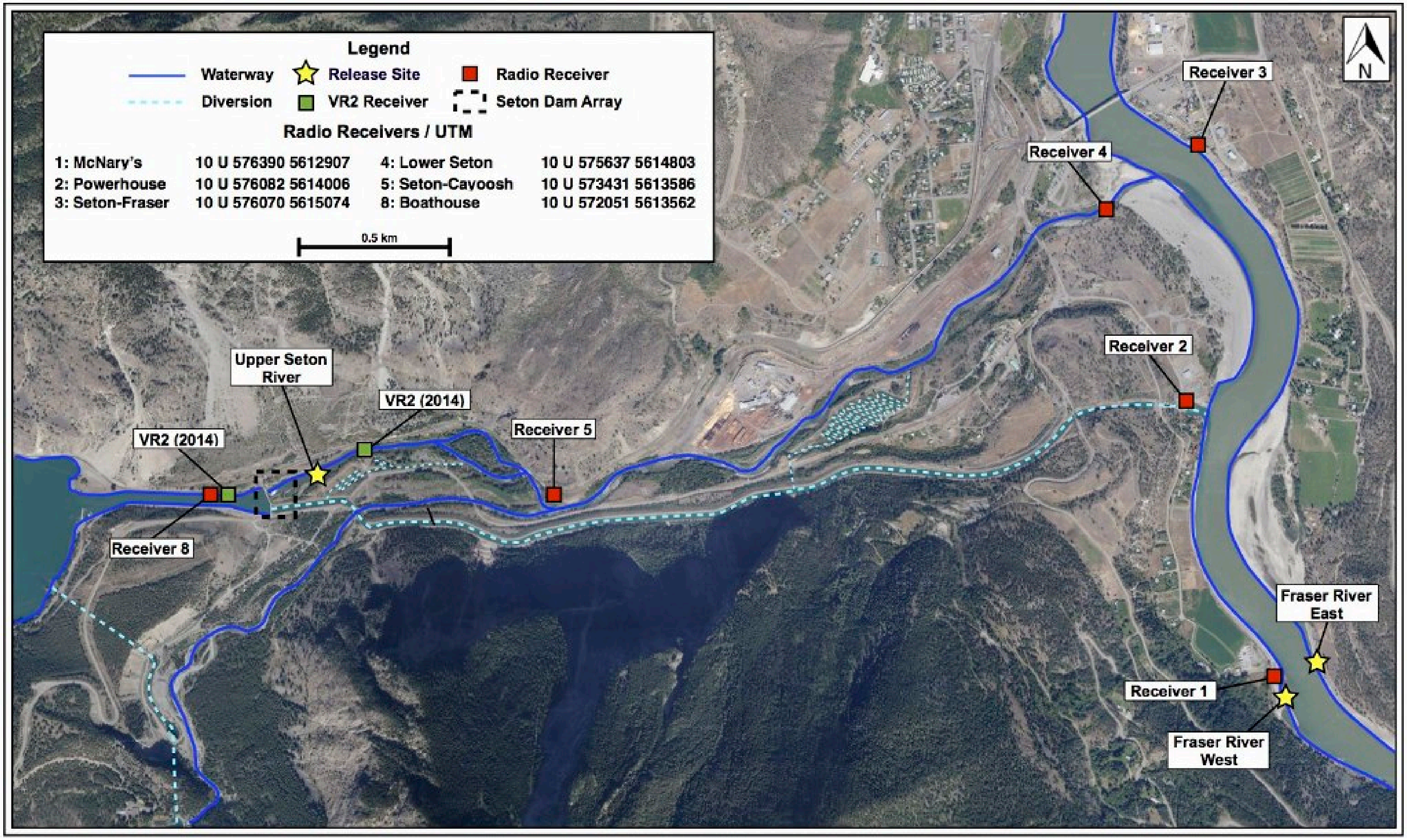

Figure 2-6: **Release sites, acoustic receiver installations, and radio receiver installations in the Fraser River, lower Seton River, Gates Creek, and Portage Creek in 2013-2015**

2.4.4 Telemetry Arrays

Migration of radio-tagged fish in 2015 was monitored using 11 radio receivers installed on the Fraser River, Seton River, Portage Creek, Gates Creek, and in the Seton Dam tailrace (Figure 2-6; Figure 2-7). Each receiver station consisted of an Orion (Sigma Eight Inc.) receiver connected to one or two Yagi 3 or 5-element antennas and powered by deep cycle batteries. Data on the radio receivers were downloaded frequently and batteries changed as required. Receivers with upstream and downstream antennas were used at the release site (Receiver 1) and the Seton River-Fraser River confluence (Receiver 3) to provide directional information on fish migration. At the Seton Generating Station (Receiver 2), the detection range was adjusted to provide coverage of the entire tailrace to the confluence with the Fraser River in order to detect fish entering and exiting the tailrace. In the Seton River, a receiver upstream of the confluence with the Fraser River confirmed river entry (Receiver 4) while a receiver upstream of the Cayoosh Creek confluence (Receiver 5) acted as a migration check-point. At Seton Dam, two receivers were used to detect arrival and residency in the tailrace (Receiver 6) and crossing attempts to the fishway entrance (Receiver 7). Passage of Seton Dam was confirmed with a receiver in the forebay (Receiver 8) and survival through Seton Lake assessed with a receiver at the entrance to Portage Creek (Receiver 9). Successful arrival at spawning grounds was confirmed with a receiver in lower Gates Creek (Receiver 10) and at the entrance to the Gates Creek spawning channel (Receiver 11). Mobile tracking was used for tag recovery (see Section 2.4.5). Acoustic telemetry was not used in 2015.

Pass-through PIT antennas were installed in the entrance and exit basins of the Seton Dam fishway (Figure 2-7), in lower Gates Creek (Figure 2-8), and at the Gates Creek spawning channel (Figure 2-8). PIT antennas at Seton Dam were constructed out of 1.5" polyvinyl chloride (PVC) pipe with 12-gauge stranded electrical wire and positioned on the upstream side of the vertical slot baffles in the fishway entrance and exit basins. Each antenna was connected to a remote tuner box (Oregon RFID, Portland, OR, USA) and a multi-antenna HDX reader (Oregon RFID). The antenna in the entrance basin was used to confirm entrance into the fishway and the antenna in the exit basin used to confirm successful passage of the fishway and Seton Dam. Seton Dam antennas operated continuously throughout the 2015 study period and were tested daily to ensure optimal read range (0.5 m) and performance.

Two PIT arrays were installed on Gates Creek on 21 July 2015. In lower Gates Creek, a 20 m wide full-span PIT antenna was installed 120 m upstream of Anderson Lake to confirm arrival at Gates Creek spawning grounds. Stranded electrical wire was fed through a garden hose held on the creek bed with sandbags and a loop returned across the stream to complete the pass-through antenna. Power to the antenna was provided by 3, 6V deep-cycle batteries running at 18V that were changed every 3-4 days. Due to malfunctioning battery charges, antenna coverage was not continuous, although the antenna was operating continuously during the peak spawning period for Gates Creek sockeye salmon (early September). Operation of the antenna continued until 20 September when a rain event increased Gates Creek flows and disabled the antenna. At the Gates Creek spawning channel, an AC-powered three-antenna 12V PIT array detected fish arrival at the channel and entrance into either the spawning channel or the diversion to Gates Creek. Antenna operation was continuous throughout the season with the exception of a brief power outage on 22 August. Removal of the Gates Creek fish fence on 18 September reduced the effectiveness of the PIT array as fish could access upper Gates Creek without entering the channel.

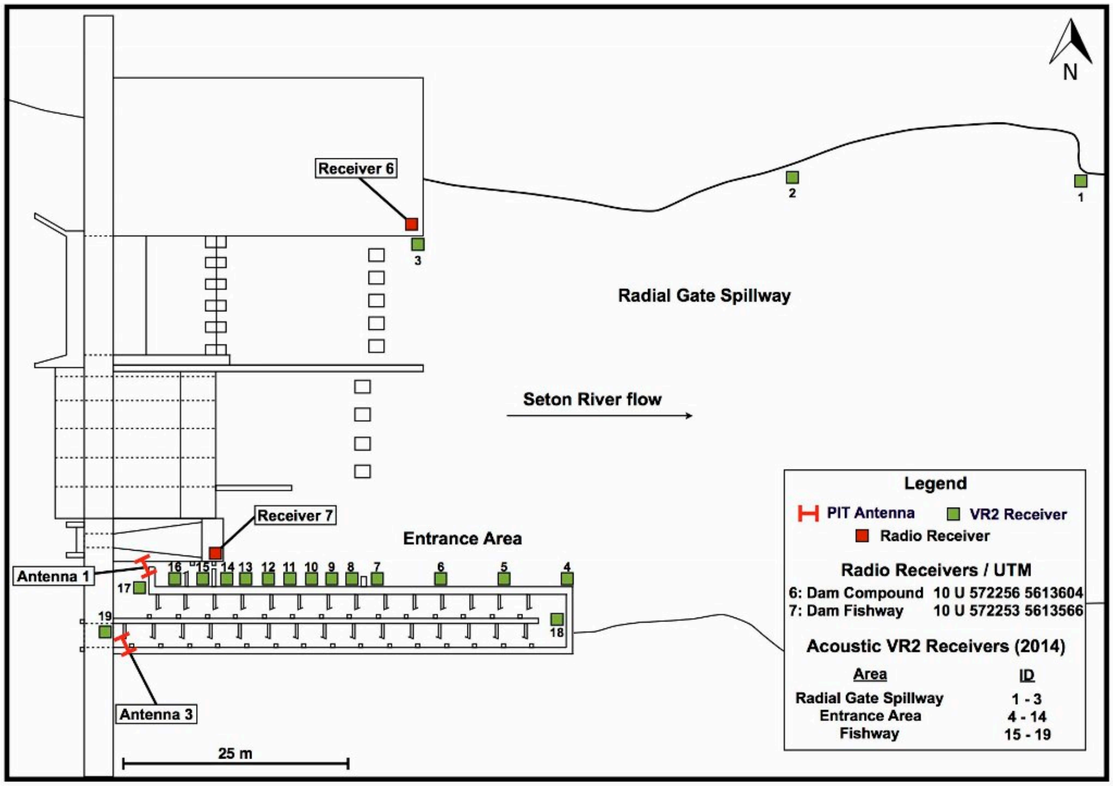

Figure 2-7: Location of radio receivers and PIT antennas in the Seton Dam tailrace and fishway in 2015. The detection range of radio Receiver 6 extended to the right-edge of the figure. Acoustic receivers deployed in 2014 are show for reference

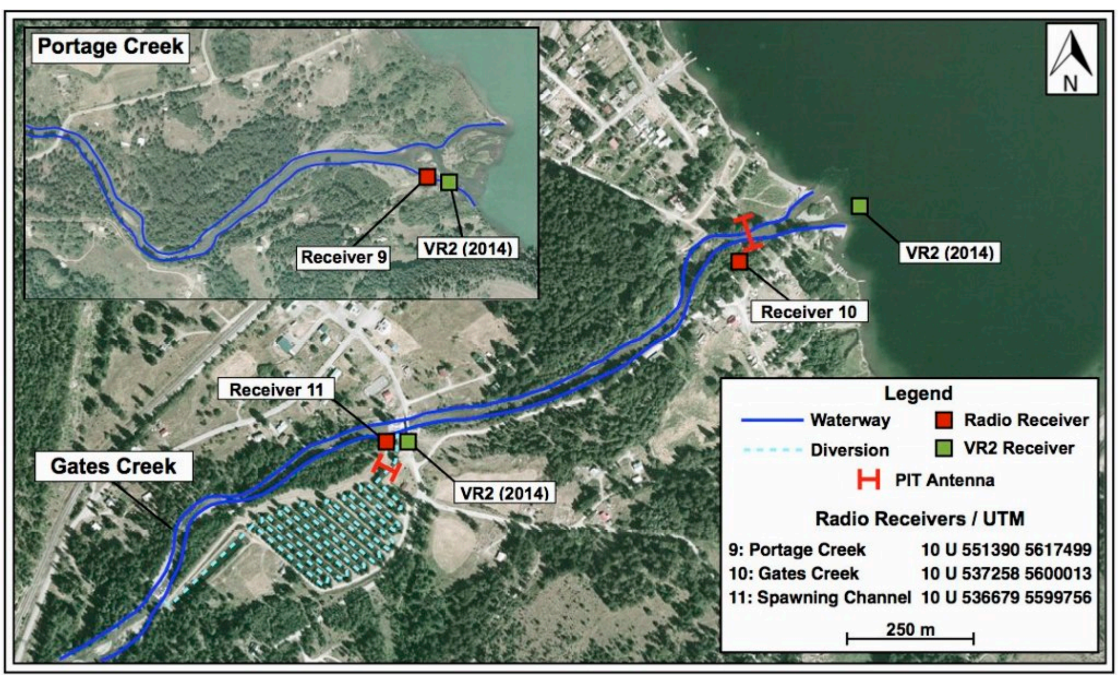

Figure 2-8: Location of radio receivers and PIT antennas in Portage Creek, Gates Creek and the Gates Creek spawning channel in 2015. Acoustic receivers deployed in 2014 are shown for reference

2.4.5 Tag Recoveries

Tags recoveries were carried out in the Seton River and Gates Creek in order to estimate the cause of migration failure, assess the spawning success of tagged fish, and provide a means to estimate the detection efficiency of the upstream-most telemetry arrays. Recovery efforts primarily focused on the Gates Creek spawning channel and Gates Creek. Deceased tagged fish were identified by the external spaghetti tag or, for radio-tagged fish, located using a portable SRX-400 radio receiver. Tags were removed from recovered fish and, where possible, sex reassessed and female spawning success estimated as either 0% (skeins tight, no egg deposition), 50% (partial egg deposition, >500 eggs remaining in body cavity), or 100% (<500 eggs remaining in body cavity). Limited tag recovery efforts took place at Portage Creek due to the low likelihood of recovering tags.

Tagged fish caught in local fisheries at Portage Creek or in the Fraser River were recovered through self-reporting by anglers, canvassing by UBC staff, or streamside surveys. Mobile tracking was used to estimate the number of radio tags that were captured but not reported, although this was not possible for PIT-tagged fish. Additional mobile radio tracking was performed on the Seton River, Bridge River, and Fraser River to locate tags from fish that did not migrate past Seton Dam. Radio transmitters that were repeatedly tracked to the same location but could not be recovered were classified as mortalities.

2.4.6 Data Quality Assurance

All data were subject to a quality assurance-quality control process. Raw field notes and digitally entered sampling data were reviewed to ensure the data were complete and accurate. Where possible, tag activation, deployment, and recovery records were cross-checked to ensure matching records. All radio telemetry data were filtered to remove detection errors, false detections and duplicate records. Individual detection histories were examined to ensure logical detection histories.

2.4.7 Data Analysis

Telemetry and spawning assessment data from 2013-2015 were used to quantify the migration behaviour and success of Gates Creek and Portage Creek sockeye salmon. Migration behaviour and success were assessed in three areas of the Seton-Anderson watershed: 1) from the Seton Generating Station to Seton Dam; 2) Within the Seton Dam tailrace, fishway, and forebay; and 3) from Seton Dam to spawning grounds at Gates Creek or Portage Creek. Stray sockeye salmon identified by stock identification DNA analysis or through gross somatic energy (GSE) screening during the Gates Creek sockeye migration (fat probe readings >2.7%) were removed from all analyses. No Portage Creek sockeye salmon were removed from analyses based on fat probe readings as the relationship between GSE estimates and stock identification has not been confirmed for this population. A subset of radio-tagged fish captured at the fishway in 2013 (n=69) were also removed from analyses because of the known effect of capture location (see 2013 Annual Report). Fish known to have been caught in fisheries on the Fraser River, Seton River, or Portage Creek were also removed. Blood samples were analyzed at the Fisheries and

Oceans Canada West Vancouver Laboratories (British Columbia, Canada). Due to time constraints, it was not possible to incorporate 2015 data into models developed for data collected in 2013 and 2014; therefore, data from 2015 is presented separately from 2013-2014 data. Data from 2015 will be incorporated with 2013-2014 data in future reports.

2.4.7.1 Migration from the Seton Generating Station to Seton Dam

The migration behaviour of Gates Creek and Portage Creek sockeye salmon at the Seton Generating Station tailrace and within the Fraser River was assessed using radio telemetry. Migration behaviour was quantified for individual radio-tagged Gates Creek (2013-2015) and Portage Creek (2013-2014) sockeye salmon using the following metrics: 1) the number of forays made into the Seton Generating Station tailrace; 2) the number of back-and-forth wandering movements prior to fish entering the Seton River; and, 3) the total time spent in the Seton Generating Station tailrace. Forays into the Seton Generating Station tailrace were defined as a series of detections occurring within 30 s of each other with the summed duration of detections used to calculate the total time in the tailrace. A fish was considering to have made multiple forays when the series of detections occurred at least 30 min apart. Wandering – used an index of exploratory behaviour within the Fraser River – was a count of the number of times an individual fish changed migration direction between the Seton Generating Station tailrace and the Seton River-Fraser River confluence. Fish with zero wandering events moved directly from the Seton Generating Station tailrace directly into the Seton River. Detection at Seton Dam was used as an overall measure of migration success as this was the first location PIT-tagged fish, that were co-released with radio-tagged fish as controls, could be detected. The behaviour of PIT-tagged fish at the Seton Generating Station could not be assessed; however, migration duration from release to detection at the Seton Dam fishway entrance was calculated for both radio and PIT-tagged fish.

For 2013-2015 data, differences in the number of forays and wandering events between sexes were tested for significance ($p<0.05$) with chi-squared tests. Non-parametric Wilcoxon rank-sum tests were used to test for differences between sexes in time spent in the Seton Generating Station tailrace, time in the tailrace for fish that were successful or unsuccessful at reaching Seton Dam, and differences in migration duration for radio and PIT-tagged fish. Finally, the migration histories of radio-tagged fish were visually assessed to determine individual fates. Fates were as assigned as 1) successful Seton River entry; 2) upstream migration in the Fraser River past the Seton River; 3) downstream migration in the Fraser River; and 4) unknown.

For 2013-2014 data, migration behaviour was related to the environmental conditions fish experienced during migration using linear models (LM) and generalized linear models (GLM). Model selection was carried out using a GLM for foray and wandering behaviour and an LM used for time spent in the tailrace. All explanatory variables were assessed for correlation and multicollinearity and excluded if $r^2>0.7$ (Zuur et al. 2010), variance inflation factor (VIF) >4 (O'Brien 2007), or if assumptions of normality, independence, or heteroscedasticity were violated. The GLMs for foray and wandering behaviour were initially fit with a Poisson distribution and assessed for over-dispersion, then subsequently fit with a negative-binomial distribution if determined to be over-dispersed. Model residuals were assessed visually following Zuur et al. 2010. Explanatory variables used in each model to define migration experience were (1) date and (2) year of tagging; (3) the dilution ratio; the temperature of the (4) Fraser River, (5) Seton Generating Station tailrace, and (6) Seton River and (7) the temperature differential between the Fraser River and Seton Generating Station tailrace with positive differentials indicating colder waters in the tailrace relative to the Fraser River. Environmental conditions experienced were calculated based on the migration histories of individual fish. Conditions during forays into the tailrace were calculated at the time of each tailrace entrance. Conditions during wandering events were calculated as means weighted by the proportion of time each fish spent at either the Seton River-Fraser River confluence or Seton Generating Station tailrace. Conditions during time spent in the tailrace were calculated as the overall mean of conditions fish experienced in the tailrace weighted by the duration of each foray event. Explanatory variables related to fish physiology also included were (8) sex; (9) plasma glucose concentration and (10) plasma lactate concentration (indicators of stress) and (11) testosterone (an indicator of maturity). For Gates Creek sockeye salmon, an interaction term (12) for sex and water temperature was also included, as migration behaviour was observed to differ between sexes with increased temperature in 2013 and 2014. Gates Creek sockeye salmon migration behaviour in 2013 and 2014 was also modeled separately due to marked differences in migration conditions. Portage Creek data were pooled across years due to low sample sizes in 2013 and similar migration conditions in 2013 and 2014. Blood samples were only processed for a subset of Portage Creek sockeye salmon; therefore, Portage Creek sockeye salmon migration was only modeled for a subset of fish (n=90). Discharge was not included as an explanatory variable as Seton River discharge displayed collinearity with the dilution ratio and Fraser River discharge during August was unlikely to affect migration (Martins et al. 2011).

All statistical analyses were conducted with R software version 3.1.3 (R Core Team 2015). To account for different measurement units amongst explanatory variables and to compare relative effect sizes within a model, continuous explanatory variables were standardized with a mean of zero and a standard deviation of two (Gelman 2008). A candidate model set was generated using the R package 'MuMIn' (Barton 2012) from all combinations of explanatory variables in each global model (Appendix I The candidate set was limited to models that maintained a 10:1 ratio of individuals to explanatory variables (Harrell 2001). Models in the candidate set were ranked by increasing order of the Akaike Information Criterion for small sample sizes (AIC_c) (Burnham and Anderson 2002) where the model with the lowest AIC_c is the most parsimonious one at describing the data while the AIC_c weight (w_i) is the probability that a given model within the candidate set is the most parsimonious model. Because AIC_c weights were small, a confidence set of best models from the candidate set was generated, which included models with cumulative AIC_c weights summed to 0.95 (Appendix I). Models in the confidence set were averaged using the 'natural average' methods to generate coefficient estimates and 95% confidence intervals for explanatory variables (Burnham and Anderson 2002; Grueber et al. 2011). Fit of linear models was evaluated using adjusted-R^2, and fit of GLMs was evaluated using a chi-squared test or pseudo-R^2 (Section 2.7.4.3) (Hosmer and Lemeshow 1989). This process was completed for the global model that describes each of the response variables in Section 2.7.4.1 and 2.7.4.3. Coefficient estimates and 95% confidence intervals were plotted for each averaged model. Untransformed data are presented as mean ± SE, unless otherwise indicated. Significance was tested at α=0.05.

For 2015 data, releases of Gates Creek sockeye salmon were pooled according to the week in August that fish were released. Migration behaviours were quantified for fish released in each week using the methods described above. Differences in the number of forays and wandering events between weeks were tested for significance ($p<0.05$) with chi-squared tests. Non-parametric Wilcoxon rank-sum tests were used to test for differences between weeks in the time fish spent in the Seton Generating Station tailrace, time in the tailrace for fish that were successful or unsuccessful at reaching Seton Dam, and differences in migration duration for radio and PIT-tagged fish.

2.4.7.2 Passage at Seton Dam

Radio, acoustic, and PIT telemetry data were used to calculate passage metrics at Seton Dam from 2012-2015. No acoustic transmitters were deployed in 2015. Passage metrics were calculated according to the definitions outlined in Table 2-4. Attraction efficiency, passage efficiency, and overall success were calculated from adjusted detection histories that used upstream detections to correct for <100% detection efficiencies of downstream radio, acoustic, and PIT arrays. For radio and acoustic-tagged fish, entrance delay was calculated for fish that were detected in the Seton Dam tailrace and at the fishway entrance. For PIT-tagged fish, entrance delay was calculated from the time of release from the Upper Seton River fence site.

For comparisons of passage success and post-passage survival between the routine and alternative flow scenarios, Monte Carlo simulations were used to generate posterior distributions (95% credible intervals) around the passage and survival estimates of PIT-tagged sockeye salmon. Simulations drew 1000 samples from a binomial Beta distribution. A GLM was used to predict spawning success. Explanatory variables were assessed for multi-collinearity and excluded if VIF <2 (Zuur et al. 2010). Explanatory variables included in models were 1) flow scenario (routine or alternative); 2) longevity on spawning grounds (in days); and 3) date of arrival on spawning grounds. All statistical analyses were conducted with R software version 3.1.3 (R Core Team 2015). Candidate models were generated and compared using the methods outlined in Section 2.4.7.1.

Table 2-4: Metrics used to assess Seton Dam fish passage and the calculations used according to tag type

Metric	Tag Type	Calculation
Attraction Efficiency	Radio Acoustic	$\frac{\text{Number of fish detected at the Seton Dam fishway entrance}}{\text{Number of fish detected in the Seton Dam tailrace}}$
	PIT	$\frac{\text{Number of fish detected at the Seton Dam fishway entrance}}{\text{Number of fish released into the Seton Dam tailrace}}$
Entrance Delay	Radio Acoustic	$\left(\begin{array}{c}\text{Time of first detection at}\\ \text{Seton Dam fishway entrance}\end{array}\right) - \left(\begin{array}{c}\text{Time of first detection in}\\ \text{Seton Dam tailrace}\end{array}\right)$
	PIT	$\left(\begin{array}{c}\text{Time of first detection at}\\ \text{Seton Dam fishway entrance}\end{array}\right) - \left(\begin{array}{c}\text{Time of release into}\\ \text{Seton Dam tailrace}\end{array}\right)$
Passage Efficiency	Radio Acoustic PIT	$\frac{\text{Number of fish detected at the Seton Dam fishway exit}}{\text{Number of fish detected at the Seton Dam fishway entrance}}$

Overall Success	Radio Acoustic	$\frac{\text{Number of fish detected at the Seton Dam fishway exit}}{\text{Number of fish detected in the Seton Dam tailrace}}$
	PIT	$\frac{\text{Number of fish detected at the Seton Dam fishway exit}}{\text{Number of fish released into the Seton Dam tailrace}}$

2.4.7.3 Migration to Spawning Grounds

Survival to spawning grounds and migration duration were determined for radio-tagged and PIT-tagged Gates Creek sockeye salmon from 2013-2015. Survival of Gates Creek sockeye salmon to spawning grounds was defined as the detection of a tagged fish on any of the telemetry arrays installed on spawning grounds (see Section 2.4.4) or recovery of at least one tag from a fish on spawning grounds. The percentage of fish surviving to spawning grounds was based upon the proportion of fish detected on spawning grounds after being detected at the fishway exit basin at Seton Dam (post-passage survival) or from release (overall survival). Migration duration to spawning grounds was calculated from the last detection at the Seton Dam fishway exit basin to the first detection on the Gates Creek telemetry array.

For radio-tagged Gates Creek sockeye salmon that successfully passed Seton Dam in 2013-2014, model averaging was used to examine the relative importance of migration experience and physiology to migration outcomes. Explanatory variables related to migration experience that were used for modeling were the year and date of tagging, the maximum discharge experienced in the Seton Dam tailrace, the maximum temperature experienced in the Seton Dam fishway or tailrace, the temperature regime experienced by fish in Seton Lake and Anderson Lake, and the date of arrival on spawning grounds. The temperature regime experienced by fish was calculated only for females in 2014 where the radio transmitter was recovered and the attached iButton temperature logger was intact. The temperature regime was calculated as the proportion of time female fish spent within an optimal temperature (T_{opt}) window (13.4-19.5°C) during their migration through Seton Lake and Anderson Lake. Temperatures for the T_{opt} window were based on previous studies with Gates Creek sockeye salmon (Eliason et al. 2011). Explanatory variables related to fish physiology also included in modeling were fork length, sex, and blood parameters plasma glucose and plasma lactate concentration (indicators of stress) and plasma testosterone and plasma estradiol concentration (indicators of maturation).

Migration outcomes modeled for Gates Creek sockeye salmon were: 1) survival to spawning grounds; 2) migration duration; 3) reproductive longevity; and, 4) egg retention. Survival to spawning grounds was modeled for fish that successfully passed Seton Dam (n=233; 2013: 37 males, 52 females; 2014: 61 males, 83 females) and migration duration was modeled for fish that reached Gates Creek (n=150; 2013: 25 males, 23 females, 2014: 52 males, 50 females).Reproductive longevity – the number of days spent on spawning grounds – was calculated for females recovered at the Gates Creek spawning channel in 2014 (n=39) and was the time difference between first detection on either the radio or PIT-array at the spawning channel entrance and the date each fish was removed from the channel during tag recoveries. Egg retention data (see Section 2.4.5) was only incorporated for females assessed for spawning in 2014 (n=38) as very few females were recovered on spawning grounds in 2013.

GLMs were used to predict survival to spawning grounds and egg retention and LMs used to predict migration duration in Seton Lake and Anderson Lake and reproductive longevity. All explanatory variables were assessed for correlation and multicollinearity and excluded if $r^2>0.7$ (Zuur et al. 2010), variance inflation factor (VIF) >4 (O'Brien 2007) or if assumptions of normality, independence, or heteroscedasticity were violated. Model residuals were assessed visually following Zuur et al. 2010. Explanatory variables included in each model varied. Models for survival to spawning grounds and migration duration included (1) year and (2) date of tagging; (3) sex; (4) fork length; (5) plasma glucose, (6) plasma lactate, and (7) plasma testosterone concentration; (8) maximum Seton Dam discharge; and (9) maximum fishway temperature. Sex and year was not included as an explanatory variable in the egg retention model as this model was for females tagged in 2014 only; however, (1) fork length, (2) plasma glucose, (3) plasma lactate, (4) plasma estradiol, (5) maximum Seton Dam discharge, and (6) maximum fishway temperature were included, as was (7) proportion of time in the T_{opt} window. The reproductive longevity model used the same variables as the egg retention model but also included (8) date of arrival on spawning grounds. Date of arrival was excluded from the egg retention model because it was collinear with maximum temperature and discharge (VIF>6) as was date of tagging (VIF>4), which was also excluded from both the reproductive longevity and egg retention models. Reproductive longevity and egg retention were modeled separately to assess whether the underlying physiological mechanisms differed for these migration outcomes. Two-sample t-tests were used to compare the reproductive longevity and arrival date at Gates Creek of females that did and did not retain eggs and to compare estradiol concentrations between years.

All statistical analyses were performed using the methods outlined in Section 2.4.7.1. The candidate sets for the egg retention and reproductive longevity models were limited to models with three or fewer explanatory variables to maintain a 10:1 ratio of individuals to variables (Harrell 2001).

2.5 Water Preference Experiments

Water preference experiments were carried out in 2013 and 2014 to determine if migrating Gates Creek and Portage Creek sockeye salmon displayed a preference for Seton River water versus Seton River water diluted with Cayoosh Creek water. Water preference experiments were not carried out in 2015.

2.5.1 Fish Collection and Holding

Gates Creek sockeye salmon were collected in 2013 from 03 to 24 August (n=174) and in 2014 from 01 to 29 August (n=164). Portage Creek sockeye salmon were collected in 2014 from 29 September to 09 October (n=108). All Gates Creek sockeye salmon were individually captured via dip net from the exit basin of the Seton Dam fishway while all Portage Creek sockeye salmon were collected from the Seton River fish fence (see Section 2.4.1). Upon collection, Gates Creek sockeye salmon were screened using the Fatmeter to identify and remove potential strays. Portage Creek sockeye salmon were not screened with the Fatmeter. Collected fish were transported in a 1,000 L oxygenated transport tank in groups of 12 to a holding tank at the Seton Dam compound and placed in individual isolation chambers made from PVC pipe measuring 8" in diameter and 28" in length for one to eight hours prior to experiments.

2.5.2 Test Apparatus

Water preference experiments were carried out at the Seton Dam compound in a custom-built Y-Maze apparatus (Figure 2-9; Figure 2-10). Water supply for the Y-Maze was supplied by two 11,365 L polyethylene supply tanks (Premier Plastics Inc., Delta, BC, Canada) One supply tank was used exclusively for Seton River water while the other contained the test mixture of Seton River water diluted with Cayoosh Creek water. Seton River water was pumped directly into the supply tanks using a submersible pump installed on the upstream side of Seton Dam. Cayoosh Creek water was trucked from Cayoosh Creek to the supply tanks using a 2,000 L transport tank. Prior to water transport, the transport tank was disinfected with Ovadine (Syndel Laboratories, Qualicum Beach, BC, Canada) to eliminate any residual odours. Each supply tank was filled with fresh water at the start of each day and the test mixture dilution ratio was pre-mixed in the supply tank. Tanks were refilled during the day as required and drained at the end of each experiment day. Water from the tanks was gravity-fed to two 1,135 L mixing tanks before draining into the Y-Maze.

The Y-Maze was a custom-built plywood test chamber (Figure 2-10) sealed with fiberglass and an odorless waterproof gel-coat. During dilution ratio experiments, water from each mixing tank gravity-fed into one of two test arms at a rate of 40 $L \cdot min^{-1}$. Dye-testing was used to confirm that water flow was unidirectional and there was no exchange of water between the two arms. Water depth in the Y-Maze was 0.6 m. For all trials, the test mixture was alternated daily between arms to control for any bias. During experiments, the test chamber was covered to prevent external visual cues from altering salmon behaviour. Behaviour of salmon was monitored remotely using a video camera installed at the rear of the test chamber and video saved to a DVR unit.

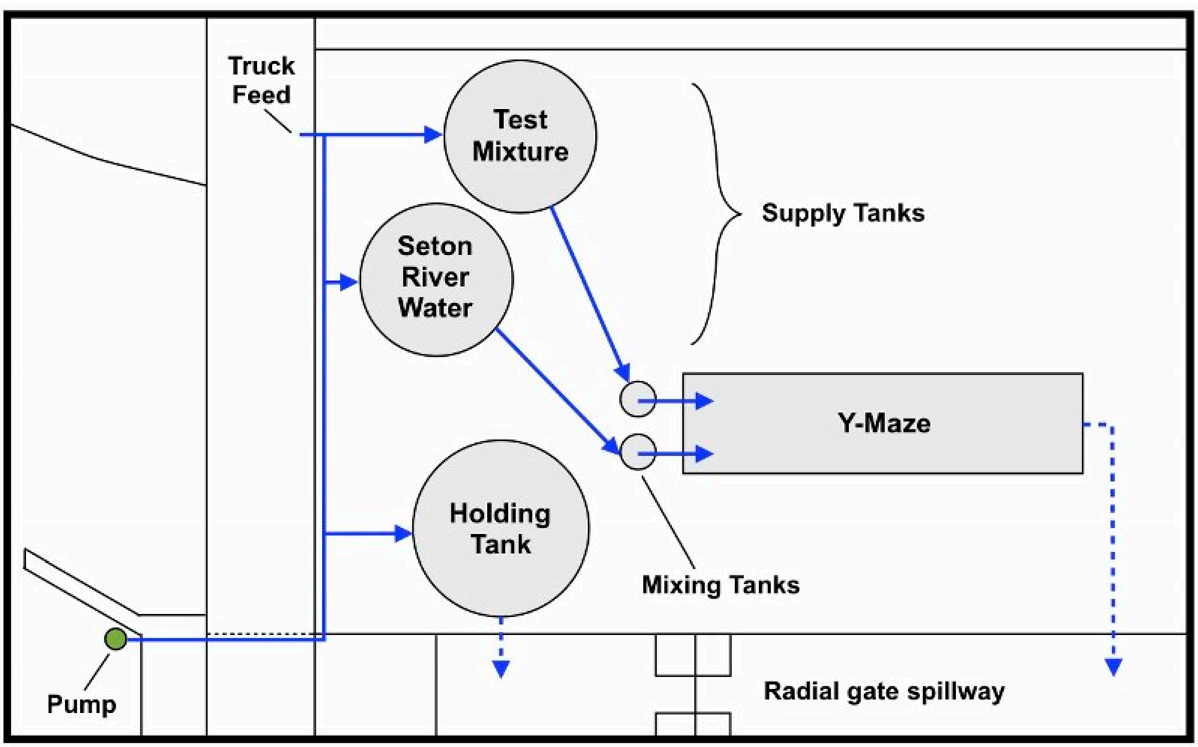

Figure 2-9: **Overview of the Y-Maze test apparatus installed at the Seton Dam compound. Supply tanks were filled with water pumped from the Seton River or truck-transported from Cayoosh Creek and drained into supply tanks (truck feed)**

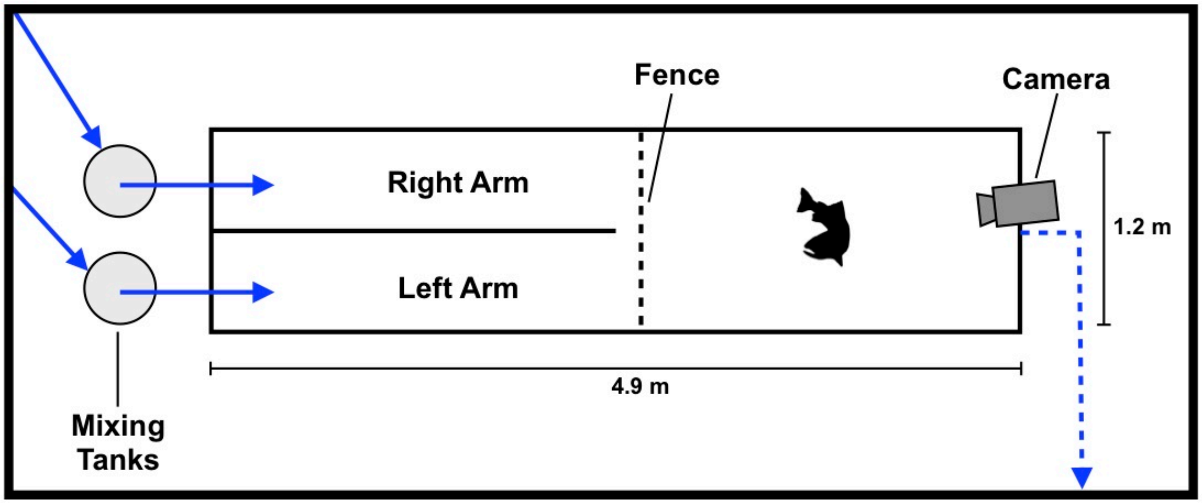

Figure 2-10: **Detailed view of the Y-Maze used for water preference experiments**

2.5.3 Experimental Protocol

Test fish were transferred from the isolation chambers to the Y-Maze and released. Each fish was allowed 10 min to acclimate to the Y-Maze prior to experiments. During the acclimation period, a temporary fence was placed at the entrance to the Y-Maze arms to prevent fish from accessing the arms but still allowed water to flow from each arm into the rear section of the Y-Maze. At the end of the acclimation period, the fence was removed and behaviour of the fish observed for 20 min. Fish were sampled at the end of the experiment using the same protocol as tagged fish (see Section 2.4.2). All fish were sampled for fork length, sex, blood, and DNA for stock identification. Fat content was only measured for Gates Creek sockeye salmon.

Different dilution ratios were tested in 2013 and 2014. In 2013, Gates Creek sockeye salmon water preference experiments were carried out at 0% (Seton River water in both arms), 5%, 20% (current dilution ratio target), and 50%. In 2014, Gates Creek sockeye salmon were only tested at a 30% dilution ratio. Portage Creek sockeye salmon water preference was tested in 2014 at dilution ratios of 10% and 20%. The need to test Portage Creek sockeye salmon at a dilution ratio of 0% was eliminated by alternating the test mixture between Y-Maze arms.

2.5.4 Data Analysis

Fish behaviour during water preference experiments was analyzed to determine the number of times a fish entered each arm of the Y-Maze, the amount of time spent in each arm, and the proportion of time spent in each arm. The time in each arm for all individuals within a treatment group was tested for normality using the Shapiro-Wilk normality test. If normally distributed, a student's t-test was used to compare the time spent in each arm. If not normally distributed, a Wilcox signed rank-test was used instead. Individuals that did not enter either arm of the Y-Maze were removed from analysis as were individuals that spent less than 5 min in the two arms combined. Stock identification DNA analysis identified a small number of stray sockeye that were removed from analysis in 2013 (n=10) and 2014 (n=10).

3.0 RESULTS

3.1 Physical Parameters

Conditions in the Fraser River and Seton River in 2013-2015 are summarized below with conditions at Seton Dam summarized for 2012-2015.

3.1.1 Discharge and the Dilution Ratio

Discharge and the dilution ratio in the Seton River during the Gates Creek sockeye salmon migration period (20 July to 31 August) varied both within and between years. Increases in discharge (Figure 3-1) and the dilution ratio (Figure 3-2) typically resulted from planned operational changes at Walden North, as Seton Dam discharges were maintained within the WUP target hydrograph each year and Cayoosh Creek discharge was low during August. For example, from 07 to 16 August 2013, Walden North maintenance ceased flows into the Seton Lake diversion tunnel, increasing Cayoosh Creek flows by ~10 $m^3 \cdot s^{-1}$ and increasing the lower Seton River dilution ratio to 27-41%. In 2015, a planned experimental dilution ratio increase occurred from 07 to 13 August 2015 that diverted Walden North flows into Cayoosh Creek, increasing discharge by ~7 $m^3 \cdot s^{-1}$ and the lower Seton River dilution ratio to 28-29%. The 2015 increase was temporary and a ramp-down that started 14 August 2015 returned Cayoosh Creek discharge to pre-experiment levels over 4 d such that the dilution ratio was 9% on 18 August 2015. Outside of these periods, natural fluctuations in discharge and the dilution ratio were brief and infrequent, with rain events increasing Cayoosh Creek discharge and the dilution ratio at either the start (2013, 2014) or end (2015) of the Gates Creek sockeye salmon migration period; however, few Gates Creek sockeye were migrating during these periods (see Section 3.3).

Decreases in discharge and the dilution ratio were also observed. In 2014, an experimental flow scenario at Seton Dam increased discharge from 08 to 19 August 2014 by ~4 $m^3 \cdot s^{-1}$, decreasing the dilution ratio from ~7% to ~5%, the lowest dilution ratios observed from 2013-2015. Overall, mean lower Seton River discharge during the Gates Greek sockeye salmon migration period was 34.6 $m^3 \cdot s^{-1}$, 33.4 $m^3 \cdot s^{-1}$, and 28.1 $m^3 \cdot s^{-1}$ in the years 2013-2015, respectively.

Increases in discharge and the dilution ratio during the Portage Creek sockeye salmon migration period (28 September to 15 November) occurred in 2014 and 2015 following rain events. Changes in the dilution ratio were typically greater during the Portage Creek sockeye salmon migration period relative to the Gates Creek sockeye salmon migration period because Seton Dam discharge was decreased mid-September to <20 $m^3 \cdot s^{-1}$ following the WUP target hydrograph (Figure 3-1). As a result, Portage Creek sockeye salmon experienced dilution ratios up to 45% in 2014, with above target ratios occurring for 21 of 49 days during the migration period, and dilution ratios up to 39% in 2015, with the dilution ratio exceeded for 48 of 49 days in 2015. However, the dilution ratio was typically within 3% of the 10% target ratio for Portage Creek sockeye salmon with the dilution ratio exceeding 13% for 12 days in 2014 and 16 days in 2015. Mean Seton River discharge during the Portage Creek sockeye salmon migration period was 17.6 $m^3 \cdot s^{-1}$, 19.3 $m^3 \cdot s^{-1}$, and 17.9 $m^3 \cdot s^{-1}$ in the years 2013-2015, respectively.

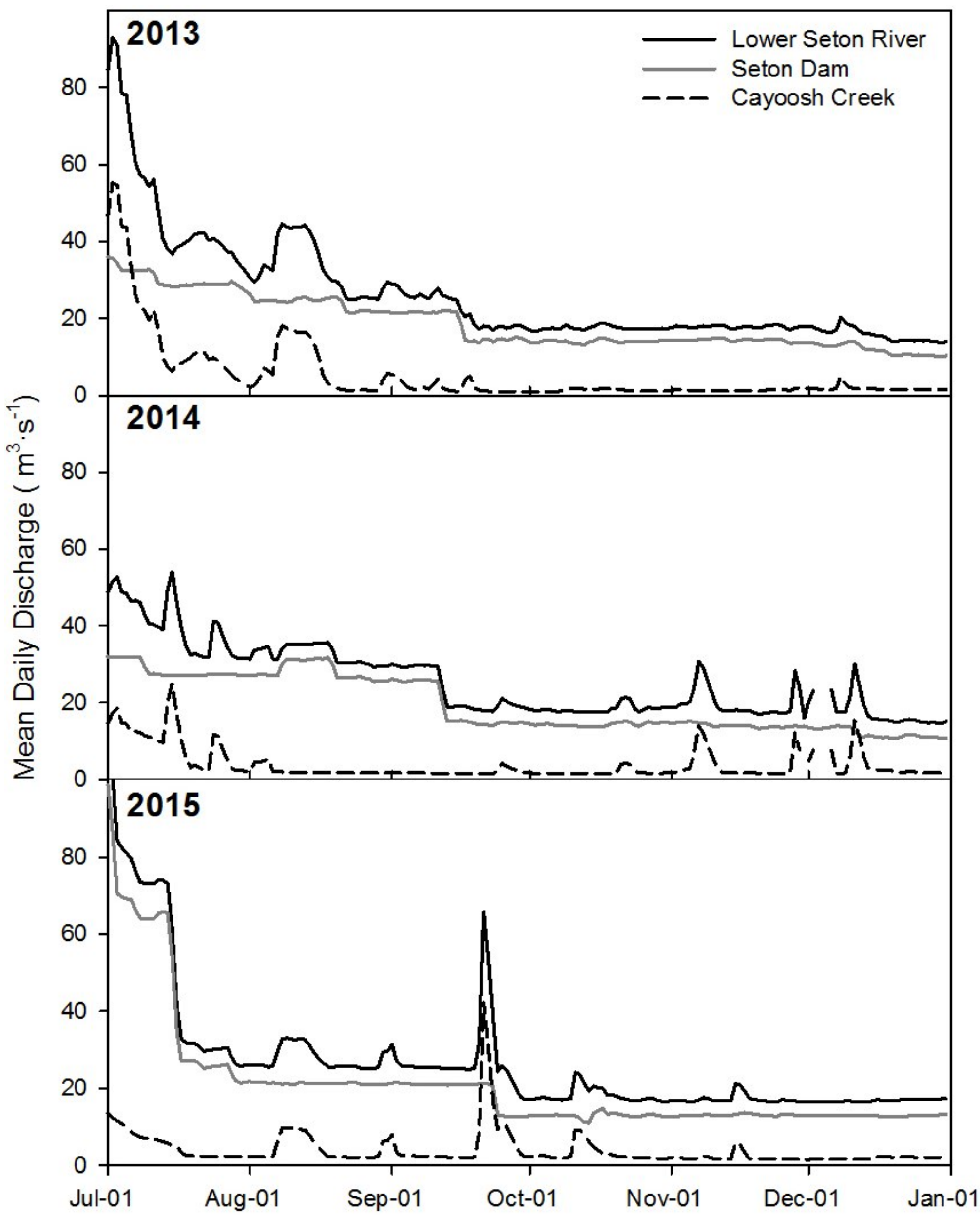

Figure 3-1: Discharge in 2013-2015 for waterways used to calculate the dilution ratio in the lower Seton River (BC Hydro data). Spawning channel discharge was constant in 2013-2015 and is not shown

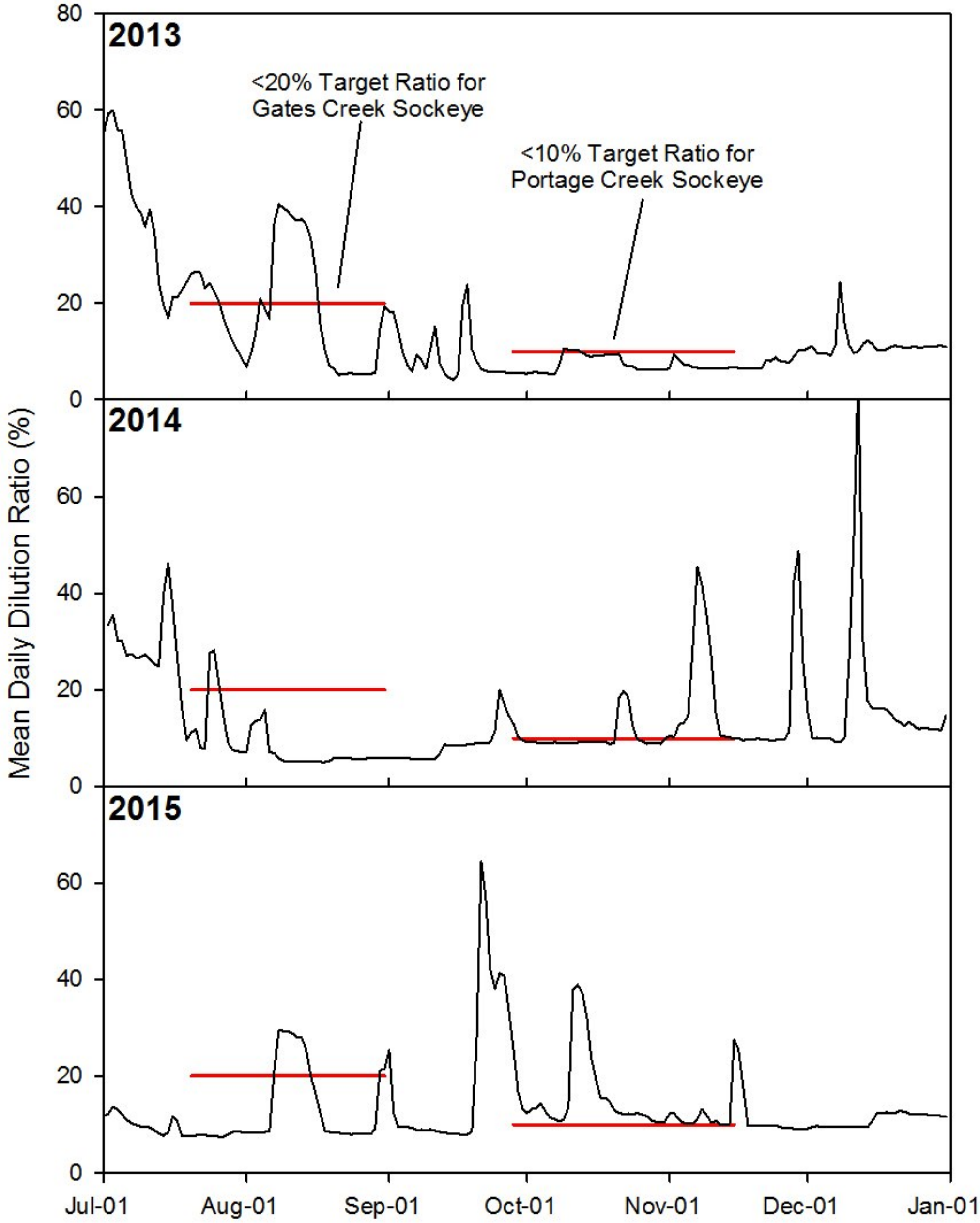

Figure 3-2: Daily dilution ratio of the Seton River in 2013-2015 (BC Hydro data). Target dilution ratios for the Gates Creek (<20%) and Portage Creek (<10%) sockeye salmon migration periods are shown in red (BC Hydro 2011)

Seton Generating Station operations varied during the Gates Creek sockeye salmon migration period in 2013-2015 (Figure 3-3). From 20 July to 26 August 2013, daily shutdowns occurred at night for 4-19 h with the majority of shutdowns lasting 5-7 h. Water was not discharged into the tailrace during these periods; therefore, Gates Creek sockeye salmon would not receive any Seton River olfactory cues from the tailrace during shutdowns. In 2014 and 2015, shutdowns were required on days Seton Dam conveyance structures were changed or a ramp-down occurred (2014: 08, 18 August, 12 September; 2015: 07,14 August). However, outside of these operations, shutdowns were infrequent.

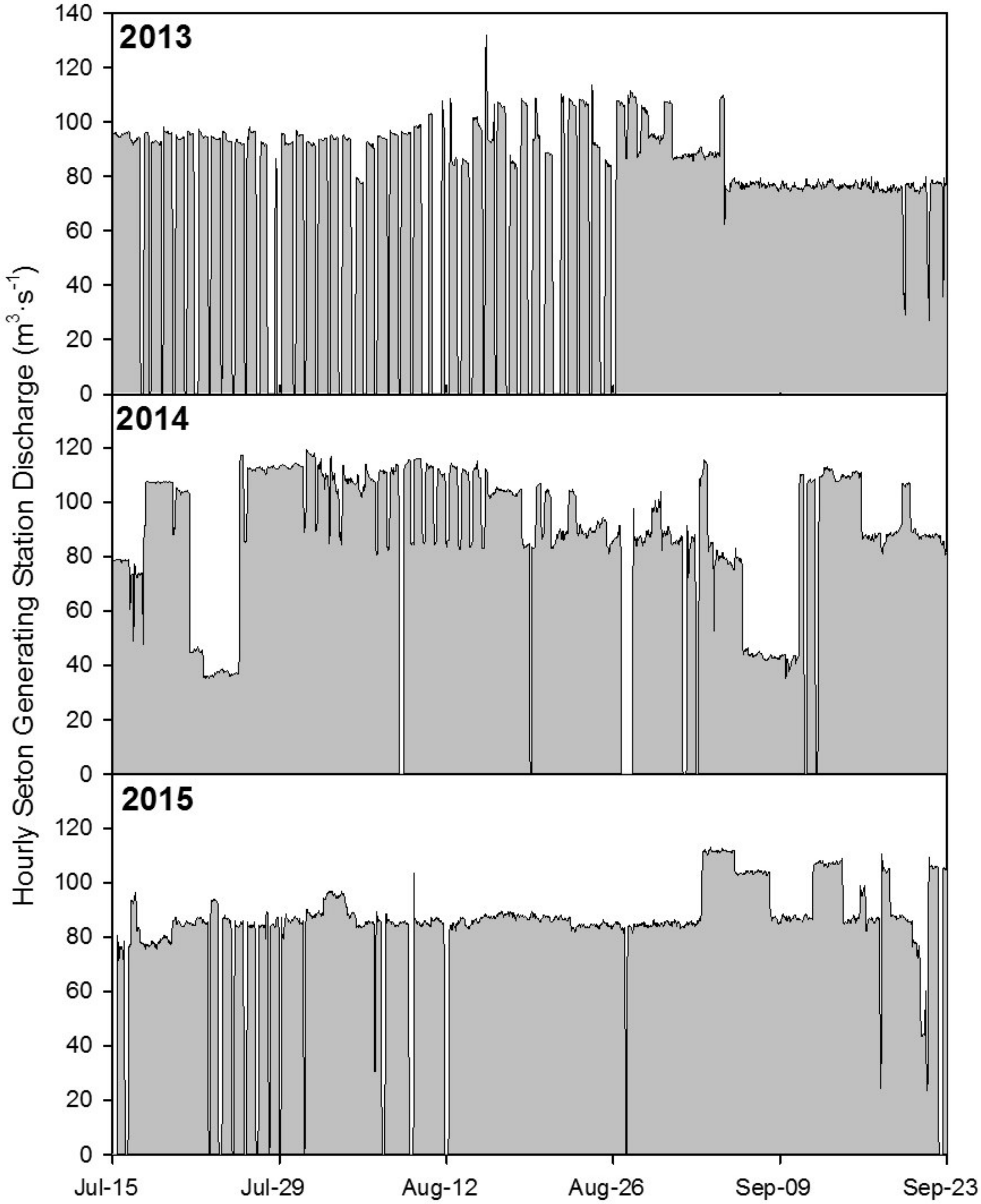

Figure 3-3: Seton Generating Station discharge from 15 July to 23 September, encompassing the Gates Creek sockeye salmon migration period (20 July – 31 August) (BC Hydro data). Gaps in the grey areas indicate Seton Generating Station shutdowns

Shutdowns at the Seton Generating Station also occurred during the Portage Creek sockeye salmon migration period (Figure 3-4). Shutdowns primary occurred in the first week of October 2014, although reductions in discharge also occurred early-September 2013 and 2015. Like Gates Creek sockeye salmon, Portage Creek sockeye salmon migrating past the Seton Generating Station during these shutdowns would not have encountered any natal water olfactory cues in the tailrace. For both Gates Creek and Portage Creek sockeye salmon telemetry, shutdowns were accounted for by calculating tailrace conditions at the time of each tailrace entry.

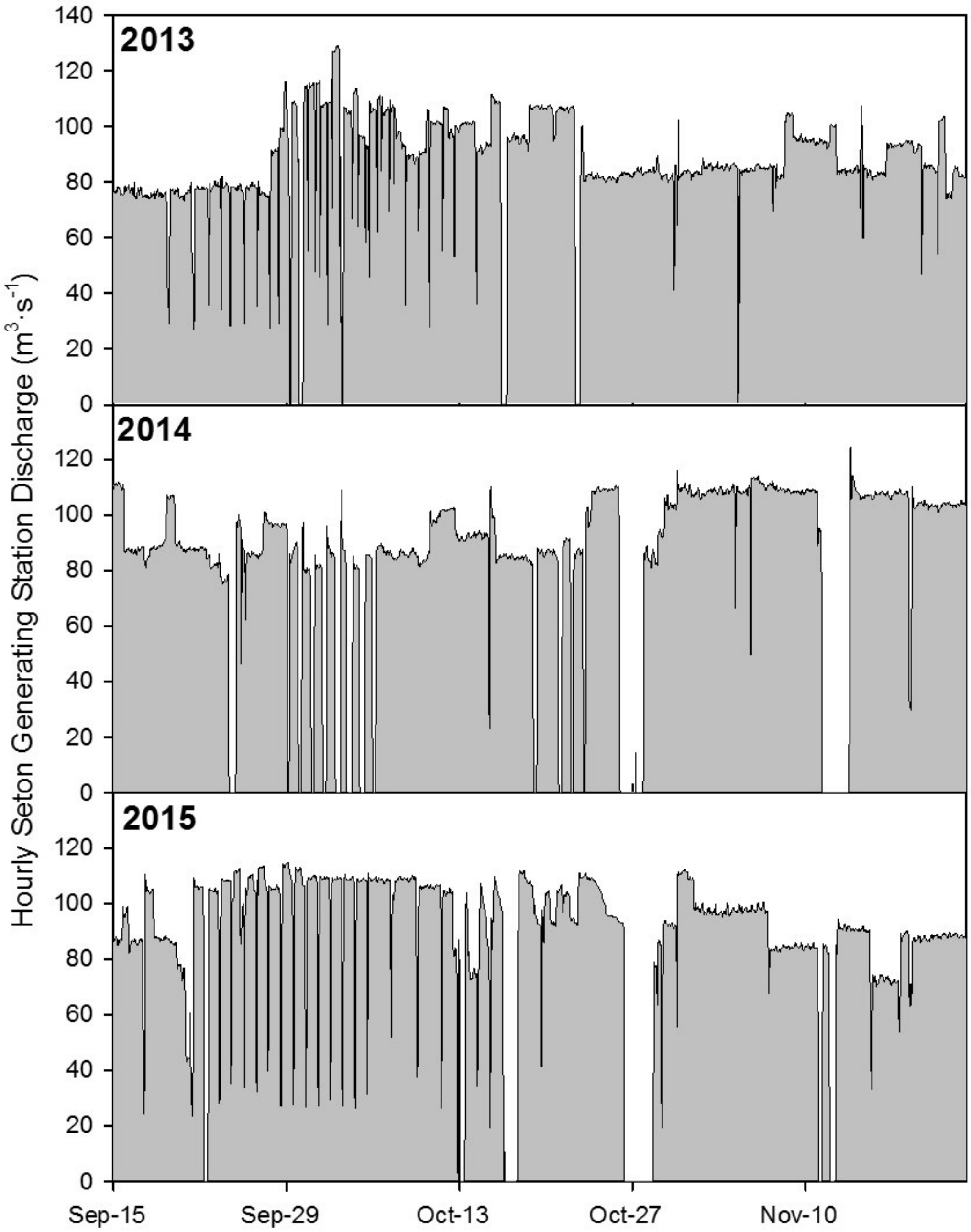

Figure 3-4: Seton Generating Station discharge from 15 September to 23 November, encompassing the Portage Creek sockeye salmon migration period

(31 September – 15 November) (BC Hydro data). Gaps in the grey areas indicate Seton Generating Station shutdowns

3.1.2 Seton Dam Discharge

Seton Dam discharge and flow patterns are an important component of the Gates Creek sockeye salmon telemetry studies that occurred from 2012-2015. Seton Dam discharge and conveyance structure use varied within and across years (Figure 3-5).

The greatest Seton Dam discharges occurred in 2012, with >100 $m^3 \cdot s^{-1}$ released at the start of the Gates Creek sockeye salmon migration period. However, discharge was reduced to 48.0 $m^3 \cdot s^{-1}$ before tagging started in mid-August 2012, and was later reduced to 35.0 $m^3 \cdot s^{-1}$ via closure of SSV3 and increased discharge from the FWRG. Radial gate openings also occurred in 2012, with one opening on 21 August temporarily increasing discharge by 11-16 $m^3 \cdot s^{-1}$ for <2 h during Gates Creek sockeye salmon telemetry studies.

In 2013-2015, total Seton Dam discharges were within the WUP-required hydrograph throughout the Gates Creek sockeye salmon migration period. However, the conveyance structures used to release water varied between years due to experimental discharge scenario testing in 2014 and unexpected operational changes in 2015. In 2013, BC Hydro operated Seton Dam normally with two discharge conditions (26.2 $m^3 \cdot s^{-1}$ and 22.8 $m^3 \cdot s^{-1}$) occurring during August, separated by a 21 August WUP-required ramp-down where FWRG discharge was decreased. In 2014, an experimental alternative flow scenario was tested where an initial discharge scenario (27.2 $m^3 \cdot s^{-1}$) was changed to the alternative scenario by reducing FWRG discharge to a minimum, closing SSV1, and opening SSV4. The alternative flow scenario increased discharge to 31.2 $m^3 \cdot s^{-1}$ but decreased flows around the fishway entrance. The alternative scenario was tested from 08 to 19 August, after which time routine flows conditions were re-established. Changes in conveyance structure use between the routine and alternative flow scenarios are summarized in Table 3-1. In 2015, discharge at Seton Dam unexpectedly decreased from 26.2 $m^3 \cdot s^{-1}$ to 21.8 $m^3 \cdot s^{-1}$ on 27 July – possibly due to an air blockage in SSV1. As a result, BC Hydro did not carry out a Seton Dam ramp-down in August 2015 and Seton Dam discharge was constant throughout August. Fishway discharge was constant across all study years.

Table 3-1: Total Seton Dam discharge and conveyance structure discharge during the 2014 routine (1 & 3) alternative (2) flow scenarios as estimated by BC Hydro (BCH) and Water Survey Canada (WSC)

Flow Scenario	Date (2014)	Discharge ($m^3 \cdot s^{-1}$)					
		Total (WSC)	Total (BCH)	Fishway	FWRG	SSV1	SSV4
1	09 July – 08 Aug	27.2	25.0*	1.1	7.6	16.3*	-
2	08 Aug – 19 Aug	31.3	28.6	1.1	1.9	-	25.6
3	19 Aug – 26 Aug	27.0	23.4	1.1	2.5	19.8	-
	26 Aug – 12 Sept	25.8	22.4	1.1	1.4	19.9	-
4	12 Sept – 18 Nov	15.0	15.0	1.2	13.8	-	-

*BC Hydro's estimated total Seton Dam and SSV1 discharge from 09 July to 08 August was reduced by 3.5 $m^3 \cdot s^{-1}$ to adjust for a known SSV1 blockage.

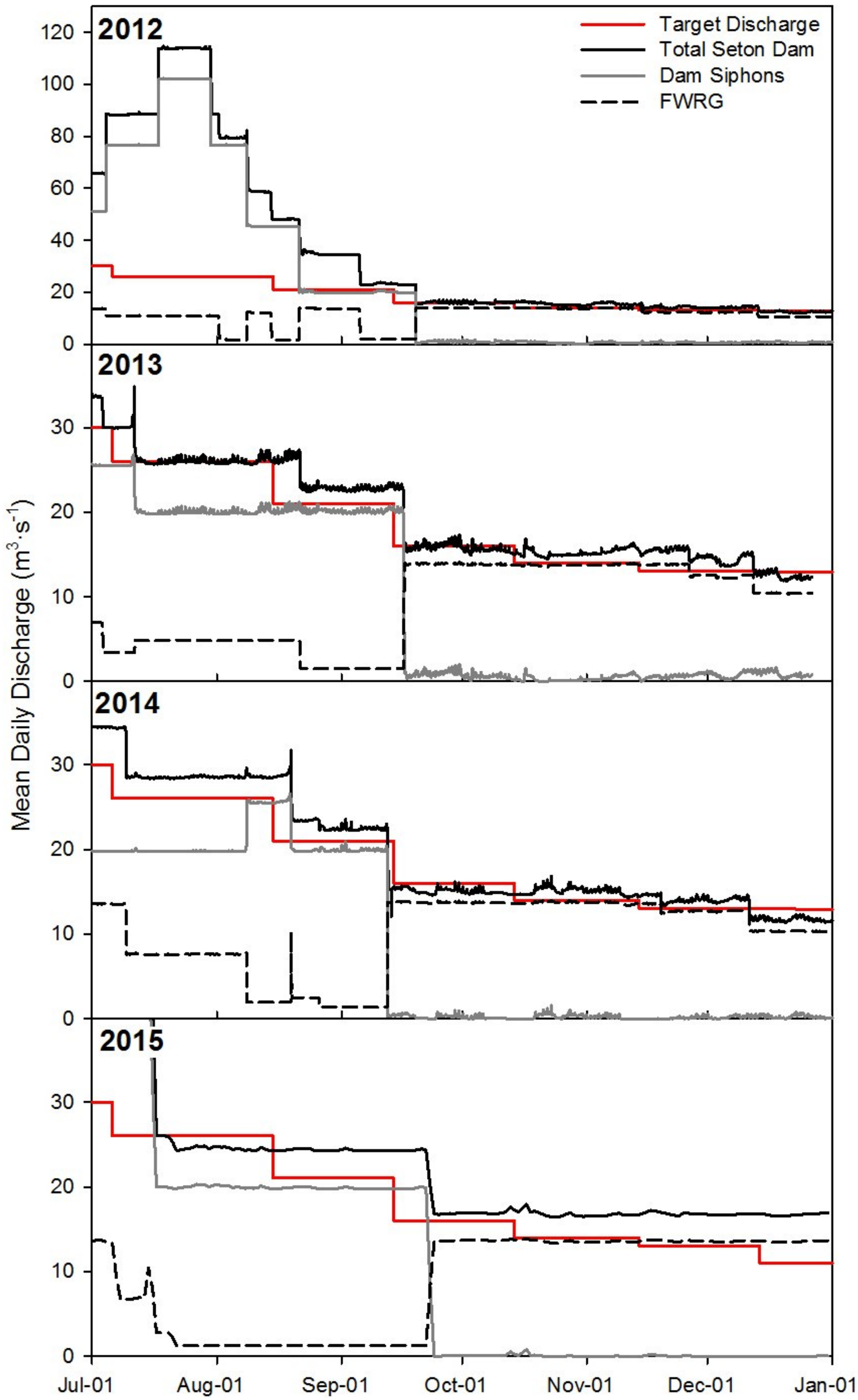

Figure 3-5: **Discharge for Seton Dam and each conveyance structure in 2012-2015 (BC Hydro data). Fishway and radial gate discharges are not shown**

3.1.3 Water Temperature

The thermal experience of Gates Creek and Portage Creek sockeye salmon prior to entering the Seton-Anderson watershed was estimated from 2013-2015 using the temperature of the Fraser River at Texas Creek ~17 km downstream of the Seton River.

During the Gates Creek sockeye salmon migration, Fraser River temperatures were 15.2-21.5°C (2013), 15.0-20.5°C (2014), and 14.0-20.9°C (2015) at Texas Creek. Fraser River temperatures exceeded 20°C, a known thermal stress threshold for sockeye salmon, continuously in 2013 from 04 to 18 August, whereas temperatures >20°C occurred intermittently during daytime peaks in 2014 from 15 to 19 August, and in 2015 continuously from 10 to 15 July. Downstream Fraser River temperatures would be expected to exceed the those measured at Texas Creek. Although determining the Fraser River thermal experience of fish is difficult, relative comparison across years suggest Fraser River temperatures in 2013 were likely the most stressful for Gates Creek sockeye salmon of the years studied and affected a large portion of the run. Temperatures in 2014 and 2015 were overall less stressful, although at times exceeded 20°C and would have caused thermal stress for fish arriving at the Seton River in mid-August 2014 or early-August 2015.

Portage Creek sockeye salmon migrating past Texas Creek (10 September to 06 October) would have experienced Fraser River temperatures of 10.2-18.3°C in 2013, 10.9-15.1°C in 2014, and 10.3-15.8°C in 2015. Fraser River temperature in 2014 and 2015 displayed the same temporal trend, declining to <15°C by early-September. Temperatures >15°C persisted until mid-September in 2013, potentially causing stressful thermal conditions; however, the optimal temperature for Portage Creek sockeye salmon is unknown.

Sockeye salmon are known to make use of thermal refuge during periods of high temperature (Mathes et al. 2010). Thermal refuge relatively high from Fraser River temperatures was available in the Seton Generating Station tailrace during the Gates Creek sockeye salmon migration period. The timing, magnitude and duration of the refuge varied year-to-year (Figure 3-7), with temperatures in the tailrace up to 3.9°C, 5.2°C, and 2.9°C cooler than the Fraser River in 2013-2015, respectively. Temperature differences >1°C occurred for 35% and 30% of the migration period in 2013 and 2014, and 10% of the migration period in 2015. However, temperature differences >1°C when the Fraser River also exceeded 20°C, occurred for 19% of the migration period in 2013, 5.6% in 2014, and did not occur in 2015. No thermal refuge was available in the tailrace for Portage Creek sockeye salmon, as tailrace temperatures exceeded Fraser River temperatures during their migration period each year from 2013-2015.

Water temperature patterns in the Seton River study area paralleled those in the Fraser River each year, with elevated temperatures occurring in 2013, relative to 2014 and 2015 (Figure 3-6). In 2013, extreme environmental conditions increased water temperatures throughout the study area. Temperatures reached a maximum on 11 August, with mean daily temperatures in the lower Seton River (19.7°C), Cayoosh Creek (15.9°C), and the Seton Dam fishway (23.0°C) coinciding with maximum Fraser River temperatures (21.5°C). Maximum temperatures in the Seton River study in 2013 area occurred in the Seton Dam fishway, where hourly temperatures were >20°C continuously from 10 to 18 August 2013, reaching a maximum of 23.7°C on 11 August 2013 and creating extremely stressful migration conditions for Gates Creek sockeye salmon. In comparison, temperatures in the Seton River study area in 2014 and 2015 were rarely >20°C, with Seton Dam fishway temperature briefly exceeding 20°C for 5 h on 05 August 2014 (20.4°C maximum) and for 5 h on 14 and 20 August 2015 (20.2°C maximum). Slightly warmer temperatures during the Portage Creek sockeye salmon migration were observed in 2014 and 2015 than 2013; however, these modest temperature increases were not expected to impair migration in any year.

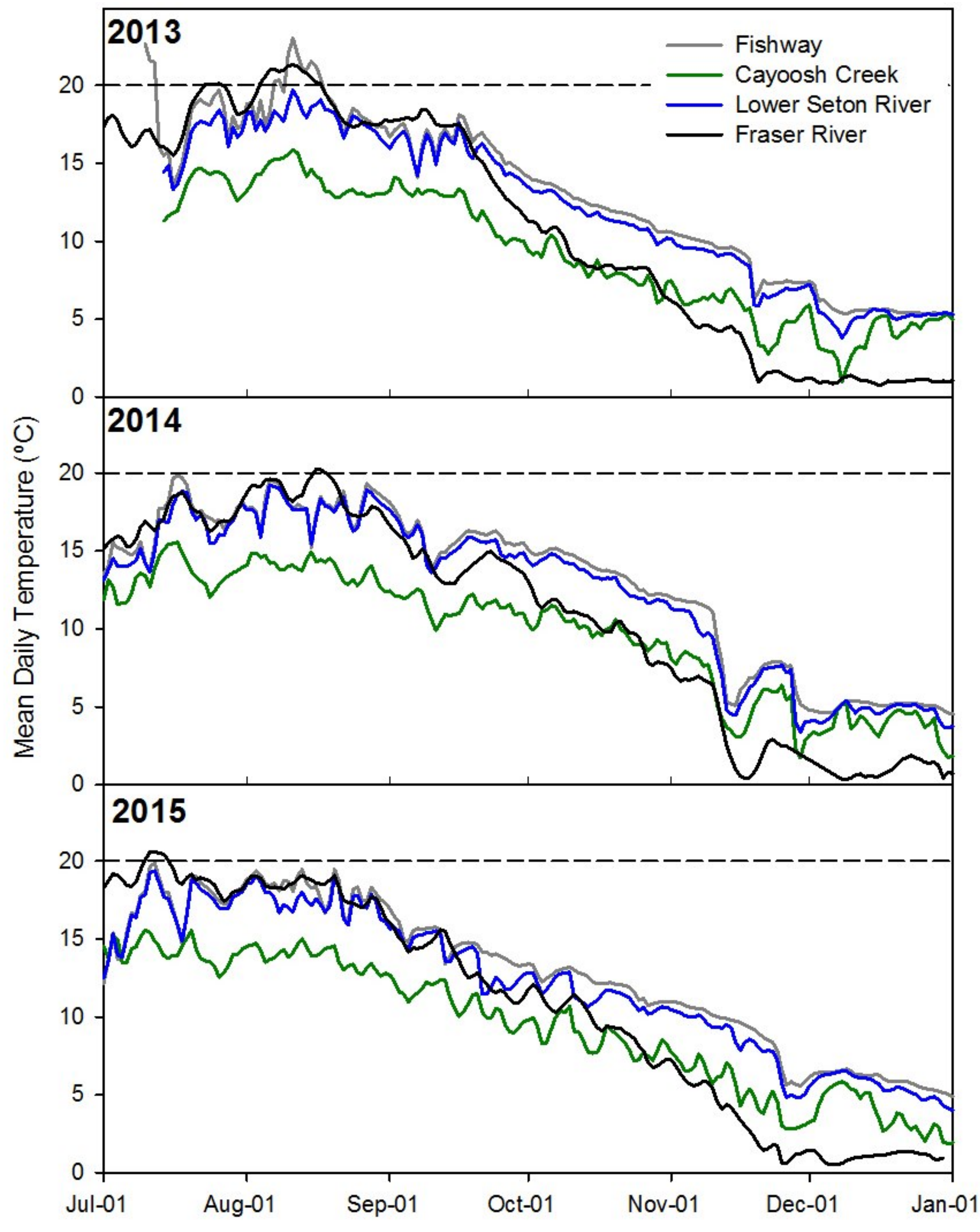

Figure 3-6: Temperature of the Fraser River, Cayoosh Creek, Seton River and Seton Dam fishway in 2013-2015. The dashed line at 20°C indicates the 20°C temperature threshold above which sockeye salmon experience stressful migration

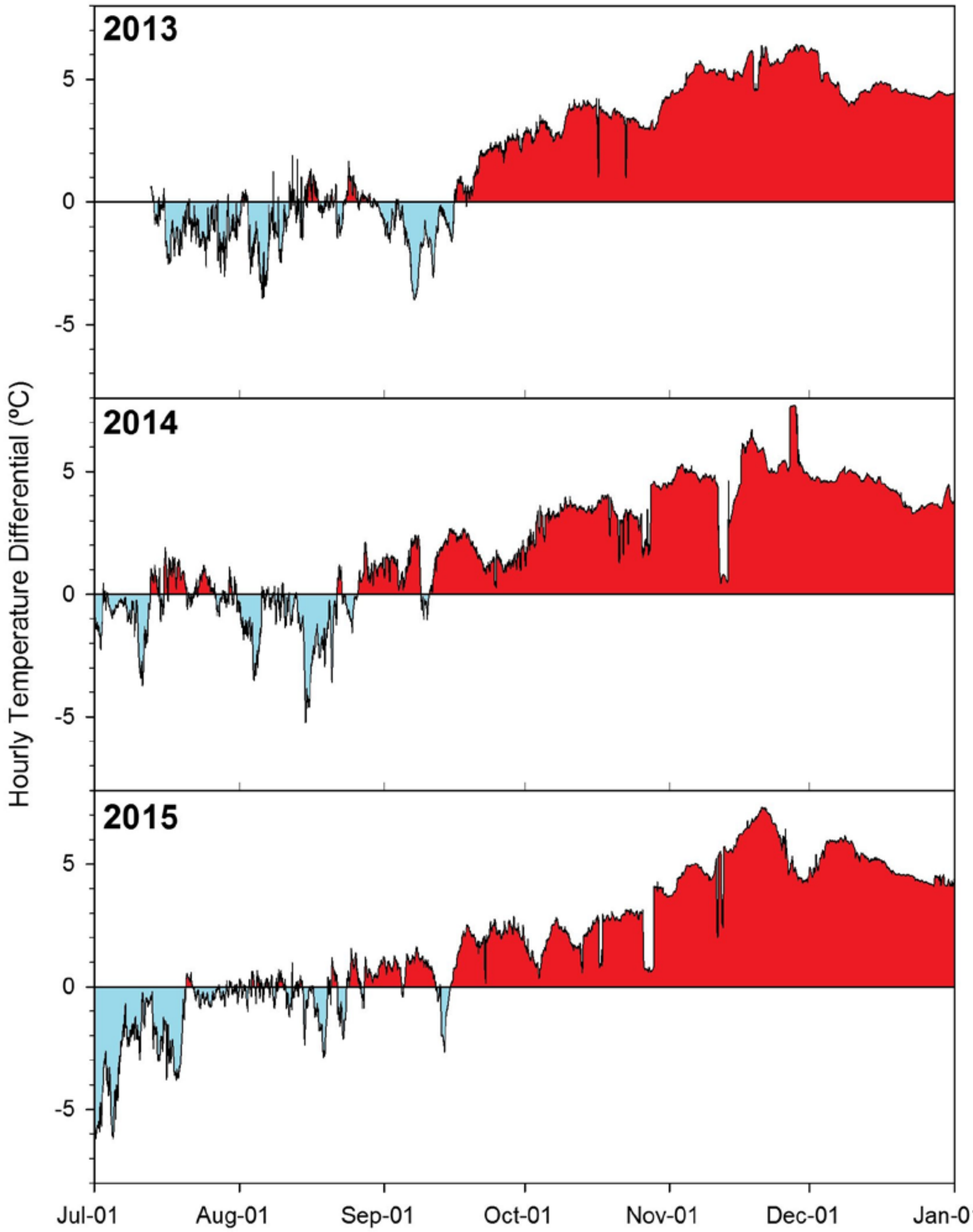

Figure 3-7: Temperature differential of the Fraser River and Seton Generating Station tailrace from 2013-2015. Negative values (blue) indicated cooler water in the tailrace and potential thermal refuge for migrating salmon

Rapid increases in water temperature and high maximum daily temperatures were observed in the fishway during shutdowns of the Seton Generating Station in 2013 (Figure 3-8). Increases in fishway temperatures occurred regularly during Seton Generating Station shutdowns in 2013. For example, fishway temperatures increased 3.7°C (19.0-22.7°C) in 4 h during an overnight shutdown on 10 August 2013 and the maximum fishway temperature (23.7°C) occurred on 11 August 2013 during a shutdown. However, temperature increases coincided with extreme Seton Lake surface water temperatures and a maintenance shutdown of the Walden North diversion to Seton Lake from 07 to 16 August 2013. Therefore, the rapid increases in fishway water temperatures during shutdowns were probably due to high-temperature Seton Lake water being withdrawn into Seton Dam fishway. Indeed, Seton Generating Station shutdowns in 2014 and 2015, when environmental temperatures were less extreme, had a reduced influence on fishway temperatures with a 26 August 2014 shutdown associated with a 1.7ºC increase in fishway temperature within 24 h and a 11 August 2015 shutdown associated with a 2.0°C increase in <4 h. Further, rapid decreases in water temperature that do not appear to be associated with Seton Generating Station shutdowns occurred in 2014 on the 03, 14 and 20 August with similar events occurring in 2015 on 15 and 22 August, suggesting temperature changes are not driven by the Seton Generating Station alone. Although the effect of these temperatures changes on salmon migration has yet to be investigated, coincidentally, up to 30 sockeye salmon were observed holding in Cayoosh Creek following the 27 August 2014 shutdown where none had previously been observed in 2014.

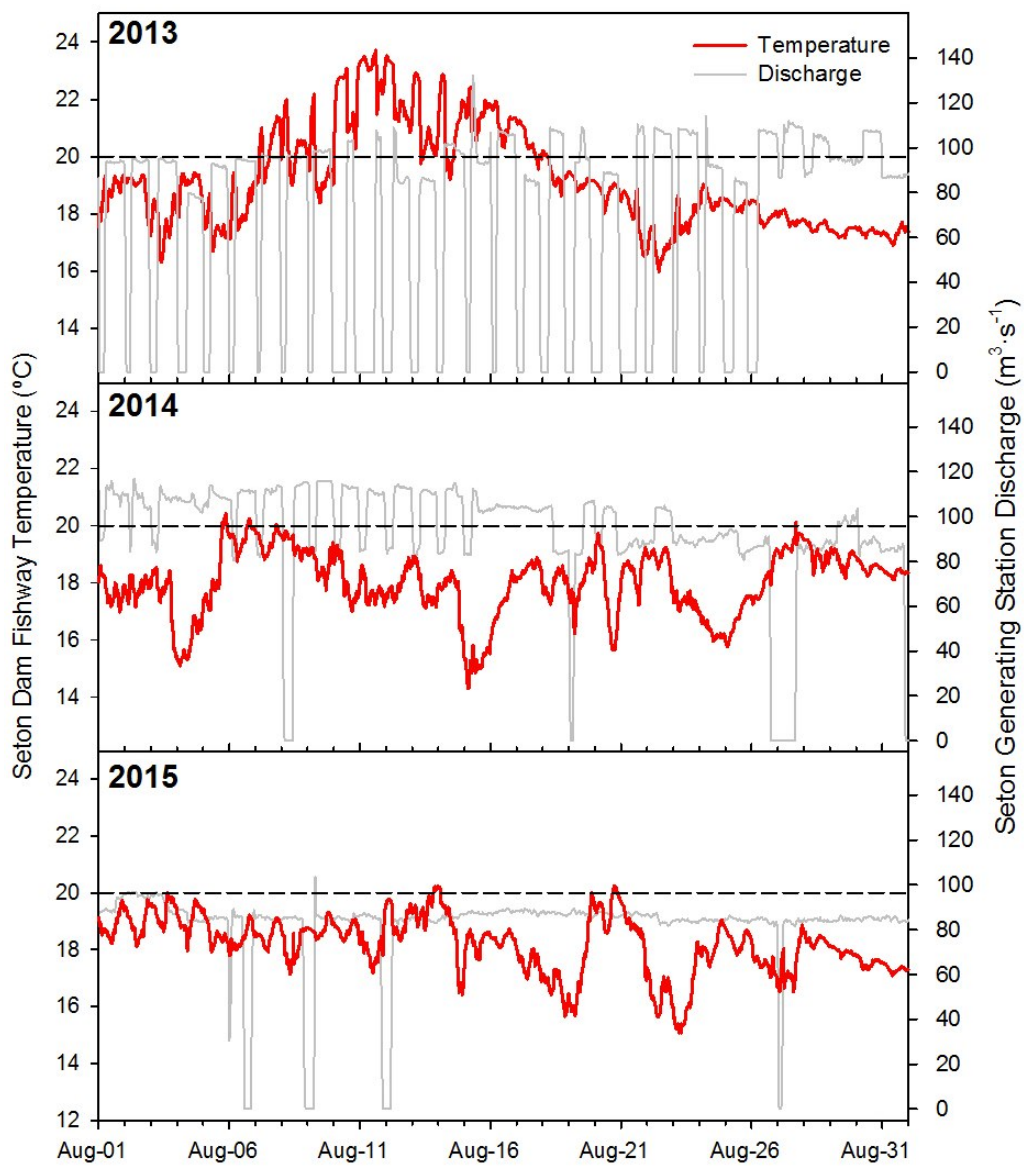

Figure 3-8: Seton Dam fishway temperature and Seton Generating Station discharge in 2013 to 2015. A dashed line at 20°C indicated temperatures above which migration is stressful for migrating sockeye salmon

3.1.4 Water Chemistry

Specific conductivity measurements in 2012-2014 displayed similar trends across years (Figure 3-9). Specific conductivity in Cayoosh Creek gradually increased throughout the study period, whereas conductivity gradually decreased in the upper Seton River. As a result, the greatest differences in conductivity occurred during the Portage Creek sockeye migration period. In 2015, conductivity measurements were collected from 01-19 August; however, readings displayed greater variation than previous years, probably due to a malfunctioning conductivity meter that failed on 20 August. Although no readings were taken for the remainder of 2015, initial readings displayed the same overall trends as in previous years.

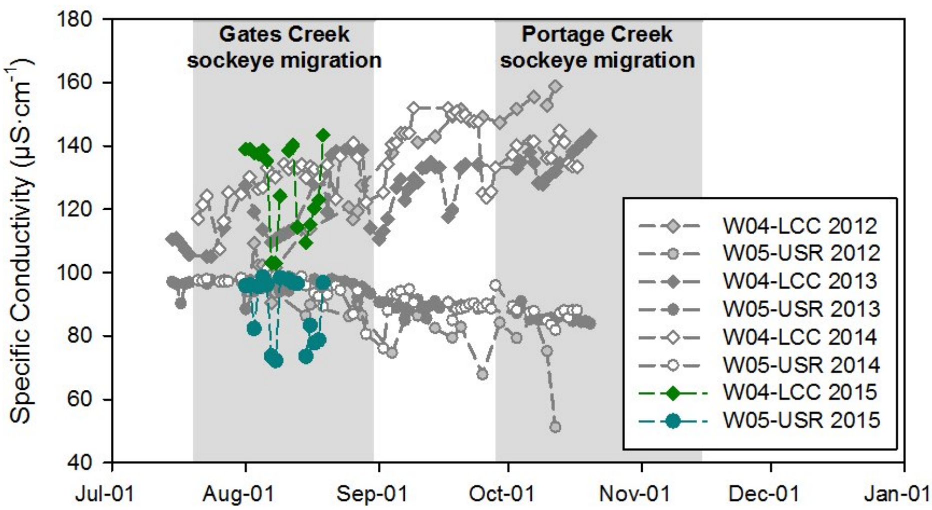

Figure 3-9: Specific conductivity readings from Cayoosh Creek (W04-LCC) and the upper Seton River (W05-USR) during the target dilution periods for Gates Creek and Portage Creek sockeye salmon in 2012-2015

3.2 Seton Dam Tailrace Flow Fields

In 2014, ADCP unit and particle tracking were used to measure flow velocities in the Seton Dam tailrace during three discharge scenarios: two routine BC Hydro flow scenarios (scenarios 1 and 3) where water was released from SSV1 and the FWRG; and an alternative flow scenario where water was released primarily through SSV4 (scenario 2). The alternative flow scenario was intended to reduce flow velocities surrounding the fishway entrance to improve fish passage. Flow measurements were not taken in 2015, but could be expected to be similar to the routine scenario in 2014.

3.2.1 Routine BC Hydro Operations

Flow velocities and flow fields in the tailrace under the two routine BC Hydro operations (scenario 1 and 3) were judged to be similar. Therefore, only results from scenario 3 are presented for comparison with the alternative flow scenario.

Discharge from SSV1 and the FWRG created highly turbulent water in the fishway entrance area during the routine scenario, preventing ADCP measurements of flow velocities through most of the entrance area (Figure 3-10). However, particle tracking in the primary SSV1 flows estimated surface flow velocities up to 4.2 $m{\cdot}s^{-1}$ downstream. At the downstream end of the fishway, where ADCP measurements were possible, peak flow velocities ranged from 4.5-4.8 $m{\cdot}s^{-1}$ at a depth of 0.5 m. Fish migrating upstream would likely have to overcome these velocities to access the fishway entrance. Upstream of the SSV1 discharge and immediately downstream of the fishway entrance, flow velocities were <2 $m{\cdot}s^{-1}$ as measured with ADCP transects. Both upstream and downstream flows occurred near the fishway entrance, likely caused by flows from the FWRG and SSV1 interacting with the submerged baffle wall.

Discharge from SSV1 created three vortices in the tailrace (Figure 3-10). Two large vortices were located on the northern bank of the Seton River and a third, smaller vortex was located on the southern bank downstream of the fishway. Flow velocities up to approximately 1 $m{\cdot}s^{-1}$ were measured in each vortex. The location, size, and flow velocities within the vortices were similar to those observed in 2013 during a similar flow scenario. Vortices on the northern bank were likely generated by the interaction of downstream flows with shallow gravel bars in the tailrace.

3.2.2 Alternative Flow Scenario

Release of water from SSV4, rather than SSV1 and the FWRG, relocated the primary discharge from Seton Dam to approximately 10 m from the fishway entrance area and into the centre of the tailrace (Figure 3-10). As a result, fish migrating to the fishway entrance would not be required to overcome turbulent flows from SSV4, although fish could still experience these flows. Peak velocities in the SSV4 discharge were up to 6.6 $m{\cdot}s^{-1}$ and extended 24 m downstream, beyond the end of the radial gate wall. Flow velocities up to 4.3 $m{\cdot}s^{-1}$ extended 75 m downstream. However, downstream of the SSV4 discharge plume, flow velocities decreased to <2.5 $m{\cdot}s^{-1}$ and then to <1 $m{\cdot}s^{-1}$ as the tailrace widened into the Seton River.

The alternative discharge from SSV4 produced two vortices on the northern bank of the tailrace and two vortices on the southern bank, one within the fishway entrance area (Figure 3-10). Vortices on the northern bank were similar in location to those observed under routine operations, although the proximity of the SSV4 discharge plume to the northern bank reduced the size of both vortices while increasing flow velocities. On the southern bank, the vortex that was observed downstream of the fishway under routine operations increased in size under the alternative scenario. A fourth vortex, that was not observed under routine operations, was created in the entrance area adjacent to the fishway wall.

At the fishway entrance, downstream flows from the fishway and FWRG, and upstream flows from the vortex in the fishway entrance area, created a flow interface 8-10 m downstream of the fishway entrance. The velocity of downstream flows from the fishway and FWRG discharge were <0.5 $m \cdot s^{-1}$ whereas upstream flows from the vortex were 0.5-1.0 $m \cdot s^{-1}$. As a result, attraction flows to the fishway entrance may have been limited under the alternative flow scenario, although comparison with routine conditions is not possible, as flows could not be measured near the fishway entrance. Regardless, flow velocities throughout the entrance area were reduced under the alternative scenario and the direction of flows reversed from downstream to upstream.

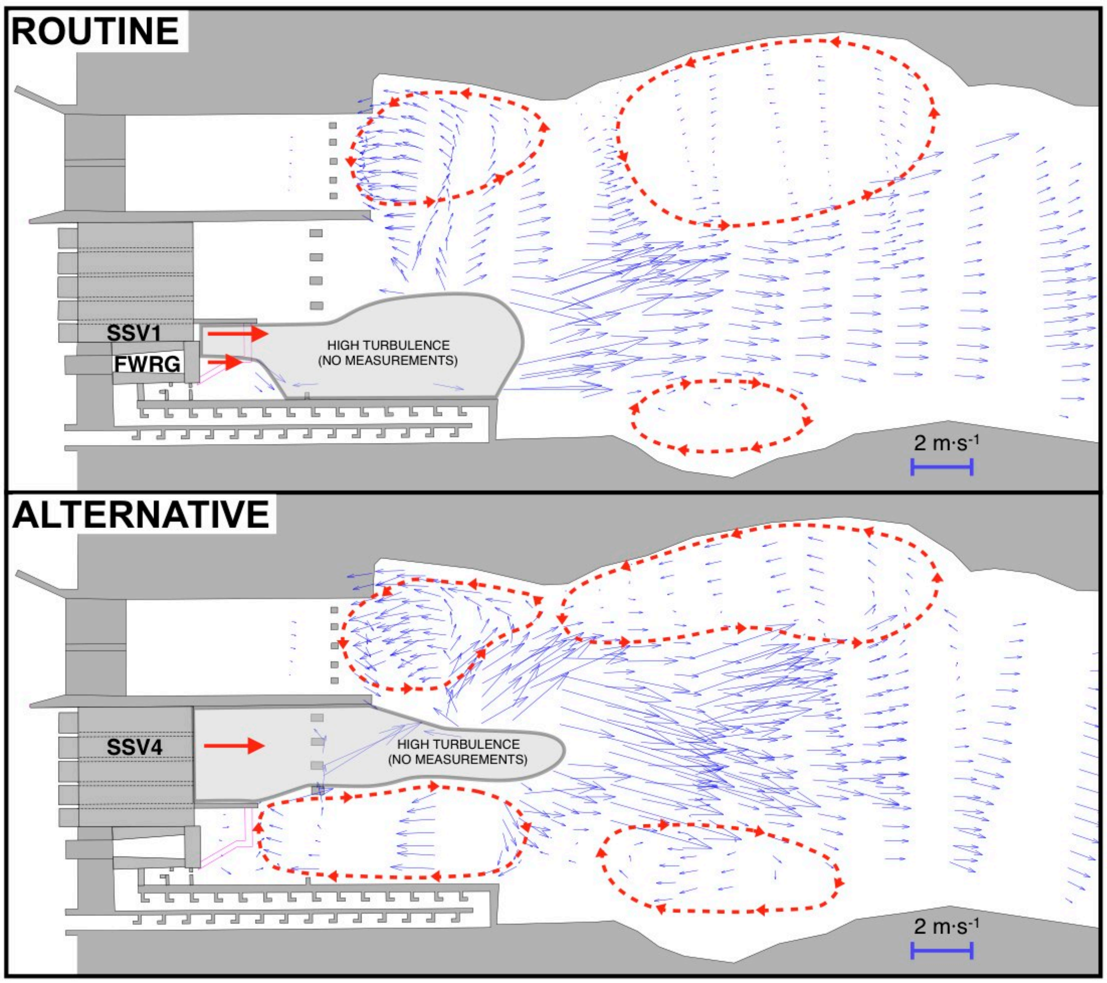

Figure 3-10: ADCP measurement transects and calculated flow velocities (blue arrows) and estimated flow fields (red arrows) in the Seton Dam tailrace in 2014 under routine BC Hydro operations (top) and an alternative flow scenario (bottom)

3.3 Fish Passage Enumeration

Abundance and run timing estimates were generated for Gates Creek and Portage Creek sockeye salmon, pink salmon, and coho salmon using a resistivity fish counter in the exit basin of the Seton Dam fishway. Chinook salmon abundance could not be estimated in 2015; however, video validation observed one Chinook salmon moving through the counter on 20 August 2015. Upper and lower credible intervals for 2015 abundance estimates could not be calculated in time for the report deadline.

3.3.1 Video and Signal Validation

Review of 38 h of video data between 20 August and 23 October 2015 recorded 3,084 fish passing upstream through the counter sensor tubes (Figure 3-11) of which 645 were Gates Creek sockeye salmon. Video validation confirmed the upstream detection accuracy for seven of the eight sensor tubes was 74-92%.

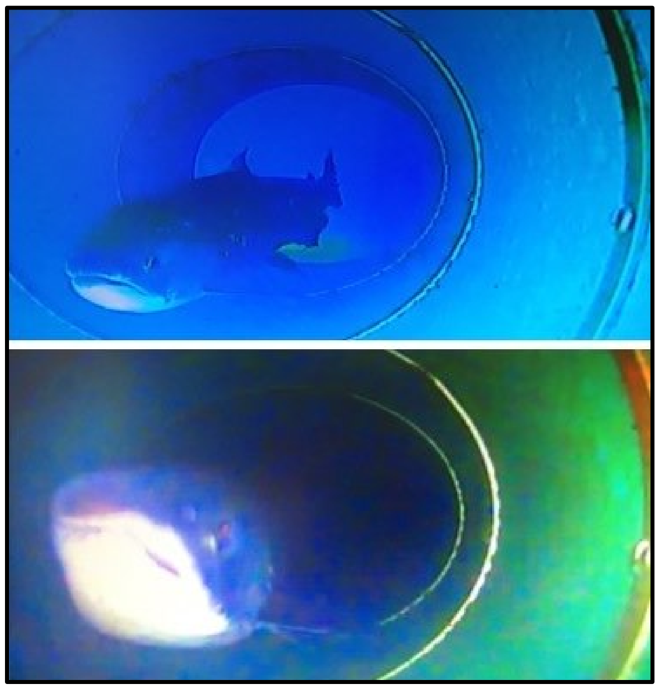

Figure 3-11: Video validation images from the Seton Dam fish counter of sockeye salmon migrating through the counter tubes in daytime (top) and nighttime (bottom)

3.3.2 Gates Creek Sockeye Salmon

A mean estimate of 26,206 Gates Creek sockeye salmon passed through the Seton Dam between 29 July and 10 September 2015 (Figure 3-12). Gates Creek sockeye salmon migration peaked between 10 and 24 August 2015, with fluctuations in daily migration rates during this period of 521-1,880 fish per day. An exact end date for the Gates Creek sockeye salmon migration could not be determined with the fish counter because the Gates Creek and Portage Creek populations cannot be visually discriminated. However, the total abundance estimate for Gates Creek sockeye salmon is relatively insensitive to the end date for the Gates Creek migration because of the low numbers of fish migrating in mid-September when Gates Creek and Portage Creek sockeye salmon migration overlap. The Gates Creek sockeye salmon run in previous years was a minimum of 54,800 in 2013 and a mean estimate of 27,192 in 2014 (credible intervals of 25,771 to 28,611).

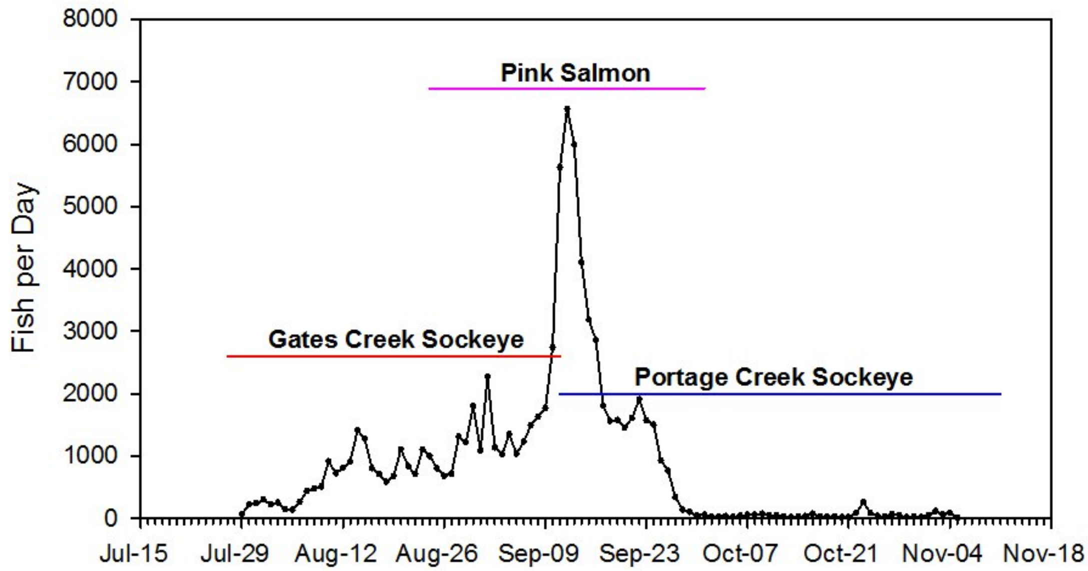

Figure 3-12: **Daily abundance of fish migrating through the Seton Dam fishway between 29 July and 05 November 2015. Horizontal lines indicate migration timing**

3.3.3 Portage Creek Sockeye Salmon

A mean estimate of 2,253 Portage Creek sockeye salmon passed through the Seton Dam between 11 September and 09 October 2015 (Figure 3-12). The peak in Portage Creek sockeye salmon migration was observed between 06 and 09 October, with daily migration rates during this period of 47-113 fish per day. The run-size of Portage Creek sockeye salmon was much less than 2014, when 38,812 fish were estimated to have passed through the counter (CI of 32,392 to 45,231 fish).

The Portage Creek sockeye salmon abundance estimate for 2015 is likely an over-estimate as abundance was highly sensitive to the migration start date due to the relatively high abundance of Gates Creek sockeye salmon in early September. The migration start date for Portage Creek sockeye salmon was set as 11 September to correspond with the 10 September end date for Gates Creek sockeye salmon; however, stock identification DNA analysis from 2014 tagging data could be used to provide a more accurate start date estimate. Stock identification DNA analysis is not possible for 2015 as tagging ended on 02 September.

3.3.4 Pink Salmon

A mean estimate of 87,032 pink salmon passed through the Seton Dam between 20 August and 04 October (Figure 3-12). Migration of pink salmon in 2013 continued for almost a month later than in 2015, likely due to higher abundance. The peak in pink salmon migration was observed between 07 and 23 September with daily migration rates ranging from 2,004 to 8,964 fish per day during this period.

3.3.5 Coho Salmon

A mean estimate of 667 coho salmon passed through the Seton Dam between 11 October and 05 November. The peak in coho salmon migration was observed between 17 October and 04 November with migration rates of 17 to 54 fish per day during this period.

3.4 Fish Sampling

3.4.1 Gates Creek Sockeye Salmon

From 2012-2015 a total of 2,580 sockeye salmon were tagged during the Gates Creek sockeye salmon migration period. Stock identification DNA analysis – used to confirm sockeye salmon as Gates Creek stock - was carried out for all fish in 2012 and a subset in 2013. Stock ID results were used to identify a relationship between gross somatic energy (GSE) and stock identification. Of sockeye salmon confirmed as Gates Creek stock in 2012-2013, 90% were found to have GSE density estimates <7.2 $MJ \cdot Kg^{-1}$ whereas 90% of stray sockeye salmon present in the Seton River had GSE density estimates >7.2 $MJ \cdot Kg^{-1}$. Therefore, in 2014 and 2015, GSE screening was applied at the time of tagging to identify Gates Creek sockeye salmon from strays. In 2014, 89 sockeye salmon tagged during the Gates Creek migration period were identified as potential strays via GSE screening. These fish received either a PIT (n=86) or radio tag (n=3), but were not included in migration analyses. In 2015, tags were not applied to sockeye salmon identified as strays from GSE estimates. Sample data from sockeye salmon identified as Gates Creek sockeye salmon is presented in Table 3-2.

Table 3-2: Mean fork length and estimated gross somatic energy (GSE) density of Gates Creek sockeye salmon sampled in 2013-2015

Year / Sex		Number of Fish	Fork Length (cm)	GSE ($MJ \cdot kg^{-1}$)
2013	All*	437	58.1 ± 3.1	6.0 ± 1.4
	Male	161	59.4 ± 3.1	5.8 ± 1.4
	Female	154	56.8 ± 2.4	6.0 ± 1.5
2014	All*	924	59.7 ± 4.0	5.8 ± 0.6
	Male	376	61.0 ± 4.4	5.7 ± 0.6
	Female	543	58.7 ± 3.5	5.9 ± 0.6
2015	All	860	58.1 ± 3.0	5.6 ± 0.6
	Male	423	59.2 ± 2.6	5.4 ± 0.6
	Female	437	56.9 ± 2.9	5.7 ± 0.6

All value are presented as mean ± SD. *A sex estimate was not available for all fish in 2013 and 2014.

3.4.2 Portage Creek Sockeye Salmon and Coho Salmon

Sampling results for Portage Creek sockeye salmon and coho salmon are presented in Table 3-3. Portage Creek sockeye salmon were primarily tagged in 2014 due to low abundance and overlap with pink salmon migration in 2013 and 2015. As a relationship between GSE density and stock identification had yet to be established for Portage Creek sockeye salmon, no GSE screening occurred in 2014. Generally, there is a low likelihood of strays during the Portage Creek sockeye salmon migration period due to the late run timing of this population amongst Fraser River sockeye salmon. As a result, all fish tagged during the Portage Creek sockeye salmon migration period were included in sampling results and migration analyses. Males made up 62% of the Portage Creek sockeye salmon collected in 2014. Coho salmon were also collected in small numbers in 2013 and 2014.

Table 3-3: Mean fork length and estimated gross somatic energy (GSE) of Portage Creek sockeye and coho salmon sampled in 2013 and 2014

Year / Sex		Number of Fish	Fork Length (cm)	GSE ($MJ\cdot kg^{-1}$)
Portage Creek				
2013	All	24	56.9 ± 1.9	4.9 ± 1.8
	Male	9	57.8 ± 2.0	3.2 ± 2.0
	Female	15	56.3 ± 1.6	5.9 ± 0.7
2014	All	661	60.4 ± 3.0	5.6 ± 0.5
	Male	410	61.9 ± 2.4*	5.5 ± 0.4*
	Female	249	58.1 ± 2.2	5.7 ± 0.5
Coho salmon				
2013	All	30	60.8 ± 5.2	7.4 ± 1.5
	Male	24	61.1 ± 5.6	7.8 ± 0.7
	Female	6	59.3 ± 2.9	6.2 ± 2.9
2014	All	9	57.0 ± 4.8	7.4 ± 0.6
	Male	2	56.3 ± 1.1	7.6 ± 0.4
	Female	7	57.2 ± 5.4	7.4 ± 0.7

All value are presented as mean ± SD.

3.4.3 Injury Monitoring

Injury monitoring was carried out on all tagged salmon from 2013-2015 as well as all deceased salmon collected from the Seton River fish fence. Injuring monitoring protocols were updated from 2013 to 2014; therefore, only 2014 and 2015 injury monitoring data is presented. Data from 2013 will be revised and included in future reports.

The proportion of Gates Creek sockeye salmon displaying injury was 63% and 88% in 2014 and 2015, respectively (Table 3-4). In both years, the majority of Gates Creek sockeye salmon were either uninjured or displayed minor injuries (injuries unlikely to cause migratory failure). Moderate or severe injuries, which could be expected to contribute to migratory failure, were present on 21% of tagged fish in 2014 and 26% of tagged fish in 2015. In comparison, 6% of Portage Creek sockeye salmon displayed moderate or severe injuries.

Table 3-4: Prevalence of injuries and severity amongst salmon tagged in 2014-2015

Species / Population	Year	Injury Severity			
		Uninjured	Minor	Moderate	Severe
Gates Creek sockeye (*n*=924)	2014	37% (*n*=345)	42% (*n*=387)	12% (*n*=109)	9% (*n*=83)
Gates Creek sockeye (*n*=860)	2015	12% (*n*=105)	62% (*n*=533)	20% (*n*=169)	6% (*n*=53)
Portage Creek sockeye (*n*=633)	2014	74% (*n*=466)	20% (*n*=124)	3% (*n*=22)	3% (*n*=21)
Coho (*n*=9)	2014	100% (*n*=9)	-	-	-

Table 3-5: The proportion of Gates Creek and Portage Creek sockeye displaying injuries originating from different sources in 2014 and 2015

Species / Population	Year	Injury Origin					
		Gillnet	Hook wound	Predator	Sea Lice	Other	Unknown
Gates Creek sockeye (*n*=924)	2014	21% (*n*=193)	8% (*n*=70)	3% (*n*=26)	16% (*n*=148)	2% (*n*=21)	23% (*n*=208)
Gates Creek sockeye (*n*=860)	2015	18% (*n*=153)	1% (*n*=8)	7% (*n*=60)	43% (*n*=366)	1% (*n*=10)	45% (*n*=391)
Portage Creek sockeye (*n*=633)	2014	2% (*n*=12)	3% (*n*=18)	1% (*n*=8)	2% (*n*=10)	3% (*n*=17)	18% (*n*=111)

Gates Creek sockeye salmon injuries were primarily attributable to gillnet entanglement or marine parasites (Table 3-5). The proportion of fish displaying gillnet injuries (Figure 3-13) was approximately equal in 2014 and 2015, although the timing of observed gillnet injuries differed (Figure 3-14). In 2014, gillnet injuries on PIT-tagged fish were most frequently observed from 11 to 23 August and from 03 to 06 September. In 2015, gillnet injuries were most frequently observed from 01 to 21 August.

Figure 3-13: Gillnet injured Gates Creek sockeye salmon in 2015. Top: Moderate gillnet injury with dorso-ventral scarring and abrasion indicating entanglement.

Bottom: Deceased sockeye salmon displaying dorso-ventral scarring below the dorsal fin and adjacent to the pelvic fins

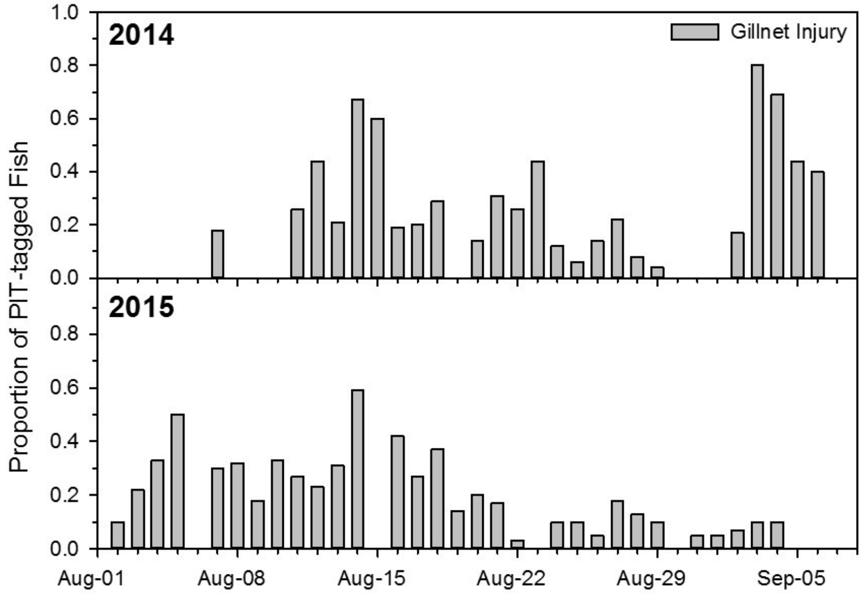

Figure 3-14: **Proportion of PIT-tagged Gates Creek sockeye salmon displaying gillnet injuries in 2014 and 2015. Note that fish were not tagged each day**

Deceased sockeye salmon recovered from the Seton River fish fence also displayed gillnet injuries in 2014 and 2015. The total number of deceased sockeye salmon recovered, and the proportion with gillnet injuries, increased approximately one week after observations of gillnet injuries increased on tagged sockeye salmon (Figure 3-15). Stock identification DNA analysis was not performed on deceased fish; however, GSE screening during tagging in 2015 suggested that the increase in gillnet injuries was associated with an increase in strays identified during tagging. These observations suggest that mortalities observed at the Seton River fish fence can, in part, be attributed to fisheries injuries sustained during upstream migration in the Fraser River and that stray sockeye salmon account for a proportion of the observed mortalities.

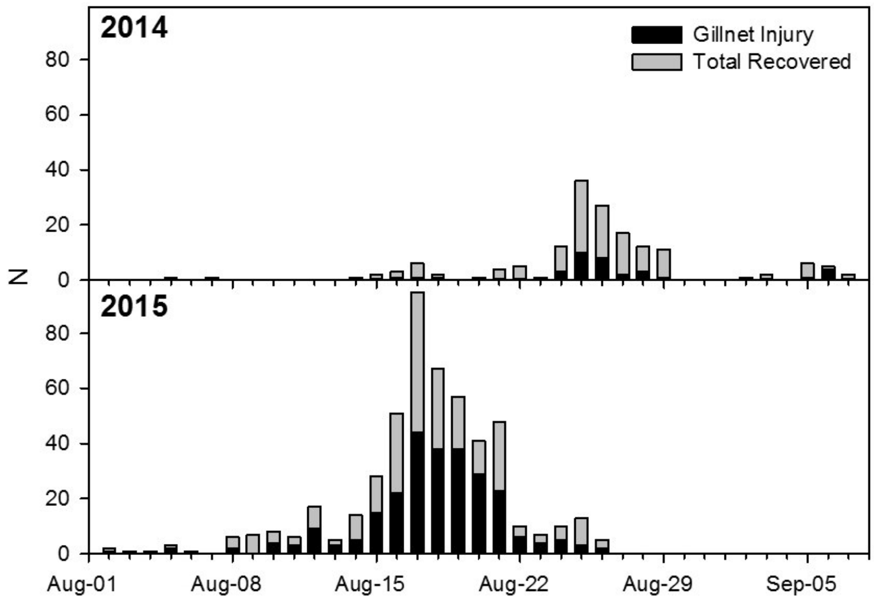

Figure 3-15: **Total number of deceased sockeye salmon recovered from the Seton River fish fence and the total that displayed gillnet injuries in 2014 and 2015**

A limited number of head injuries were identified on Gates Creek sockeye salmon in 2014 (*n*=12) and 2015 (*n*=7). Review of photographs identified five individuals in 2014 with injuries that may have originated from attempted migration at the Seton Generating Station. For example, a Gates Creek sockeye salmon collected on 10 August 2014 (Figure 3-16) had head injuries that were judged to be the result of recent abrasive contact. However, given the overall low number of head injuries, there is little evidence to suggest that operation of the Seton Generating Station caused injury to salmon in 2014 or 2015.

Figure 3-16: Gates Creek sockeye salmon with head injury in 2014. Note lack of fungal growth, suggesting recent injury

3.5 Migration in the Fraser River and Seton River

Analyses were completed separately for 2013-2014 (Section 3.5.1) and 2015 (Section 3.5.2) as different explanatory variables were available for these datasets. Future analyses will combine data across all study years.

3.5.1 2013-2014 Gates Creek Sockeye Salmon

Telemetry data from 2013-2014 were used to quantify Gates Creek sockeye salmon migration behaviour in the Seton Generating Station tailrace, migration behaviour in the Fraser River, and migration success to Seton Dam. Model averaging was used to identify significantly explanatory variables for migration behaviour.

3.5.1.1 Migration Conditions

A detailed overview of migration conditions is presented in Section 3.1. In brief, tagged Gates Creek sockeye salmon were released in the Fraser River from 2013-2014 at different dilution ratios (Table 3-6) and under varied temperature conditions. In 2013, the dilution ratio exceeded the 20% Gates Creek sockeye salmon target dilution ratio for 10 d during releases; however, the dilution ratio increase coincided with water temperatures >20°C in the Seton River and Fraser River and fish were captured from the fishway during this period, confounding analyses. At the Seton Generating Station, some thermal refuge opportunities were available for Gates Creek sockeye salmon. In 2014, all radio-tagged Gates Creek sockeye salmon were released at a dilution ratio <20%, with moderate Fraser River and Seton River water temperatures throughout the migration period. Thermal refuge in the Seton Generating Station tailrace was available for Gates Creek sockeye salmon at times in 2014. Fraser River discharge in August would not be expected to affect sockeye salmon migration; however, Seton Generating Station shutdowns occurred throughout August 2013 and may have affected migration behaviour.

Table 3-6: Releases of fence-caught radio-tagged Gates Creek sockeye salmon in Fraser River in 2013-2014 by dilution ratio at time of release

Population	Year	Dilution Ratio at Release				
		<10%	10-20%	20-30%	30-40%	>40%
Gates Creek sockeye salmon	2013	72	23	12	-	-
	2014	159	4	-	-	-

3.5.1.2 Migration Behaviour in the Fraser River

Gates Creek sockeye salmon migration behaviour at the Seton Generating Station and in the Fraser River was examined throughout the migration period in 2013 and 2014.

Nearly all Gates Creek sockeye salmon were detected in the Seton Generating Station tailrace while the station was operating, although fish were also detected during shutdowns. In 2013, of the Gates Creek sockeye salmon released in the Fraser River and detected in the tailrace for >30 s (*n*=113), 92% (*n*=104) were detected in the tailrace while the station was operational. A portion of fish (22%; *n*=25) were detected during station shutdowns, indicating use of the tailrace by Gates Creek sockeye salmon outside of operational periods. The proportion of fish detected during shutdowns was also approximately equal to the proportion of time the station was shut down in 2013 (20%; 168 h from 05 August to 08 September 2013). In 2014, when station shutdowns were less frequent (6%; 51 h from 05 August to 08 September), a reduced proportion of released Gates Creek sockeye salmon were detected in the tailrace during shutdowns (3%; *n*=5/151). During operational periods at the Seton Generating Station in 2014, 99% (*n*=150) of fish were detected. Detections during station shutdowns require further investigation, as fish may have entered the tailrace but for less time than during active operations. However, these initial data suggest that in 2013 and 2014 Gates Creek sockeye salmon may have entered the Seton Generating Station tailrace regardless of tailrace operations.

Gates Creek sockeye salmon migration behaviour at the Seton Generating Station tailrace was quantified as the number of forays fish made into the tailrace and the total time fish spent in the tailrace. Movements within the Fraser River were quantified using wandering, a sum of the number of changes in migration direction fish made in the Fraser River prior to entering the Seton River.

In 2013 and 2014 the majority of Gates Creek sockeye salmon made one foray into the Seton Generating Station tailrace, with 51% of fish entering the tailrace once in 2013 and 58% entering the tailrace once in 2014 (Figure 3-17). There was no difference in the mean number of forays fish made in 2013 (1.9 ± 0.1) and 2014 (1.9 ± 0.1) and no differences between males and females within or between years. The distribution of the number of forays fish made approximately equally between years, with male Gates Creek sockeye salmon making the greatest number of forays.

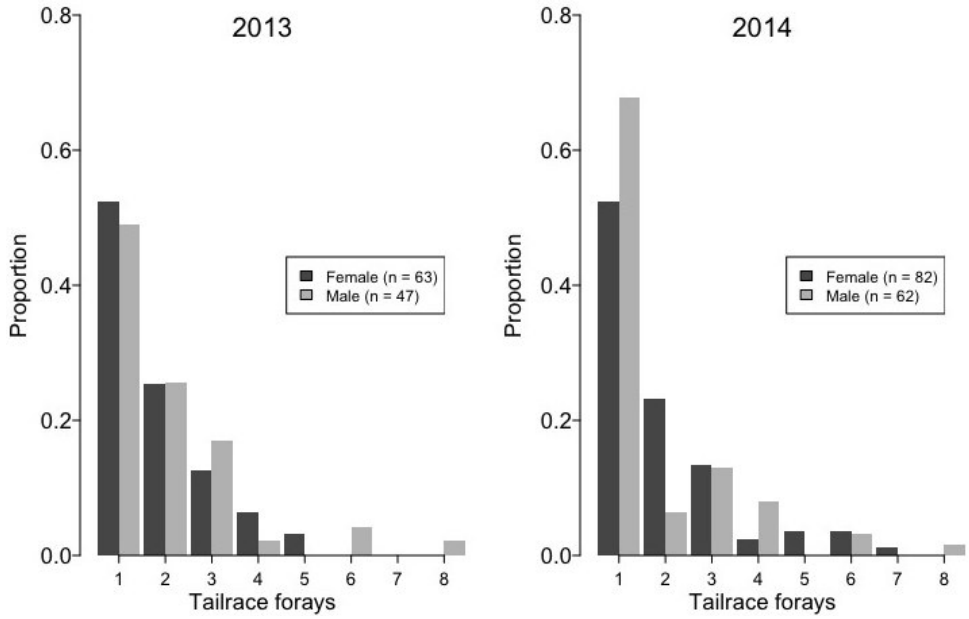

Figure 3-17: Histogram of Gates Creek sockeye salmon forays at the Seton Generating Station tailrace in 2013 and 2014. Detections in the tailrace for >30 s were considered a foray with detections >30 min apart considered multiple forays

Gates Creek sockeye salmon spent greater time in the Seton Generating Station tailrace in 2014 than 2013 (Figure 3-18). Fish spent 3.4 ± 0.4 h (mean ± SE) in the tailrace in 2013 and 5.4 ± 0.4 h in 2014 (Mann-Whitney rank sum test; T=12,373; p=0.003). Females spent 3.1 ± 0.5 h in the tailrace in 2013 and 7.0 ± 0.8 h in 2014, a significant difference (Mann-Whitney rank sum test; T=3,534; p<0.001), whereas males spent the same amount of time in 2013 (3.7 ± 0.6 h) and 2014 (3.1 ± 0.5 h) (Mann-Whitney rank sum test: T=2,701; p=0.48).

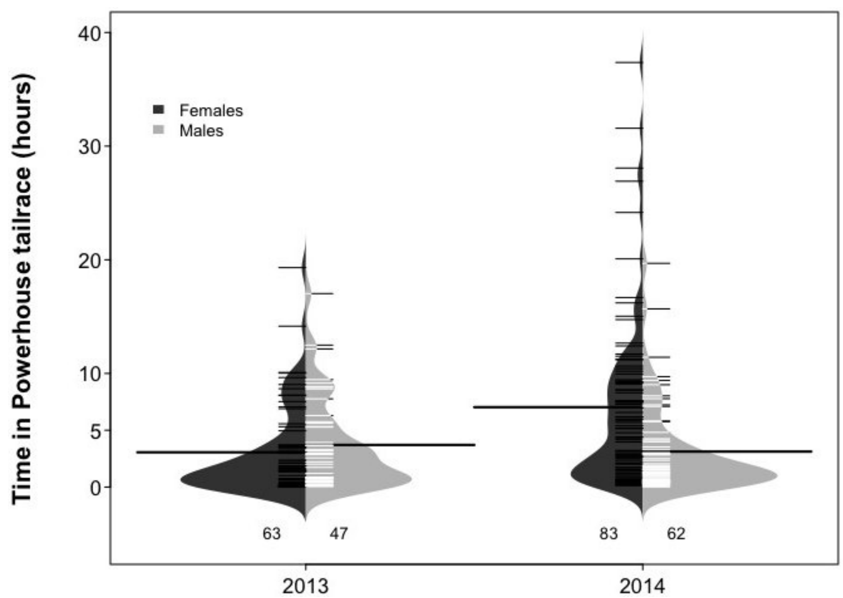

Figure 3-18: Bean plots of male and female Gates Creek sockeye salmon time in the Seton Generating Station (powerhouse) tailrace in 2013 and 2014. Time in the tailrace was the sum of detections lasting >30 s. Long horizontal black bars represent means whereas short horizontal bars represent individuals

Gates Creek sockeye salmon displayed limited wandering behaviour in the Fraser River and the majority of fish moved directly into the Seton River in 2013 (79%) and 2014 (88%) (Figure 3-19). Although there was no difference in the proportion of fish making direct movements into the Seton River between years (chi-squared test: x^2=2.788, df=1, p=0.095) a greater proportion of males moved directly into the Seton River in 2014 than females (chi-squared test: x^2=4.738, df=1, p=0.03).

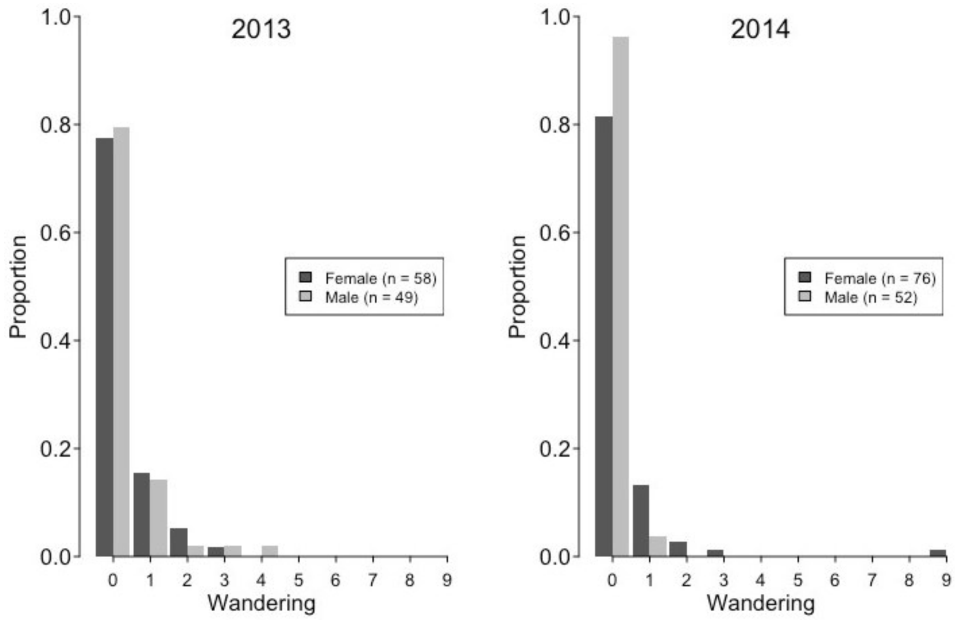

Figure 3-19: Histogram of the number of wandering events made by male and female Gates Creek sockeye salmon during Fraser River migration in 2013 and 2014. No wandering events are fish that moved directly into the Seton River. One or more events indicate the number of times fish altered the direction of their migration prior to Seton River entry

3.5.1.3 Migration Behaviour Models

Migration behaviour was related to migration experience using linear and generalized linear models fit to standardized explanatory variables. Candidate model sets were generated for 2013 and 2014 Gates Creek sockeye salmon migration data independently and with both years combined. Top candidate model sets were averaged to generate coefficient estimates and 95% confidence intervals for explanatory variables (Appendix I). Results for 2013 and 2014 modeled independently are presented in Figure 3-20 and 2013 and 2014 combined presented in Figure 3-21.

Independent analyses of the 2013 and 2014 data found no significant explanatory variables related to migration conditions or fish physiology for Gates Creek sockeye salmon foray or wandering behaviour. All variables, including dilution, had relatively small and similar effect estimates with large confidence intervals that crossed zero. Sex was identified as a significant explanatory variable for time in the tailrace in both 2013 and 2014, with males (positive values) spending increased time in the tailrace in 2013 and less time in the tailrace in 2014. Tagging date was a significant explanatory variable in 2013, with later-migrating fish spending additional time in the Seton Generating Station tailrace. Similarly, testosterone – an indicator of maturity – was positively related to time in the tailrace, although not significantly. Other physiological parameters, such as glucose and lactate plasma concentrations, were not significant.

The effect of dilution on migration behaviour in 2013 and 2014 was uncertain given the large confidence intervals that crossed zero in both years (Figure 3-20). Uncertainty in the effect of dilution was a result of low variability in the dilution ratio in both years with only a small number of fish in 2013 (*n*=9) experiencing a dilution ratio greater than the 20% target ratio. There was some indication that increased thermal refuge in the Seton Generating Station tailrace was associated with increased time in the tailrace in 2014; however, the result was not significant. Temperature in the Fraser River, Seton River or Seton Generating Station were not significant explanatory variables for behaviour.

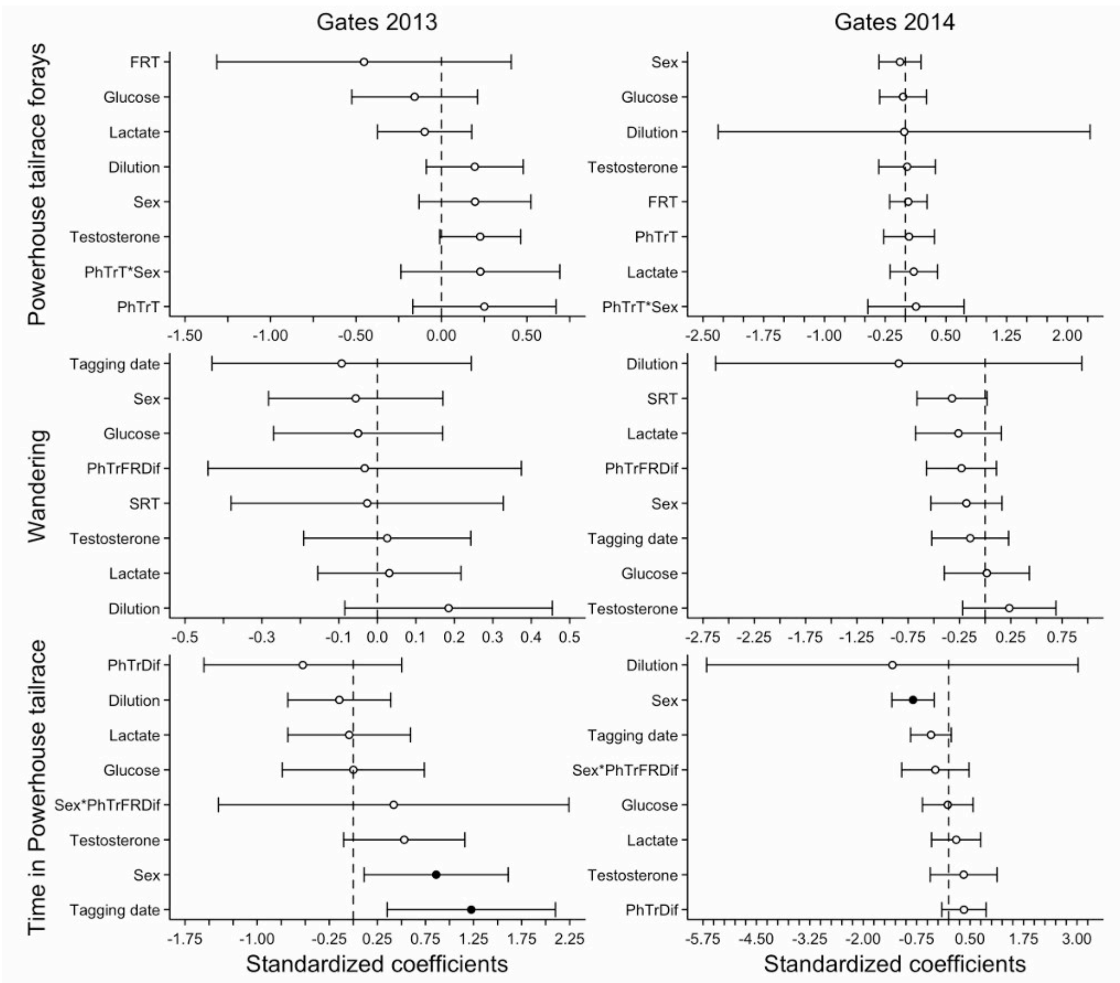

Figure 3-20: **Model averaging results for Gates Creek sockeye salmon migration behaviour in 2013 and 2014. Forays into the tailrace, wandering events, and time in the Seton Generating Station (powerhouse) tailrace were modeled. Standardized coefficients were used to compare relative effect sizes amongst different explanatory variables: Fraser River temperature (FRT), powerhouse tailrace temperature (PhTrT), Tailrace-Fraser River temperature differential (PhTrFRDif / PhTrDif), and Seton River temperature (SRT). Interaction terms are denoted by a * between variables. Solid symbols denote significance. Note different x-axis scales between panels**

Analyses of the combined 2013 and 2014 data found sex and year were both significant explanatory variables for time in the tailrace (Figure 3-21), supporting the results of the independent models. No explanatory variables related to environmental conditions, including dilution, were significant. Again, few fish experienced high dilutions in 2013 and none in 2014. The temperature difference between the tailrace and the Fraser River was associated with increased time in the Seton Generating Station tailrace, although the result was not significant. Increased plasma testosterone concentration was a significant predictor for increased time in the tailrace and was associated with a non-significant increase in tailrace forays. Although this result is somewhat counter-intuitive, as more mature fish would be expected to have more direct migration, mature fish may be more sensitive to homestream olfactory cues that would be present in the Seton Generating Station tailrace discharge. Moreover, mature fish would be expected to have decreased somatic energy stores and may be more likely to use the tailrace to recovery during upstream migration in the Fraser River.

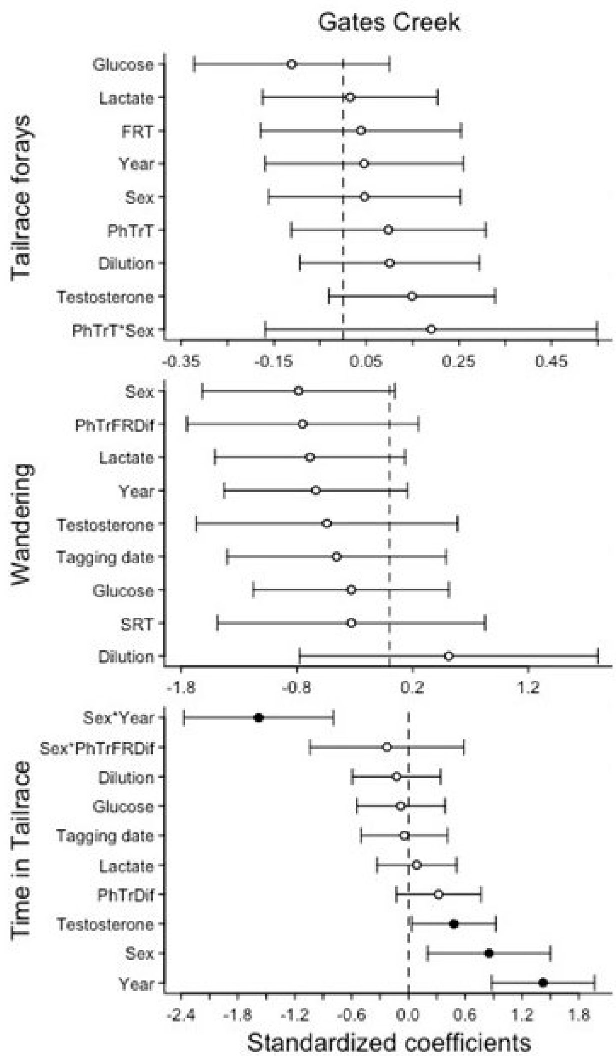

Figure 3-21: Model averaging results for Gates Creek sockeye salmon migration behaviour in 2013 and 2014 combined. Forays into the tailrace, wandering events, and time in the Seton Generating Station (powerhouse) tailrace were

modeled. Standardized coefficients were used to compare relative effect sizes amongst different explanatory variables: Fraser River temperature (FRT), powerhouse tailrace temperature (PhTrT), Tailrace-Fraser River temperature differential (PhTrFRDif / PhTrDif), and Seton River temperature (SRT). Interaction terms are denoted by a * between variables. Solid symbols denote significance. Note different x-axis scales between panels

3.5.1.4 Migration Success to Seton Dam

Gates Creek sockeye salmon migration success to Seton Dam, for radio-tagged fish released in the Fraser River downstream of the Seton Generating Station, was comparable for fence-caught fish released in 2013 and 2014 (Table 3-7). Migration success of fence-caught fish in 2013 represented the latter-half of the Gates Creek sockeye salmon migration period as fish tagged earlier in the migration period (up to 14 August) were captured from the fishway during elevated water temperatures up to 23.7°C and not included in analyses. Overall migration success to Seton Dam in 2013 was 75% (*n*=127/169) for both fishway and fence-caught fish. In 2014, when fence-caught radio and PIT-tagged fish were released in the Fraser River, the proportion of fish surviving to Seton Dam, and the migration time to Seton Dam, did not differ between tag types.

Table 3-7: Migration success to Seton Dam of fence-caught radio and PIT-tagged Gates Creek sockeye salmon released in the Fraser River in 2013-2014

Metric	2013[a]	2014	
	Radio	Radio	PIT
Success to Seton Dam	92% (108/117)	90% (147/163)	88% (157/188)
Migration Time from Release	40.4 ± 1.8 h (11.3 – 115.8 h)	33.8 ± 1.3 h (11.7 – 93.6 h)	32.9 ± 1.4 h (-)

[a] 2013 data only include fish captured from the Seton River fish fence

Time in the Seton Generating Station did not differ for Gates Creek sockeye salmon that were successful or unsuccessful at reaching Seton Dam (Figure 3-22). For fish that were successful or unsuccessful at reaching Seton Dam and detected in the Seton Generating Station tailrace, mean time in the tailrace was 3.4 ± 0.4 h *versus* 3.0 ± 1.3 h in 2013 and 5.2 ± 0.5 h *versus* 6.8 ± 2.5 h in 2014. Differences in sample sizes between successful and unsuccessful fish limited statistical comparison.

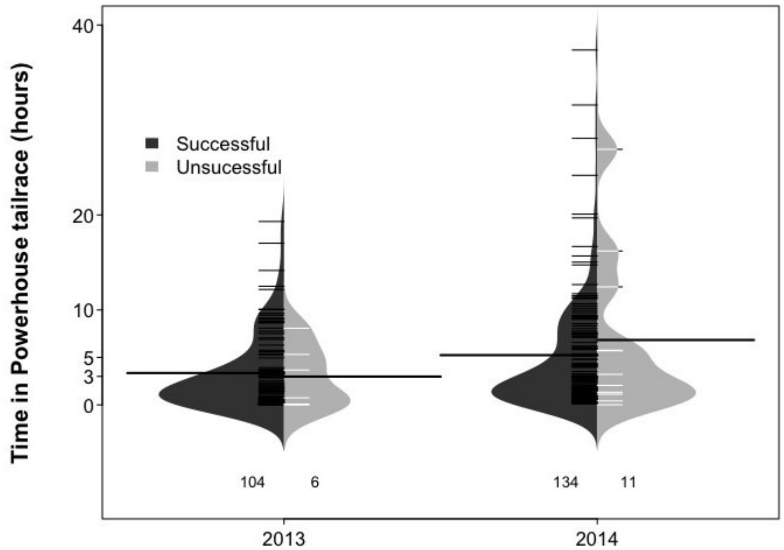

Figure 3-22: Bean plot of the time in the Seton Generating Station (powerhouse) tailrace for radio-tagged Gates Creek sockeye salmon that were successful and unsuccessful at reaching Seton Dam. Mean (long horizontal lines) and individual (short horizontal lines) values are shown

Review of detection histories for fence-caught Gates Creek sockeye salmon found fish that did not reach Seton Dam either fell-back downstream in the Fraser River and out of the study area (2013: *n*=5; 2014: *n*=1), continued migrating past the Seton River-Fraser River confluence (2013: *n*=2; 2014: *n*=5), or had an unknown fate (2013: *n*=1; 2014: *n*=5). Of the radio-tagged fish that migrated past the Seton River in 2014, two were recovered at the base of Terzaghi Dam on the Bridge River and another captured in fisheries at the Bridge River-Fraser River confluence.

3.5.2 2015 Gates Creek Sockeye Salmon

In 2015, an experimental dilution ratio increase was used to determine the effect of above-target dilution ratios on Gates Creek sockeye salmon migration behaviour and success. Above-target dilution ratios occurred for one week in August 2015, preceded by one week of below-target ratios and followed by two weeks of below-target ratios. Migration behaviour of radio-tagged fish released in the Fraser River was examined by quantifying forays at the Seton Generating Station, time in the tailrace, and wandering in the Fraser River for each week. Migration time and success to Seton Dam were also quantified for radio and co-released PIT-tagged fish.

3.5.2.1 Migration Conditions

From 07 to 13 August 2015, Walden North flows were diverted to increase Cayoosh Creek discharge and raise the lower Seton River dilution ratio to 28-29%. Gates Creek sockeye salmon were tagged and released in the Fraser River during these high dilution ratios, as well as prior to and following the high dilution ratios when dilution were at below-target levels. To simplify comparison between migration conditions, releases were grouped by week according to Table 3-8. A brief increase in the dilution ratio occurred on 30 August with one group of radio-tagged fish (*n*=10) and one group of PIT-tagged fish (*n*=10) released after this date. Fraser River and Seton River temperatures did not exceed 20°C throughout August, limiting thermal refuge availability in the Seton Generating Station tailrace in 2015. Seton Generating Station shutdowns were also limited, occurring for 26 h (<3% of time) between 03 August and 15 September 2015.

Table 3-8: The number of Gates Creek sockeye salmon released in the Fraser River according to week and dilution ratio in August to September 2015

Week	Release Dates	Dilution Ratio	Radio-tagged Releases (*n*)	PIT-tagged Releases (*n*)
1	03, 06 Aug	8%	11	8
2	08 Aug – 13 Aug	28-29%	76	72
3	18 Aug – 22 Aug	8-9%	59	57
4	24 Aug – 02 Sept	9-25%	60	60

3.5.2.2 Migration Behaviour in the Fraser River

No differences were observed in the number of forays Gates Creek sockeye salmon made into the Seton Generating Station tailrace between weeks, with the majority of fish in each week making one foray into the tailrace (Figure 3-23). Although there was no difference in the mean number of forays made by fish released in each week (Week 2: 1.6 ± 0.1; Week 3: 1.7 ± 0.2; Week 4: 1.3± 0.1) a greater proportion of fish released in Week 4 made single forays into the tailrace than fish in Week 2 and Week 3 (Week 2: 65%; Week 3: 63%; Week 4: 84%). This suggests later-migrating Gates Creek sockeye salmon exhibit reduced exploratory behaviour into the tailrace.

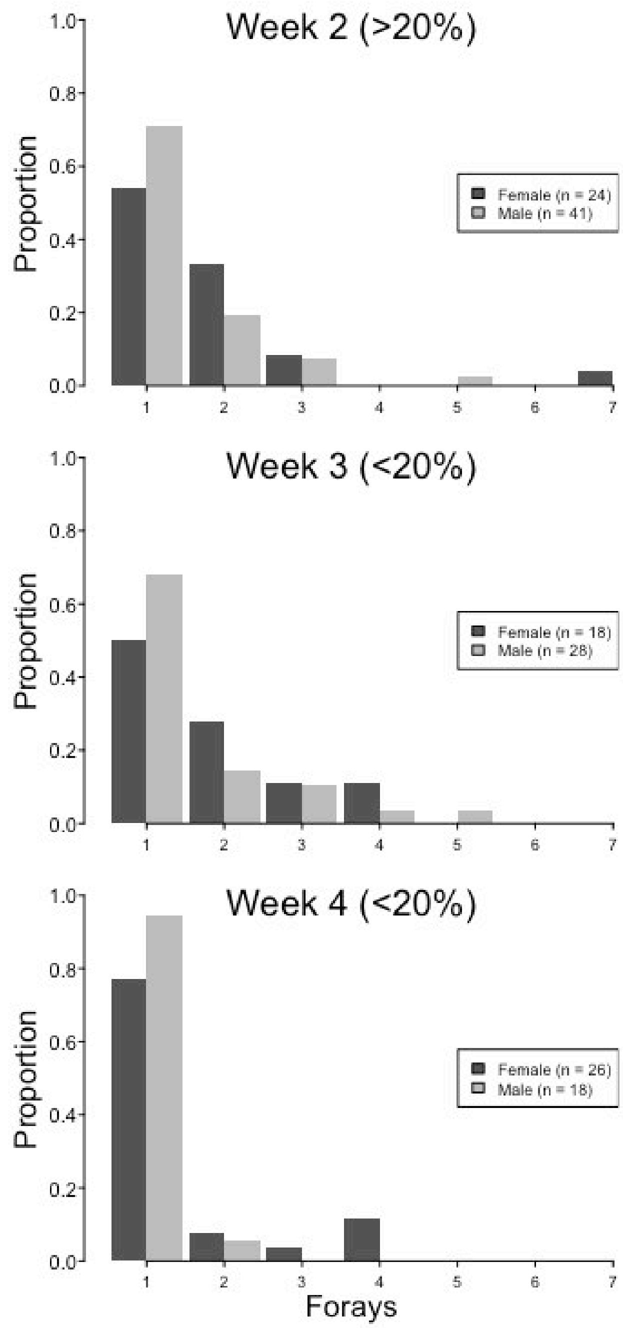

Figure 3-23: **Histogram of radio-tagged male and female Gates Creek sockeye salmon forays at the Seton Generating Station tailrace in 2015. Fish were grouped by release timing and conditions during release with fish released during above-target dilution ratios in Week 2 and below target dilution ratios in Week 3 and 4. Fish detected in the tailrace for >30 s were considered to have made a foray with detections >30 min apart considered multiple forays**

The mean time Gates Creek sockeye salmon spent in the tailrace did not differ between fish released in Week 2 (4.2 ± 0.5 h) and Week 3 (3.5 ± 0.6 h) (Figure 3-24). However, mean time in the tailrace for fish released in Week 4 (1.9 ± 0.5 h) was significantly less than time in the tailrace for fish released in Week 2 and Week 3 (ANOVA on ranks: H=23.935, df=2, $p<0.001$). These results support those of foray behaviour and again indicate that later-migrating Gates Creek sockeye salmon exhibit reduced exploratory behaviour in the tailrace compared with fish migrating earlier in August during similar dilution ratios and environmental conditions.

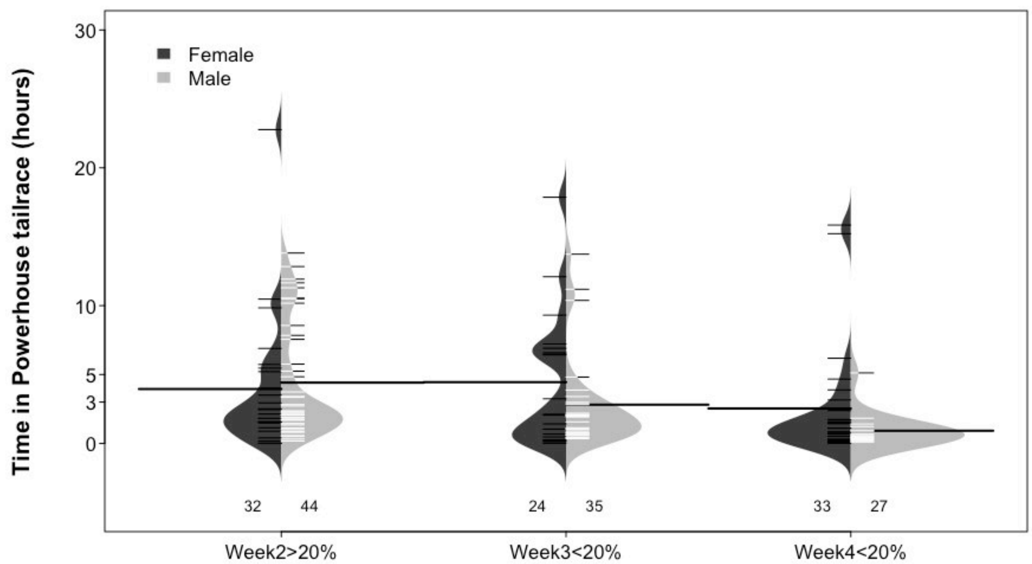

Figure 3-24: **Bean plots of male and female Gates Creek sockeye salmon time in the Seton Generating Station (powerhouse) tailrace for each week in 2015. Time in the tailrace was the sum of detections lasting >30 s. Long horizontal black bars represent means whereas short horizontal bars represent individuals**

Wandering results indicated that Gates Creek sockeye salmon displayed increased exploratory behaviour in the Fraser River during the week of above-target dilution ratios (Figure 3-25). The proportion of fish that moved directly into the Seton River was significantly greater during both weeks of below-target dilution ratios than during the week of above-target ratios (Week 2 vs 3 chi-squared test: x^2=11.105, df=1, $p<0.001$; Week 2 vs 4 chi-squared test: x^2=15.116, df=1, $p<0.001$). These results contrast with the migration behaviour observed at the Seton Generating Station, where the number of forays and time in the tailrace did not differ between the week of above-target dilution ratios and the week immediately after, but differences were observed between the above-target week and the second week of below-target dilution ratios.

Overall, migration behaviour of Gates Creek sockeye salmon displayed a trend towards more-directed movement past the Seton Generating Station and into the Seton River in the latter portion of the migration period. Fish tagged and released during elevated dilution ratios did display increased exploratory behaviour in the Fraser River, but were also tagged in the earlier portion of the run and may have had inherently slower migration. However, the overview analysis presented here was performed by week and the conditions individual fish experienced during their migration has yet to be quantified. Individual conditions experienced by Gates Creek sockeye salmon will be part of future analyses.

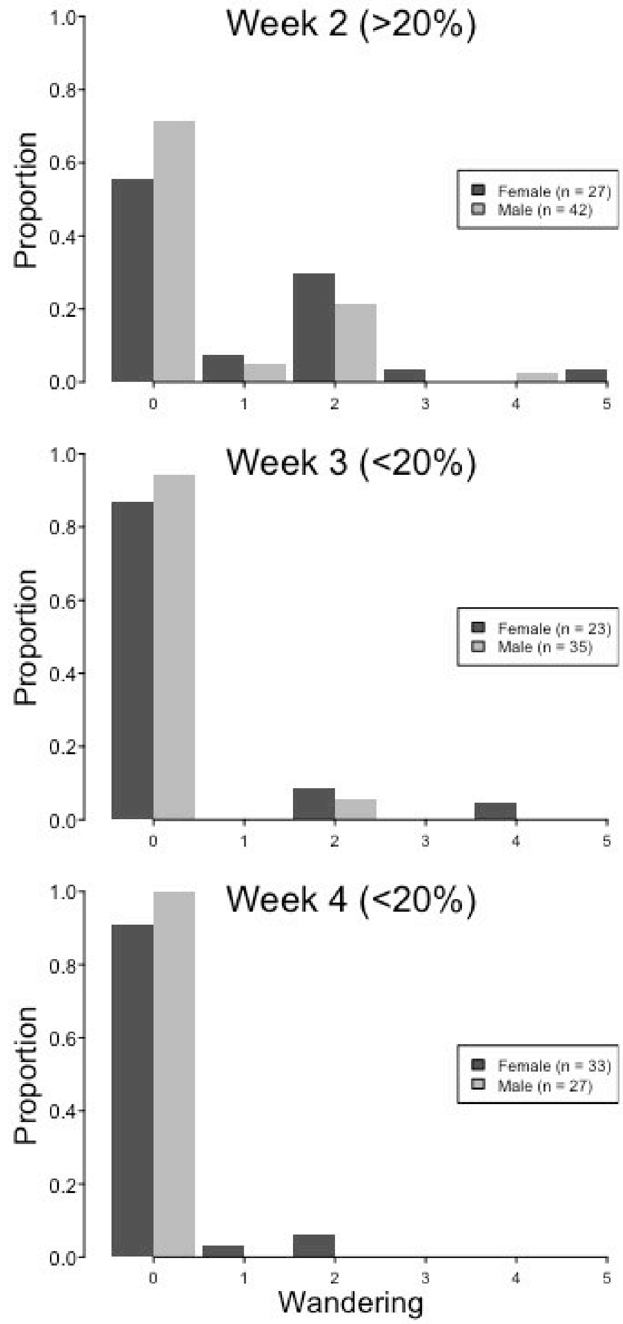

Figure 3-25: **Histogram of radio-tagged male and female Gates Creek sockeye salmon wandering behaviour in the Fraser River in 2015. Fish were grouped by release timing and conditions during release with fish released during above-target dilution ratios in Week 2 and below target dilution ratios in Week 3 and 4. Fish that did not wander (wandering = 0) migrated directly into the Seton River. One or more wandering events represents the number of times fish altered their migration direction in the Fraser River**

3.5.2.3 Migration Success to Seton Dam

Survival of Gates Creek sockeye salmon to Seton Dam was lowest for radio-tagged fish released in Week 1 (Table 3-9), although the small sample size did not allow survival to be compared with Week 2 to Week 4. Radio-tagged fish that failed to reach Seton Dam in Week 1 (*n*=4) were observed to fall back in the Fraser River and out of the study area. PIT-tagged fish released during Week 1 had greater survival than radio-tagged fish; however, the sample size was also small for this release group (*n*=8).

Survival to Seton Dam during Week 2, when Gates Creek sockeye salmon were released at above-target dilution ratios, was significantly lower than survival in Week 3 or 4, when the dilution ratio was at below-target levels (Table 3-9). Survival in Week 2 was significantly less for radio-tagged (chi-squared test: x^2=19.138, df=2, p<0.001) and PIT-tagged fish (chi-squared test: x^2=21.446 df=2, p<0.001). Review of detection histories found that radio-tagged Gates Creek sockeye salmon that did not reach Seton Dam in Week 2 (*n*=18) either fell back downstream in the Fraser River (*n*=13), migrated past the Seton River-Fraser River confluence (*n*=4), or had an unknown fate (*n*=1). Fall-back of fish in the Fraser River suggests fish condition or environmental conditions may have been factors affecting survival of these early-migrating Gates Creek sockeye salmon. However, radio-tagged fish were also observed to fall back in the Fraser River in Week 4 (*n*=2). Upstream movement of fish suggests a portion of fish responded to high dilution by avoiding entry into the Seton River, although upstream movements were observed in 2014 when dilution did not exceed 20%. Detection histories were unavailable for PIT-tagged fish; however, fisheries in the Fraser River upstream of the Seton River recovered three tags from PIT-tagged fish released during Week 2, indicating that both radio and PIT-tagged fish migrated past the Seton River-Fraser River confluence.

Table 3-9: Gates Creek sockeye salmon survival and migration time to Seton Dam for each week in August 2015

Week	Release Dates	Dilution Ratio	Radio-tagged		PIT-tagged	
			Survival	Migration Time	Survival	Migration Time
1	03, 06 Aug	8%	64% (7/11)	46.2 ± 5.4 h (37.4-75.0 h)	88% (7/8)	50.4 ± 8.3 h (29.1-82.7 h)
2	08 – 13 Aug	28-29%	76% (58/76)	43.3 ± 2.4 h (14.2-98.6 h)	76% (54/72)	42.1 ± 2.5 h (14.9-98.0 h)
3	18 – 22 Aug	8-9%	97% (57/59)	47.0 ± 2.7 h (21.9-108.7 h)	100% (57/57)	45.1 ± 2.7 h (15.8-108.6 h)
4	24 Aug – 02 Sept	9-25*%	97% (58/60)	39.8 ± 3.2 h (13.2-163.7 h)	93% (56/60)	36.5 ± 2.5 h (8.9-94.2 h)

*Above target dilution ratios occurred 30 August to 01 September.

Migration time to Seton Dam did not differ between Week 2 and either Week 3 or Week 4 for radio or PIT-tagged Gates Creek sockeye salmon. However, migration time in Week 4 was significantly less than Week 3 for both radio (ANOVA on ranks: H=6.206, df=2, p=0.045) and PIT-tagged fish (ANOVA on ranks: H=7.108, df=2, p=0.029), supporting the migration behaviour results that indicated later-migrating fish had more-direct migration into the Seton River.

Overall survival to Seton Dam for Gates Creek sockeye salmon released in the Fraser River in 2015 was 88% (*n*=181/206) for radio-tagged fish and 89% (*n*=175/189) for PIT-tagged fish. Similar survival was observed in 2013 and 2014 (see Section 3.5.1.4). Overall migration time from release to the Seton Dam fishway in 2015 was 43.4 ± 1.5 h (*n*=179) for radio-tagged fish and 41.6 ± 1.5 h (*n*=174) for PIT-tagged fish.

3.5.3 Portage Creek Sockeye Salmon

Portage Creek sockeye salmon migration behaviour in the Seton Generating Station tailrace and Fraser River, and migration success to Seton Dam, was quantified using 2013-2014 radio telemetry data. Analyses were similar to those for Gates Creek sockeye salmon; however, Portage Creek sockeye salmon telemetry data for 2013 and 2014 was pooled due to low sample sizes in 2013. Migration behaviour was modeled for a subset of Portage Creek sockeye salmon (*n*=90) because blood parameters were not available for all fish.

3.5.3.1 Migration Conditions

Cayoosh Creek discharge temporarily increased in late-September 2014, increasing the dilution ratio to 15% during the Portage Creek sockeye migration. Radio-tagged Portage Creek sockeye salmon were released during this increased dilution ratio (Table 3-10); although, dilution was <1% above the target ratio for one release (*n*=20). Remaining radio-tagged Portage Creek sockeye salmon were released at dilution ratios <10%. A total of 194 PIT-tagged Portage Creek sockeye salmon were released in the Fraser River in 2014 with eight fish released at a dilution ratio >10%.

Table 3-10: Releases of radio-tagged Gates Creek sockeye salmon in Fraser River in 2013-2015 by dilution ratio at time of release

Population	Year	Dilution Ratio				
		<10%	10-20%	20-30%	30-40%	>40%
Portage Creek sockeye salmon	2013	19	5	-	-	-
	2014	137	52	-	-	-

3.5.3.2 Fraser River Migration Behaviour

Portage Creek sockeye salmon were detected in the Seton Generating Station tailrace during station shut downs in 2014. Tagged Portage Creek sockeye salmon were released in the Fraser River from 27 September and 15 October 2014 with 18% (*n*=31) of released fish (*n*=170) detected during shutdowns that occurred for 191 h (16% of time) between 27 September and 15 November. All (100%) radio-tagged Portage Creek sockeye salmon were detected during operational periods. No Portage Creek sockeye salmon were detected during shutdowns in 2013; however, shutdowns were infrequent in 2013 (26 h or 2% of time after radio-tagged releases 03 October) and few tagged fish (*n*=24) released. Further investigation is required to assess Portage Creek sockeye salmon use of the Seton Generating Station tailrace during shutdowns in 2014.

Portage Creek sockeye salmon most frequently entered the Seton Generating Station tailrace once during their migration from release to the Seton River (43%; *n*=39/90); however, the majority of fish made multiple forays into the tailrace (Figure 3-26). The mean number of forays in the tailrace was 3.6 ± 0.4 (3.9 ± 0.6 for males and 3.3 ± 0.6 for females) and the mean time fish spent in the tailrace was 21.1 ± 2.4 h with no differences in forays between males and females (Figure 3-27).

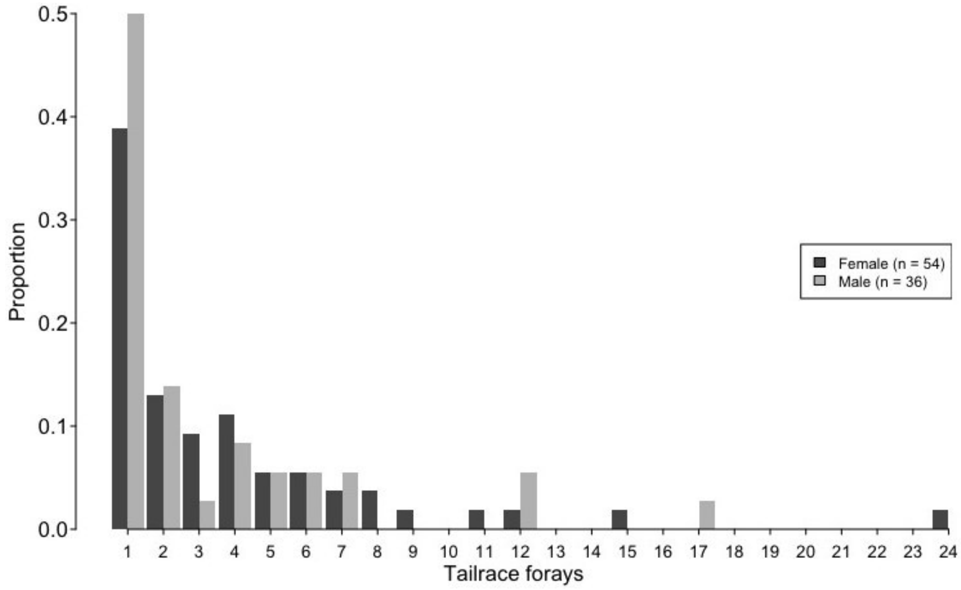

Figure 3-26: Histogram of Portage Creek sockeye salmon forays at the Seton Generating Station tailrace in 2013-2014. Detections of fish in the tailrace for >30 s was considered a foray with detections >30 min apart considered multiple forays

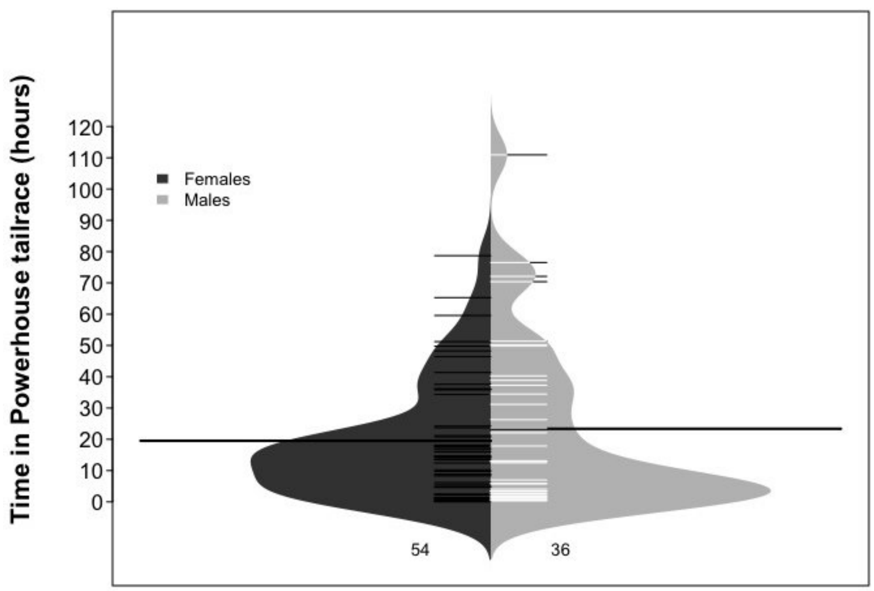

Figure 3-27: Bean plot of male and female Portage Creek sockeye salmon time in the Seton Generating Station (powerhouse) tailrace in 2013-2014. Time in the tailrace was the sum of detections lasting >30 s. Long horizontal black bars represent means whereas short horizontal bars represent individuals

The majority of Portage Creek sockeye salmon (73%; n=57) moved directly into the Seton River from release with limited wandering activity between telemetry receivers (Figure 3-28). Given that the migration time for Portage Creek sockeye salmon to reach Seton Dam was up to 479 h (see Section 3.5.2.4), additional unquantified wandering events may have occurred but at a finer scale than could be detected on the Fraser River radio receivers installed at the Seton River-Fraser River confluence and the Seton Generating Station. Regardless, Portage Creek sockeye salmon displayed a greater number of multiple wandering events than Gates Creek sockeye salmon and spent a greater amount of time migrating from release to Seton Dam.

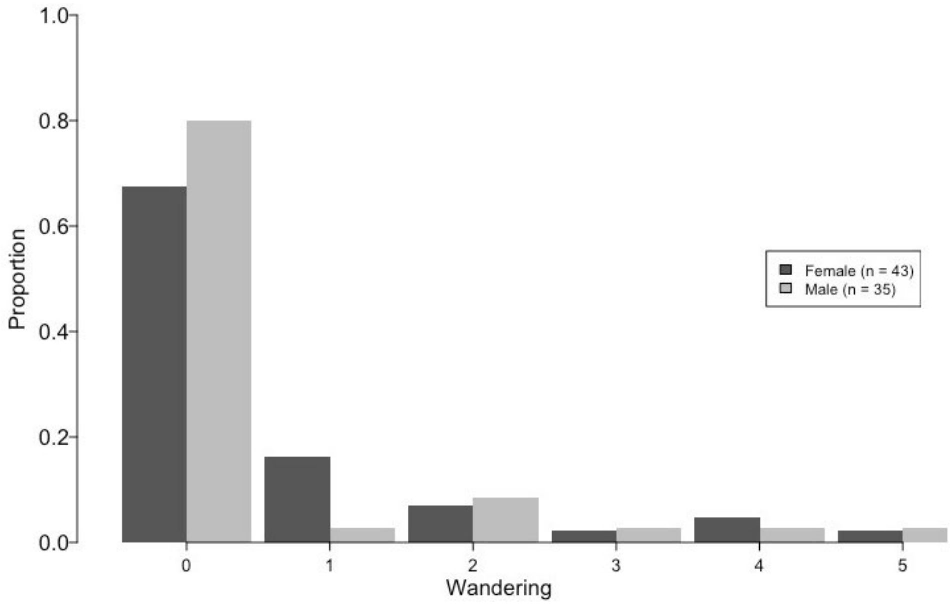

Figure 3-28: Histogram of the number of wandering events made by male and female Portage Creek sockeye salmon during Fraser River migration in 2013-2014. No wandering events are fish that moved directly into the Seton River. One or more events indicate the number of times fish altered migration direction

3.5.3.3 Migration Behaviour Modeling

Portage Creek sockeye salmon migration behaviour was related to migration experience using linear and generalized linear models fit to standardized explanatory variables. Candidate model sets were generated for fish in 2013-2014 where blood parameter data were available (n=90). Top candidate model sets were averaged to generate coefficient estimates and 95% confidence intervals for explanatory variables (Appendix I). Results are presented in Figure 3-29.

Dilution was a significant explanatory variable for both the number of forays Portage Creek sockeye salmon made into the Seton Generating Station tailrace, as well as the time spent in the tailrace. Increases in the Seton River dilution ratio had a positive effect on tailrace forays and time in the tailrace. Water temperature in the Seton Generating Station tailrace was also found to be a significant explanatory variable for tailrace forays, with higher water temperatures associated with a decrease in forays. Higher tailrace water temperatures occurred in the earliest part of the migration period for Portage Creek sockeye salmon, when Fraser River water temperatures were cooler than the tailrace and Portage Creek sockeye salmon could be expected to use the Fraser River as cool water refuge. No significant explanatory variables were identified for wandering behaviour. Blood parameters were not significantly related to any migration behaviour and there was no evidence to suggest a temporal component to migration behaviour within the Portage Creek sockeye salmon migration period as tagging date was not significant in any behaviour model.

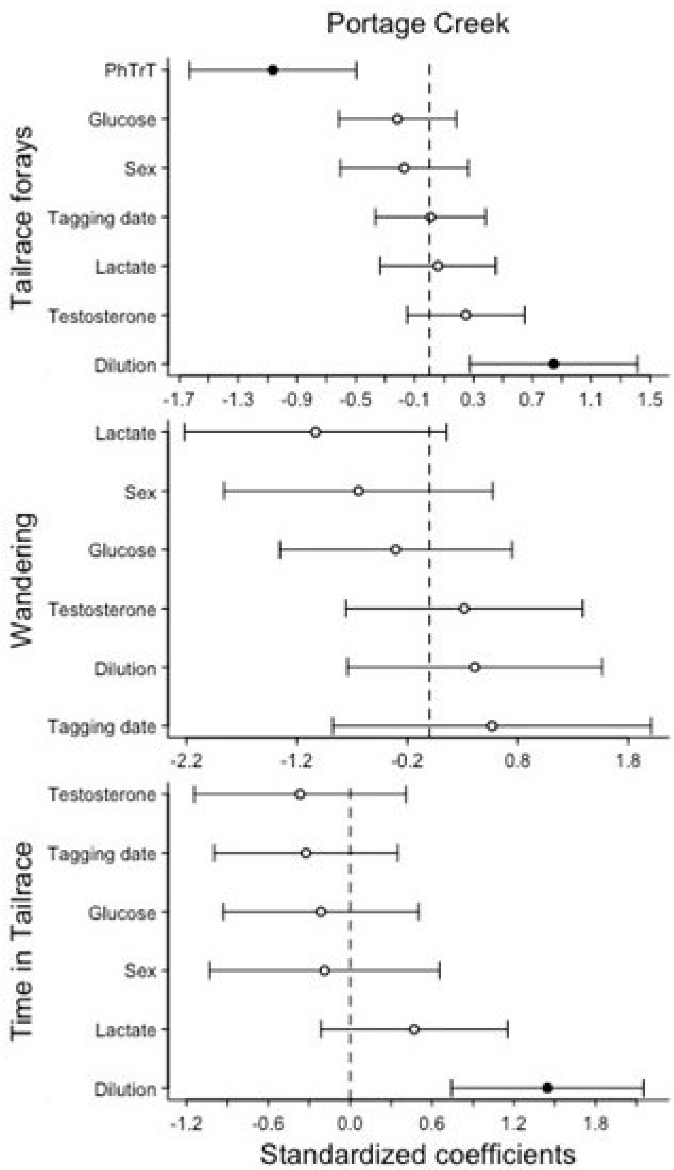

Figure 3-29: Model averaging results for Portage Creek sockeye salmon migration behaviour in 2013-2014. Forays into the tailrace, wandering events, and time in the Seton Generating Station tailrace were modeled for fish with blood parameter data available (*n*=90). Standardized coefficients were used to compare relative effect sizes amongst explanatory variables. PhTrT: Powerhouse tailrace temperature. Solid symbols denote significance. Note different x-axis scales between panels

3.5.3.4 Migration Success to Seton Dam

Migration success data for Portage Creek sockeye salmon is unchanged from 2014.

Migration success and time to Seton Dam was compared for radio and PIT-tagged Portage Creek sockeye salmon released in the Fraser River in 2014. Survival to the Seton Dam fishway entrance for radio-tagged Portage Creek sockeye salmon was 88% (n=167/189) in 2014 with a mean migration time of 126.7 ± 6.2 h. The migration time for PIT-tagged fish was 115.0 ± 7.3 h. Survival was lower for PIT-tagged Portage Creek sockeye salmon (73%; n=141/194), particularly for female PIT-tagged fish (57%; n=36/63) versus males (81%; n=105/129). Lower female survival was also observed with radio-tagged fish (Males: 93%; n=91/98; Females: 84% n=76/91), although the difference was not as great as with PIT-tagged fish. Explanations for differences in survival between tag types has yet to be investigated.

Time in the Seton Generating Station tailrace was found to be significantly greater for Portage Creek sockeye salmon that did not successfully migrate to Seton Dam. Fish that successfully migrated to Seton Dam spent 22.8 ± 2.4 h at the Seton Generating Station whereas fish that were unsuccessful at reaching Seton Dam spent 33.8 ± 8.6 h (Mann-Whitney U-test: W=1314, p=0.03).

3.5.4 Coho Salmon

Coho salmon were radio-tagged and released downstream in 2014. No coho salmon were tagged in 2015. Estimating the migration success of radio-tagged coho salmon from release to Seton Dam, or spawning grounds downstream of Seton Dam, was complicated by a low sample size (n=7) in 2014. Regardless, four coho salmon released in the Fraser River successfully migrated to Seton Dam. Migration time for these fish ranged from 27.6-82.3 h. Coho salmon that successfully migrated to Seton Dam spent 1.1-1.9 h (n=4) in the Seton Generating Station tailrace whereas unsuccessful coho salmon spent 0-2.7 h (n=3). Coho salmon that did not migrate to Seton Dam spent 1.2 ± 0.8 h in the tailrace. For all individuals, time in the tailrace ranged from 0.0 h (no detections) to 43.4 h.

3.6 Passage at Seton Dam

Adult salmon passage at Seton Dam was examined from 2012-2015 using a combination of telemetry methods. From 2012-2014 acoustic accelerometers were first piloted (2012) then deployed (2013-2014) to measure Gates Creek sockeye swimming speeds in different areas of the tailrace during different discharges and flow scenarios. Radio and PIT tags were used to assess Gates Creek (2013-2015) and Portage Creek (2013-2014) sockeye salmon delay in the Seton Dam tailrace and overall passage success. Discharge at Seton Dam followed routine BC Hydro operations in 2012, 2013 and 2015 while an experimental alternative discharge scenario was tested in 2014 to determine if fish passage could be improved. Data from studies in previous years (2005, 2007) has been included for comparison.

3.6.1 Gates Creek Sockeye Salmon

3.6.1.1 Migration Conditions

Migration conditions at Seton Dam during the Gates Creek sockeye salmon migration period varied in 2012-2015 both within and between years. Within year variation is due to operational requirements at Seton Dam to maintain discharge within the WUP target hydrograph (BC Hydro 2011). Discharge is required to be decreased mid-August during the Gates Creek sockeye salmon migration via reductions in conveyance structure discharge or change-over to conveyance structures with lower total discharge volume. As a result, Gates Creek sockeye salmon typically migrate during two distinct discharge and flow conditions. However, variation in upstream factors, such as Bridge River Generation inflows, may cause the WUP target hydrograph to be exceeded in some years and requiring modifications to routine Seton Dam operations. Further, temperature can also vary year to year with changes in the prevailing environmental conditions. Detailed information on migration conditions in 2012-2015 can be found in Section 3.1.

Tagged Gates Creek sockeye salmon were released at two discharge conditions in 2012 and 2013, three in 2014, and one in 2015. In 2012, Seton Dam discharge was high during the two discharge scenarios (48 $m^3{\cdot}s^{-1}$ via SSV1 and SSV3; 35 $m^3{\cdot}s^{-1}$ via SSV1 and FWRG), with a radial gate opening used to facilitate the ramp-down. In 2013, two discharges scenarios were again studied (26.1 $m^3{\cdot}s^{-1}$ via SSV1 and FWRG; 22.8 $m^3{\cdot}s^{-1}$ via SSV1) that were both within the WUP target hydrograph; however, Seton Dam water temperatures during the first scenario were elevated up to 23.7°C. In 2014, an experimental flow scenario was tested that changed Seton Dam discharge from routine operations (27.0 $m^3{\cdot}s^{-1}$ via SSV1 and FWRG) to an alternative scenario (31.3 $m^3{\cdot}s^{-1}$ via SSV4 and FWRG) for one week before routine flows were re-established. In 2015, discharge from SSV1 unexpectedly decreased in late-July, eliminating the need for Seton Dam discharge to be decreased, resulting in a 21.8 $m^3{\cdot}s^{-1}$ discharge via SSV1 and FRWG throughout August. Analyses found temperature was not a factor in passage success at Seton Dam in 2014 or 2015.

3.6.1.2 Seton Dam Passage Success

Acoustic and PIT-tagged Gates Creek sockeye salmon released at the Upper Seton River site were used to compare passage success in 2012-2015. Past studies in 2005 and 2007 had similar tagging methods. In 2015, Gates Creek sockeye salmon were not tagged with acoustic transmitters; therefore, PIT-tag fish were used for comparison as the release site was the same as for acoustic-tagged fish in 2013-2014. Passage success for all fish and discharge conditions in each year is summarized in Table 3-11.

Nearly all PIT-tagged Gates Creek sockeye salmon released in 2015 successfully located and ascended the Seton Dam fish ladder. The proportion of tagged fish that located the Seton Dam fishway in 2015 was comparable to acoustic-tagged fish in 2014 and greater than all study years prior to 2014. Overall success in 2015, the proportion of fish known to have reached the Seton Dam tailrace and successfully passed Seton Dam, was the highest yet observed. Mean entrance delay in 2015 was similar to 2013 and 2014, and was lower than all estimates of entrance delay in years prior to 2014. Passage efficiency remained high. For comparison, overall success of PIT-tagged fish released at the Upper Seton River was 94% (*n*=502/537) in 2014.

Table 3-11: Passage success of Gates Creek sockeye salmon at Seton Dam in 2005 (radio tags), 2007 (acoustic tags), 2012-2014 (acoustic), and 2015 (PIT tags)

Variable	2005[a]	2007[b]	2012	2013	2014	2015
Attraction Efficiency	77% (23/30)	86% (44/51)	69% (18/26)	83% (45/54)	98% (44/45)	97% (445/457)
Entrance Delay*	18.0±4.7 h	16.3±3.1 h (0.5-92.6 h)	18.8±6.8 h (0.5-114.7 h)	10.8±1.4 h (0.1-58.4 h)	12.9±1.6 h (0.7-50.9 h)	13.3±0.9 h (0.9-196.0 h)
Passage Efficiency	100% (23/23)	93% (41/44)	89% (16/18)	98% (44/45)	98% (43/44)	99% (441/445)
Overall Success	77% (23/30)	80% (41/51)	62% (16/26)	81% (44/54)	96% (43/45)	97% (441/457)

*Entrance delay is mean ± S.E. Data from [a]Pon et al. (2006) and [b]Roscoe and Hinch (2008). Assessed discharges ($m^3 \cdot s^{-1}$) were: 15.8, 12.7, 11.0 (2005); 60.0, 35.0 (2007); 48.0, 35.0, radial gate opening (2012); 26.1, 22.8 (2013); 27.0, 27.2, 31.3 (2014); and 21.8 (2015).

Differences in Gates Creek sockeye salmon passage success across years can be attributed to differences in discharge and environmental conditions. Low passage success in 2012 was due to a radial gate opening on 21 August where attraction efficiency was 0% (*n*=0/5) and all fish fell back from Seton Dam after 1.1–37.1 h. Passage success outside of the radial gate opening was 86% (*n*=18/21), comparable to success in other years. In 2013, water temperatures greater than 21°C were found to reduce Gates Creek sockeye salmon passage success (Figure 3-30). High water temperatures primarily occurred during the initial discharge scenario in 2013 (up to 21 August), with an overall passage success for acoustic tagged fish of 74% (*n*=26/35). In comparison, overall passage success was 95% (*n*=18/19) during the second discharge scenario when temperature had decreased to <21°C. In 2014 and 2015, maximum Seton Dam tailrace temperatures were 20.4°C and 20.2°C, respectively, and passage success high in both years. In 2014, the alternative discharge scenario (Section 3.6.3/3.6.4) was found to increase the passage success of PIT-tagged fish over routine operations (89% vs 98%). There was no difference in the passage success of radio and acoustic-tagged passage success; however, delay for both acoustic and radio-tagged fish was greater under the alternative flow scenario.

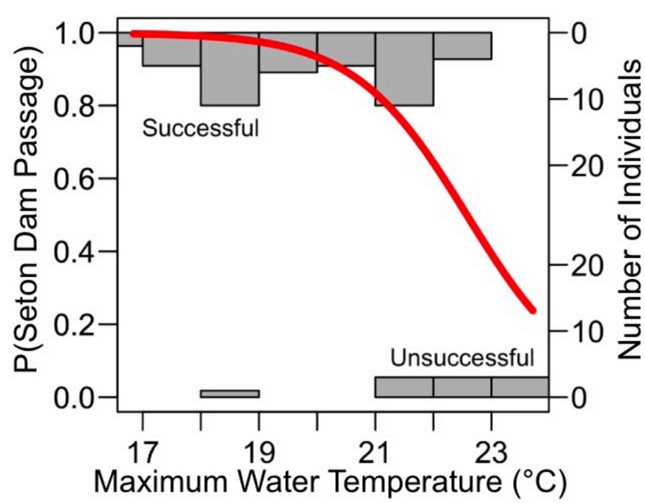

Figure 3-30: Logistic regression of the predicted probability (red line) of Gates Creek sockeye salmon passing Seton Dam in 2013 after experiencing different maximum water temperatures downstream of the dam

Passage success and entrance delay for Gates Creek sockeye salmon differed between release locations (Table 3-12). Acoustic-tagged fish released from the Upper Seton River site delayed longer in the Seton Dam tailrace than radio-tagged fish that migrated to Seton Dam following release in the Fraser River. Given that the downstream detection range of the Seton Dam acoustic and radio telemetry arrays was equal, differences are likely due to acoustic-tagged fish recovering in the tailrace post-tagging. Entrance delay of PIT-tagged fish, calculated from the time of release at the Upper Seton River site, was also longer than radio-tagged fish in 2014 (9.1 ± 0.5 h; *n*=510) and 2015 (13.3 ± 0.9 h; *n*=445). These data suggest downstream released radio-tagged fish may be most representative of Gates Creek sockeye salmon migration delay at Seton Dam. However, downstream migration conditions may also contribute to the reduced passage success of radio-tagged fish as compared to acoustic-tagged, as both Seton River and Fraser River temperatures were elevated in 2013 when the passage success of radio-tagged fish was lower than acoustic-tagged fish.

Table 3-12: Passage success of acoustic- and radio-tagged Gates Creek sockeye salmon at Seton Dam in 2013-2014 and radio-tagged fish in 2015

Metric	2013		2014		2015
	Acoustic	Radio	Acoustic	Radio	Radio
Release Site	Fence	DSW	Fence	DSW	DSW
Attraction Efficiency	83% (45/54)	74% (114/155)	98% (44/45)	98% (143/146)	100% (180/180)
Entrance Delay*	10.8 ± 1.4 h (0.1-58.4 h)	8.8 ± 1.3 h (0.1-80.3 h)	12.9 ± 1.6 h (0.7-50.9 h)	8.3 ± 1.3 h (0.0-95.9 h)	7.6 ± 0.6 h (2.0 – 50.4 h)
Passage Efficiency	98% (44/45)	95% (108/114)	98% (43/44)	100% (143/146)	99% (178/180)
Overall Success	81% (44/54)	70% (108/155)	96% (43/45)	98% (143/146)	99% (178/180)

*Entrance delay is mean ± SE. Entrance delay is the time difference between first detection in the Seton Dam tailrace and first detection at the fishway entrance. Sample sizes for entrance delay of radio-tagged sizes were: *n*=99 (2013); *n*=117 (2014); *n*=180 (2015)

3.6.1.3 Alternative Flow Scenario Passage Success

In 2014, Gates Creek sockeye salmon passage at Seton Dam was examined under routine BC Hydro operating conditions and an alternative flow scenario that reduced flow velocities around the fishway entrance (see Section 3.2). Swimming activity and behaviour was examined using acoustic-tagged fish while passage success during each flow scenario was assessed using acoustic, radio, and PIT-tagged fish.

Fish behaviour in the Seton Dam tailrace differed between the two flow scenarios. Acoustic-tagged fish that experienced the alternative flow scenario delayed significantly longer below the dam (Mann-Whitney *U*-test: W=133, p=0.022) and made significantly more tailrace crossings from the fishway entrance area to the radial gate spillway (Mann-Whitney *U*-test: W=95, p=0.001) (Table 3-13). Radio-tagged fish also delayed significantly longer under the alternative flow scenario (Mann-Whitney *U*-test: W=1,025, p=0.003) (Table 3-14). Acoustic tagged fish also appeared to prefer delaying in the entrance area during the alternative flow scenario, spending five times longer in the entrance area than in the radial gate spillway, although this difference was not significant (Mann-Whitney *U*-test: W=158, p=0.252).

Table 3-13: Acoustic-tagged Gates Creek sockeye salmon passage at Seton Dam during routine BC Hydro operations and an alternative flow scenario in 2014

Variable	Flow Scenario	
	Routine	Alternative
Attraction Efficiency	97% (29/30)	100% (15/15)
Entrance Delay (Range)	10.0 ± 1.3 h (0.7-25.9 h)	18.8 ± 3.5 h* (1.6-50.9 h)
Passage Efficiency	97% (28/29)	100% (15/15)
Overall Success	93% (28/30)	100% (15/15)
Tailrace Crossing (Range)	2.0 ± 0.2 (1-4)	4.5 ± 0.8* (1-12)
Entrance area: radial gate delay ratio (Range)	1.6 ± 0.2 (0.2-4.9)	5.4 ± 1.8 (0.3-20.4)
Anaerobic Recruitment	6.9 ± 1.6%	8.2 ± 2.1%
Forebay Delay	1.1 ± 0.3 h*	0.6 ± 0.3 h

All values are presented as mean ± S.E. A (*) indicates a significant difference.

Table 3-14: Radio-tagged Gates Creek sockeye salmon passage at Seton Dam during routine BC Hydro operations and an alternative flow scenario in 2014

Variable	Flow Scenario	
	Routine	Alternative
Attraction Efficiency	98% (102/104)	98% (41/42)
Entrance Delay (Range)	6.7 ± 1.7 h[a] (0.0-95.9 h)	11.1 ± 2.0 h[b]* (0.1-54.2 h)
Passage Efficiency	100% (102/102)	100% (41/41)
Overall Success	98% (102/104)	98% (41/42)

Entrance delay is mean ± S.E. *indicates a significant difference. [a]*n*=74. [b]*n*=41.

Although fish delayed longer during the alternative flow scenario, Monte Carlo simulations found that PIT-tagged Gates Creek sockeye salmon passage success was significantly greater under the alternative flow scenario (98%; *n*=199/204) than routine BC Hydro operations (89%; *n*=344/388) (Table 3-15). Acoustic-tagged Gates Creek sockeye salmon also had increased passage success during the alternative flow scenario. However, due to the small sample size of acoustic-tagged fish, these differences were not significant. No differences in passage success were found for radio-tagged fish that successfully migrated to Seton Dam from the Fraser River West release site (Table 3-14). However, a portion of radio-tagged fish released downstream failed to migrate to Seton Dam (Section 3.5). The loss of these fish downstream, rather than in the Seton Dam tailrace as would have occurred for acoustic fish, may account for the lack of difference in passage success of radio-tagged fish at each flow scenario. No sex-specific differences in passage success were apparent for either radio- or PIT-tagged fish during either flow scenario.

Swimming speeds of Gates Creek sockeye salmon during each of the flow scenarios did not differ in any of the areas of the tailrace (Figure 3-31). The proportion of time fish would have recruited anaerobic muscle during dam passage, an indicator of passage difficulty, also did not differ between flow scenarios, although these measurements may have been limited by the detection range of the acoustic receivers, which was attenuated during the routine scenario due to high turbulence in the entrance area. Delay in the upstream dam forebay, however, was significantly greater during the routine flow scenario (Mann-Whitney *U*-test: W=336, p=0.001) suggesting fish required additional time to recover post-passage, possibly due to increased swimming effort during passage that was not detected on the acoustic array.

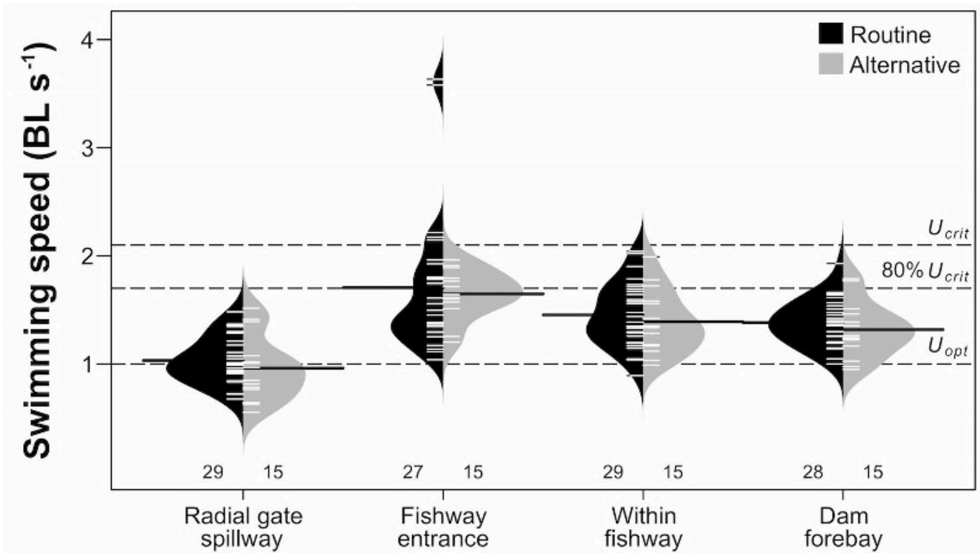

Figure 3-31: **Swimming speeds of Gates Creek sockeye salmon during the routine flow scenario (black) and alternative flow scenario (grey) in different areas of the Seton Dam tailrace in 2014. Mean (black horizontal lines) and individual (white horizontal lines) values are shown. Dashed horizontal lines indicate the optimal (U_{opt}), 80% critical (80% U_{crit}), and critical (U_{crit}) swimming speeds for Gates Creek sockeye salmon**

3.6.1.4 Alternative Flow Scenario Post-Passage Survival

Gates Creek sockeye salmon survival to spawning grounds in 2014 was examined following passage through Seton Dam during either the routine or alternative flow scenario. All acoustic-tagged fish that passed Seton Dam during the alternative scenario survived to spawning grounds (Table 3-15). In comparison, less than half the fish that passed the dam during the routine scenario survived. Together with differences in passage success, the cumulative survival of acoustic-tagged Gates Creek sockeye salmon from release to spawning grounds was 55% greater under the alternative flow scenario. Post-passage survival of PIT-tagged Gates Creek sockeye salmon mirrored that of acoustic-tagged fish, with PIT-tagged fish that passed Seton Dam under the alternative flow scenario having 7% greater survival from the dam to spawning grounds and 14% greater cumulative survival. Monte Carlo simulations found differences in the cumulative survival of PIT-tagged fish between flow scenarios. Radio-tagged fish released at the Fraser River West site also had increased survival to spawning grounds under the alternative flow scenario; however, the increase was not significant.

The increase in post-passage survival of PIT-tagged fish between the routine and alternative scenario may be an underestimate due to the timing of the alternative flow experiment. While Gates Creek sockeye salmon were found to have decreased post-passage survival during the routine scenario, the majority of tags were released during flow scenario 3, that occurred after the alternative scenario. However, fish released later in the migration could be expected to have increased survival compared with earlier migrants since earlier migrating Gates Creek sockeye salmon were more likely to encounter warmer water temperatures (see Section 3.1.2) and fisheries (see Section 3.4.3), both of which have been shown to reduce survival (Martins et al. 2011; Nguyen et al. 2014). Future studies could benefit from a repeated study design where the alternative scenario occurs in both the early and latter portions of the Gates Creek sockeye salmon migration period.

Table 3-15: Seton Dam passage success and survival to spawning grounds for Gates Creek sockeye salmon during routine and alternative flow scenarios in 2014

Tag Type / Variable	Flow Scenario	
	Routine	Alternative
Acoustic-tag releases (Upper Seton River)		
Dam Passage	93% (28/30)	100% (15/15)
Post-Passage Survival	48% (13/27)	100% (15/15)
Cumulative Survival	45% (13/29)	100% (15/15)
PIT-tag releases (Upper Seton River)		
Dam Passage	89% (344/388)	98%* (199/204)
Post-Passage Survival	81% (279/344)	88% (176/199)
Cumulative Survival	72% (279/388)	86%* (176/204)
Radio-tag releases (Fraser River West)		
Dam Passage	98% (102/104)	98% (41/42)
Post-Passage Survival	76% (78/102)	80% (33/41)
Cumulative Survival	75% (78/104)	79% (33/42)

A (*) indicates non-overlapping 95% credible intervals.

3.6.2 Portage Creek Sockeye Salmon

Passage success of Portage Creek sockeye salmon was studied in 2013-2014. Additional data for PIT-tagged fish analyzed since the 2014 report is presented below. Portage Creek sockeye salmon were not studied in 2015 due to low abundance.

3.6.2.1 Migration Conditions

Tagged Portage Creek sockeye salmon experienced one flow scenario in 2013 (15.0 $m^3 \cdot s^{-1}$) and 2014 (14.5 $m^3 \cdot s^{-1}$) as Seton Dam discharge was adjusted prior to and after the Portage Creek sockeye salmon migration period in each year. Temperatures during releases were 13.1-14.2°C in 2013 and 13.9-16.6ºC in 2014.

3.6.2.2 Seton Dam Passage Success

Passage success of Portage Creek sockeye salmon was high in 2013-2014 (Table 3-16). Attraction efficiency was lower for acoustic-tagged fish, probably due the small sample size of this release group. Entrance delay was lowest for radio-tagged fish released in the Fraser River, with increased delay observed for fence-released acoustic and PIT-tagged fish. Entrance delay for radio-tagged fish did not differ in 2013 and 2014. For all radio-tagged Portage Creek sockeye salmon released downstream, including those not detected in the tailrace, passage success was 86% (*n*=162/189). Dam arrival could not be confirmed for PIT-tagged fish released downstream; however, passage success for this group was 94% (*n*=180/192). Overall passage success for all Portage Creek sockeye salmon released in 2014 was 88% (*n*=557/634).

Table 3-16: Radio, acoustic, and PIT-tagged Portage Creek sockeye salmon passage at Seton Dam in 2013 and 2014

Variable	2013	2014		
	Radio	Radio	Acoustic	PIT
Release Site	DSW	DSW	Fence	Fence
Attraction Efficiency	95% (21/22)	98% (163/167)	80% (8/10)	95% (229/241)
Entrance Delay	12.6 ± 2.9 h (0.2-42.8 h)	14.9 ± 2.2 h (0.1-74.0 h)	26.9 ± 8.5 h (2.5-74.0 h)	27.5 ± 2.7 h (0.6-352.0 h)
Passage Efficiency	95% (20/21)	99% (162/163)	100% (8/8)	98% (225/229)
Overall Success	91% (20/22)	97% (162/167)	80% (8/10)	93% (225/241)

*Entrance delay is mean ± SE. Discharge was 15.0 $m^3 \cdot s^{-1}$ (2013) and 14.5 $m^3 \cdot s^{-1}$ (2014).

Swimming speeds (mean ± SE) of Portage Creek sockeye salmon within the fishway entrance area (1.72 ± 0.07 $BL \cdot s^{-1}$) and the fishway (1.66 ± 0.12 $BL \cdot s^{-1}$) were significantly greater than swimming speeds in the radial gate spillway (1.02 ± 0.07 $BL \cdot s^{-1}$) or Seton Dam forebay (1.35 ± 0.07 $BL \cdot s^{-1}$) (One-way ANOVA: F=15.48, d.f.=3, p<0.001). Critical swimming speeds are unknown for Portage Creek sockeye salmon; however, swimming speeds in the fishway entrance exceeded 80% of the critical swimming speed for Gates Creek sockeye salmon. Overall, swimming speeds approximated those observed for Gates Creek sockeye salmon in 2013 and 2014.

3.6.3 Coho Salmon

Four of the seven radio-tagged coho salmon released at the Fraser River West site in 2014 were detected in the Seton Dam tailrace. All four coho salmon successfully located and ascended the fishway (100% attraction and passage efficiency). Delay was 8.0 ± 3.9 h (mean ± SE). Two PIT-tagged coho salmon released from the fence also passed Seton Dam.

3.7 Migration to Spawning Grounds

3.7.1 Gates Creek Sockeye Salmon

Survival to spawning grounds was examined for radio and PIT-tagged Gates Creek sockeye salmon in 2013-2015 and migration timing examined for radio-tagged fish in 2013-2014. The importance of migration experience and physiology to reproductive success was assessed using radio-tagged female Gates Creek sockeye salmon in 2014.

3.7.1.1 Survival and Migration Timing

Gates Creek sockeye salmon survival to spawning grounds following passage of Seton Dam (post-passage survival) varied with tag type, release site, sex and year (Table 3-17). Survival in 2014-2015 was greatest for PIT-tagged fish released from the Seton River fish fence with >80% of fish surviving from Seton Dam to spawning grounds each year. Lowest survival was for radio-tagged fish released in the Fraser River in 2013, likely due to high temperatures in the Seton River (Section 3.1.3), that also reduced Seton Dam passage success (Section 3.6.2). Radio and PIT-tagged fish released in the Fraser River had approximately equal survival to spawning grounds in 2015. For 2014, the post-passage survival of tagged fish was greater than the overall post-passage survival of the Gates Creek sockeye salmon stock, that was 62%, based on fish counter enumeration (*n*=27,192) and escapement estimates via spawner surveys at Gates Creek (*n*=16,929; S. Lingard, pers. comm.).

Table 3-17: Survival to spawning grounds following Seton Dam passage for Gates Creek sockeye salmon in 2013-2015

Tag Type/ Release Site	Post-Passage Survival		
	2013	2014	2015
PIT (Fence)	-	84% (455/543)	84% (358/427)
Radio (DSW)	54% (48/89)	78% (111/143)	69% (115/167)
PIT (DSW)	-	70% (111/157)	72% (122/169)

Survival of PIT-tagged fish was lower in 2014, due to poor survival of male Gates Creek sockeye salmon released in the Fraser River (Table 3-18). Male Gates Creek sockeye salmon typically have greater survival than females, as was found in 2013 and 2015, and in other studies of Fraser River sockeye salmon (Martins et al. 2012). It is unknown why male survival to spawning grounds was lower than females in 2014.

Table 3-18: Survival to spawning grounds following Seton Dam passage for male and female of Gates Creek sockeye salmon in 2013-2015

Tag Type/ Release Site	Post-Passage Survival					
	2013		2014		2015	
	Males	Females	Males	Females	Males	Females
PIT (Fence)	-	-	81% (179/220)	85% (276/323)	87% (182/210)	81% (176/217)
Radio (DSW)	68% (25/37)	44% (23/52)	87% (54/62)	70% (57/81)	70% (69/98)	67% (46/69)

PIT (DSW)	-	-	62% (41/66)	77% (70/91)	80% (65/81)	65% (57/88)

The cumulative survival of all tagged Gates Creek sockeye salmon from release to spawning grounds was 72% in 2014 (*n*=705/977) and 72% in 2015 (*n*=595/828). Given that passage success for all tagged fish was 91% in 2014 and 92% in 2015 (8-9% mortality), Gates Creek sockeye salmon mortality in these years primarily occurred upstream of Seton Dam in Seton Lake and Anderson Lake. In comparison, mortality of tagged fish in 2013 occurred downstream (31%) and upstream (28%) of Seton Dam in approximately equal proportions, likely a result of high water temperatures increasing mortality downstream of Seton Dam and overall.

Model averaging of radio-tagged male and female Gates Creek sockeye salmon survival identified year, sex, and plasma glucose and lactate concentrations as significant predictors of migration success (Figure 3-32). Radio-tagged males were more likely to survive than females in 2013 and 2014, matching the trends observed with survival data (Table 3-18). Males and females were both less likely to survive in 2013 than 2014, possibly due to elevated water temperatures in 2013, although the maximum temperature fish experienced in the Seton Dam tailrace (T_{max}) was not identified as a significant factor affecting survival. Increased glucose levels were associated with a reduced likelihood of survival, suggesting fish that survived to Gates Creek were less stressed than fish that died in Seton Lake and Anderson Lake. The opposite was observed with plasma lactate, with fish that had increased concentrations having an increased likelihood of survival. Both plasma glucose and lactate concentrations increase in response to physiological stressors because fish mobilize glucose as an energy substrate for swimming and lactate is a by-product of anaerobic effort (Hoar et al. 1992; Wendelaar Bonga 1997). Gates Creek sockeye salmon that survived to spawning grounds may have exhibited greater vigour during capture and tagging, increasing plasma lactate concentrations before a blood sample was obtained. Discharge experienced at Seton Dam was not related to survival, probably as a result of greater radio-tagged mortality downstream of Seton Dam relative to fence-released fish.

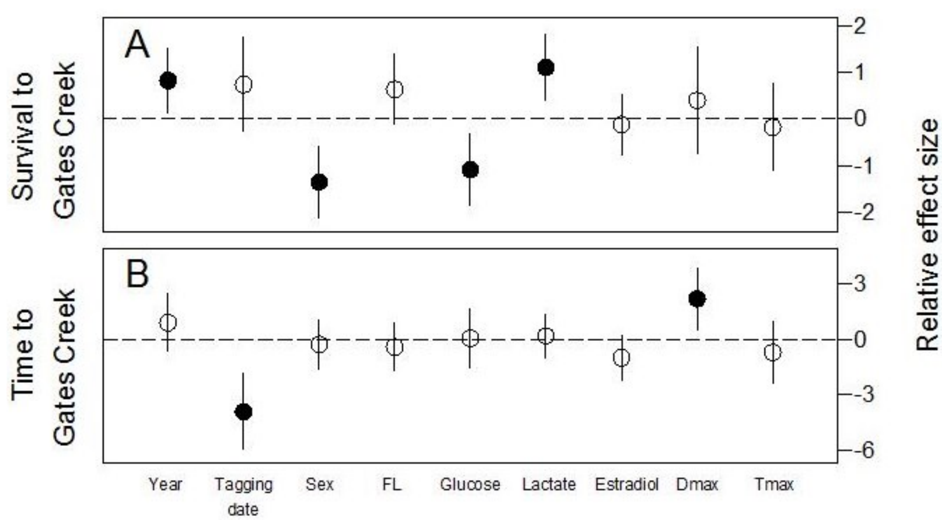

Figure 3-32: **Model-averaged standardized coefficients (mean=0, SD=2) with 95% confidence intervals for models describing Gates Creek sockeye salmon (A)**

survival and (B) migration time. Filled circles denote significance ($p<0.05$). Coefficient short forms are: FL (fork length), Estradiol (plasma 17-ß estradiol concentration at tagging), D_{max} (maximum discharge experienced at Seton Dam), T_{max} (maximum temperature experienced at Seton Dam)

Migration time to Gates Creek was dependent on tagging date as well as Seton Dam discharge (Figure 3-32). Coordinated arrival of salmon on spawning grounds is important to ensure that fish arrive during conditions suitable for reproduction and egg development (Quinn 2005). As a result, early-migrating sockeye salmon would be expected to hold in lakes for a period of time before entering spawning grounds, while later-migrating fish may move directly to spawning grounds or only hold for a short period of time in the lakes. This was observed for Gates Creek sockeye salmon in 2013 and 2014, as fish that were tagged earlier in the migration period spent significantly longer in Seton Lake and Anderson Lake than fish that were tagged later in the migration period ($r=-0.6$) Although increased discharge was associated with increased migration time, Seton Dam discharge was greatest during the first half of the Gates Creek sockeye salmon migration period in 2013-2014. Therefore, increased migration time to Gates Creek is more likely due to date of arrival at Seton Dam, rather than dam discharge.

3.7.1.2 Thermal Experience

The thermal experiences of radio-tagged Gates Creek sockeye salmon were recorded in 2013-2014 using gastrically-implanted temperature loggers that were recovered from deceased fish at spawning grounds (n=90). Data from two fish are in Figure 3-33.

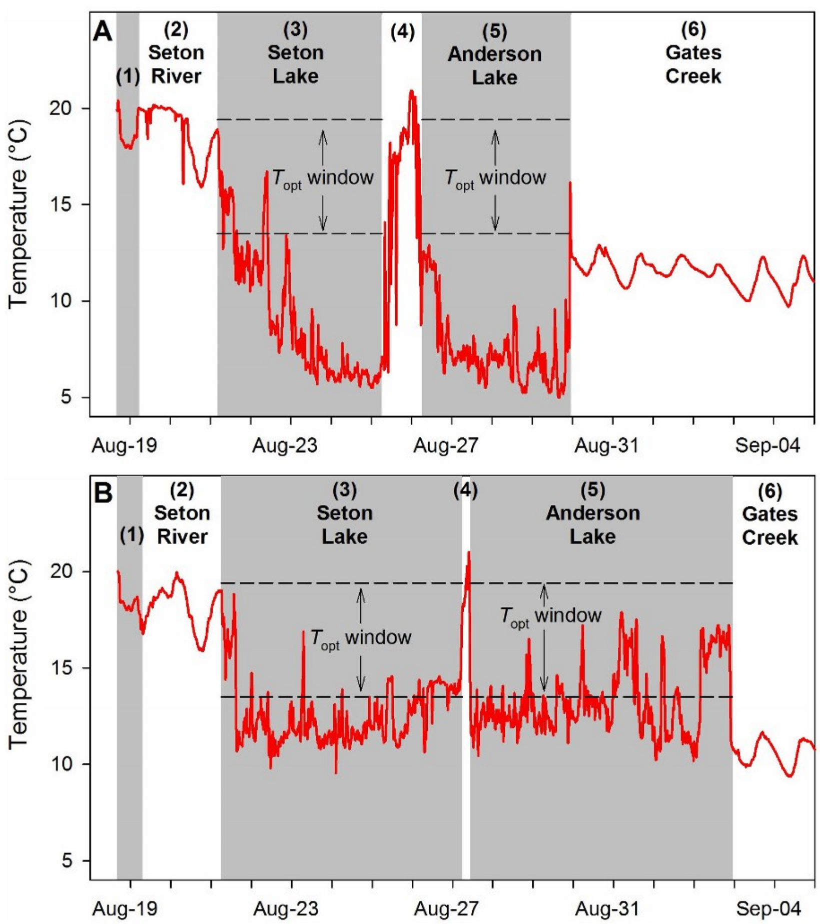

Figure 3-33: Thermal experiences of Gates Creek sockeye salmon migrating from release to spawning grounds in 2014. Profiles are for two female sockeye that unsuccessfully (A) and successfully (B) spawned. The optimal temperature (T_{opt}) window for Gates Creek sockeye salmon (13.4-19.5°C) is shown for in-lake migration. Locations not shown are (1) Fraser River and (4) Portage Creek

Temperature data was integrated with telemetry data to determine fish thermal experience in each segment of the Seton-Anderson watershed during migration. Thermal experience and migration time varied for individuals, in particular, during migration through Seton Lake and Anderson Lake where a range of available temperatures allowed for thermoregulation. For example, two female Gates Creek sockeye salmon co-released at the Fraser River West site on 18 August 2014 displayed different thermoregulatory behaviour (Figure 3-33), with fish (A) spending 8.8 d in the lakes with a median in-lake temperature of 8.8ºC, whereas fish (B) spent 12.8 d in the lake with a median in-lake temperature of 12.9ºC. At spawning grounds, fish (A) with a lower median lake temperature did not successfully spawn whereas fish (B) with a higher median lake temperature was successful. Individual thermal experiences for a subset of recovered females (n=39) were summarized as the proportion of time each fish spent within 3ºC of T_{opt} (16.4ºC; Lee et al. 2003; Eliason et al. 2011). Overall, females spent between 8-80% of time in lakes within the T_{opt} window (13.4-19.5°C), and this metric was incorporated into spawning success and reproductive longevity models.

3.7.1.3 Reproductive Longevity and Spawning Success

Tagged Gates Creek sockeye salmon that were deceased on spawning grounds were identified using the external spaghetti tag on carcasses or the tags alone were located with visual surveys and mobile telemetry. Tag recoveries (all types) at Gates Creek totaled 437 in 2014 and 326 in 2015. Tags were recovered in 2013 but not all fish were assessed for spawning and so these data are not presented.

Where the carcass of a tagged female Gates Creek sockeye salmon was recovered intact, spawning success was measured according to the Fisheries and Oceans Canada 0/50/100% assessment (Table 3-19). In both 2014 and 2015, the majority of tagged females fully spawned (<500 eggs retained), although the proportion that successfully spawned was greater in 2014 than 2015. Males could not be assessed for spawning success as ~50% of male gonad size can be retained after spawning.

Table 3-19: Spawning success of radio and PIT-tagged Gates Creek sockeye salmon in 2014-2015. Fish from all release sites are included in totals

Spawning Percent	Female Spawning Success	
	2014	2015
100%	68% (183/268)	53% (73/137)
50%	9% (24/268)	13% (18/137)
0%	23% (61/268)	34% (46/137)

Reproductive longevity, the time fish were on spawning grounds before dying, and spawning success were modeled separately for downstream-released radio tagged and fence-released PIT-tagged females in 2014. Sample sizes, handling and survival to spawning grounds differed between these two groups. For PIT-tagged fish, tagged and released at the fence with minimal handling, 174 of 234 tagged females reached spawning grounds (74%). For radio-tagged females released in the Fraser River, that received additional handling for blood sampling, gastric tag and temperature logger implantation, and transport downstream, 39 of 94 survived to spawning grounds (41%). However, sampling permitted additional explanatory variables to be included in modeling. For the purpose of the egg retention model, DFO spawning success assignments were grouped to create two categories: eggs deposited (50% or 100% spawned) and eggs retained (0% spawned).

For PIT-tagged females, once fish had arrived on spawning grounds, dam flow condition was not found to be a significant predictor of spawning success (see Appendix II - Burnett et al. 2015). Instead, longevity and date of arrival on spawning grounds explained 76% of the variation in spawning success and longevity had two times the effect on spawning success compared to date of arrival on spawning grounds. For the smaller radio-tag dataset, spawning success was 68% (*n*=26) successful (eggs deposited) and 32% (*n*=12) unsuccessful (eggs retained) – similar to the overall spawning success of radio and PIT-tagged females in 2014 (Table 3-19). Radio-tagged females that successfully spawned were on spawning grounds for 12.4 ± 0.8 d (4-22 d) while unsuccessful females were on spawning grounds for 6.8 ± 0.8 d (4-11 d), a significant difference (two-sample t-test; t=-5.25, p<0.001).

Model-averaging of radio-tagged females found that fish that spent a greater proportion of their time within the T_{opt} window survived longer on spawning grounds and retained fewer eggs (Figure 3-34). Females migrating within their T_{opt} window have the greatest surplus of metabolic oxygen available for physiological processes, which may favour gonadal maturation (Eliason and Farrell 2016), allowing females to retain energy, prolong time on spawning grounds, and increase the likelihood of spawning. Since reproductive outcomes were the primary focus of models, factors affecting the time fish spent in the T_{opt} window were not examined. However, numerous factors including migration experience within the Seton River study area, as well as more difficult to quantify factors including prior migration experience in the Fraser River, may play a role. These factors will be examined and presented in a future report.

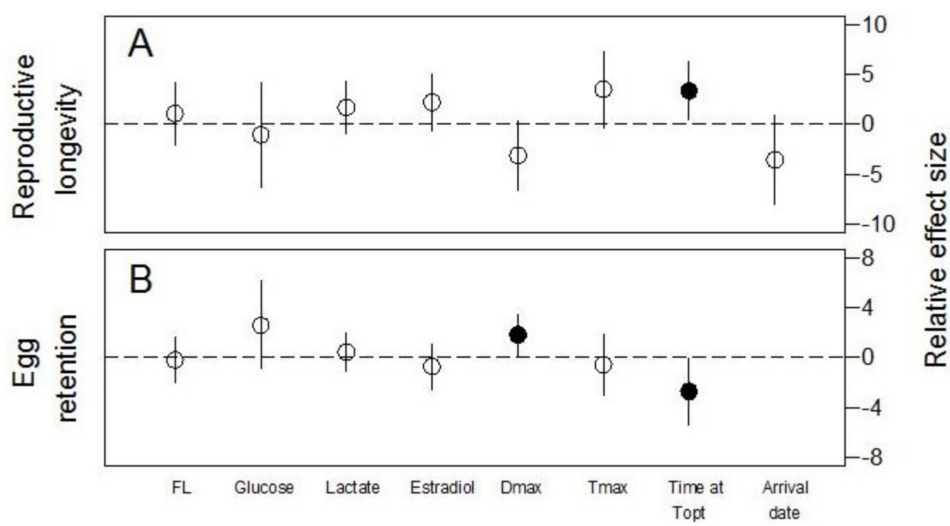

Figure 3-34: Model-averaged standardized coefficients with 95% confidence intervals for models describing female Gates Creek sockeye salmon (A) reproductive longevity and (B) egg retention. Significance denoted by filled circles

(p<0.05). Coefficient short forms are: FL (fork length), Estradiol (plasma 17-ß estradiol concentration at tagging), D_{max} (maximum discharge experienced at Seton Dam), T_{max} (maximum temperature experienced at Seton Dam), Time at T_{opt} (proportion of migration in optimal temperature window of 13.4-19.5°C), Arrival date (arrival date at Gates Creek)

3.7.2 Portage Creek Sockeye Salmon

Survival to spawning grounds was determined for radio-tagged Portage Creek sockeye salmon in 2014-2014 and acoustic tags in 2014. A PIT antenna could not be installed in Portage Creek so survival data is unavailable for PIT-tagged fish. As there was a low likelihood of recovering tags in Portage Creek, no tag recovery efforts were made and spawning success could not be assessed. Portage Creek sockeye were not tagged in 2015 due to low abundance and co-migrating pink salmon.

3.7.2.1 Survival to Spawning Grounds

Post-passage survival of Portage Creek sockeye in 2014 (Table 3-20) was double that observed in 2013. In 2013, survival to spawning grounds from Seton Dam for radio-tagged fish was 35%, although the low sample size in 2013 (*n*=24) may have been a factor in this result. Low post-passage survival of acoustic-tagged fish in 2014 may also be due to a low sample size and likely accounts for the difference in survival of acoustic- and radio-tagged Portage Creek sockeye salmon following Seton Dam passage. Post-passage survival was equal for males and females.

Cumulative survival of radio-tagged Portage Creek sockeye salmon from release to spawning grounds was 61% (*n*=116/189) (39% mortality) in 2014. Mortality primarily occurred in Seton Lake with 14% of radio-tagged fish failing to migrate past Seton Dam and a subsequent 25% failing to migrate to spawning grounds. Similar patterns were seen with Gates Creek sockeye salmon in 2014.

Models similar to those used for Gates Creek sockeye salmon will be applied to Portage Creek sockeye salmon migration in the future.

Table 3-20: Survival of Portage Creek sockeye salmon following Seton Dam passage in 2014

Release Site / Tag Type	Post-Passage Survival		
	Male	Female	Combined
Fraser River West			
Radio-tagged	72% (63/87)	71% (53/75)	72% (116/162)
Upper Seton River			
Acoustic-tagged	40% (2/5)	50% (1/2)	43% (3/7)

3.8 Water Preference Experiments

Behavioural water preference experiments were completed for Gates Creek and Portage Creek sockeye salmon in 2013-2014. Pink salmon were tested in 2013.

3.8.1 Gates Creek Sockeye Salmon

Gates Creek sockeye salmon displayed no water preference during control tests indicating that no arm bias in the Y-Maze. No significant differences were found in the amount of time fish spent in each arm (Wilcoxon signed rank test: *n*=19, V=66, p=0.25) (Figure 3-35), the proportion of time spent in each arm (Wilcoxon signed rank one sample test: µ=0.5, V=121, p=0.31) (Figure 3-36) or in the number of arm entrances (Student's t-test: t=-1.10, p=0.29) (Figure 3-37). Increasing the dilution ratio to 5% or 20% did not result in a water preference by Gates Creek sockeye salmon. At 5% and 20%, no difference was found in the total time spent in each arm (5%: Student's t-test: *n*=9, t=1.92, p=0.09; 20%: Student's t-test: *n*=26, t=-0.58, p=0.57) (Figure 3-35), the proportion of time spent in each arm (5%: One-sample t-test: µ=0.5, t=-2.11, p=0.07; 20%: One-sample t-test: µ=0.5, t=0.62, p=0.54) (Figure 3-236), or entrances (5%: Student's t-test: t=1.60, p=0.15; 20%: Student's t-test: t=0.9605, p=0.35) (Figure 3-37).

Gates Creek sockeye salmon showed a preference for Seton River water over Cayoosh Creek water when the dilution ratio was 30%. At a 30% dilution ratio, fish spent more time in the arm containing 100% Seton River water (Student's t-test: *n*=30, t=5.64, p<0.01) (Figure 3-35) and a greater proportion of time in the arm (One sample t-test: µ=0.5, t=-6.24, p<0.01) (Figure 3-36). There was no significant difference in the number of entrances into each arm (Wilcoxon signed rank test: *n*=30, V=247, p=0.17) (Figure 3-37). At a 50% dilution ratio, fish spent significantly more time in the arm containing 100% Seton River water (Student's t-test: *n*=26, t=4.32, p<0.01) (Figure 3-35), spent a greater proportion of time in this arm (One-sample t-test: µ=0.5, t=-4.3206, p<0.01) (Figure 3-36), and entered the arm more frequently (Student's t-test: *n*=26, t=2.14, p=0.04) (Figure 3-37).

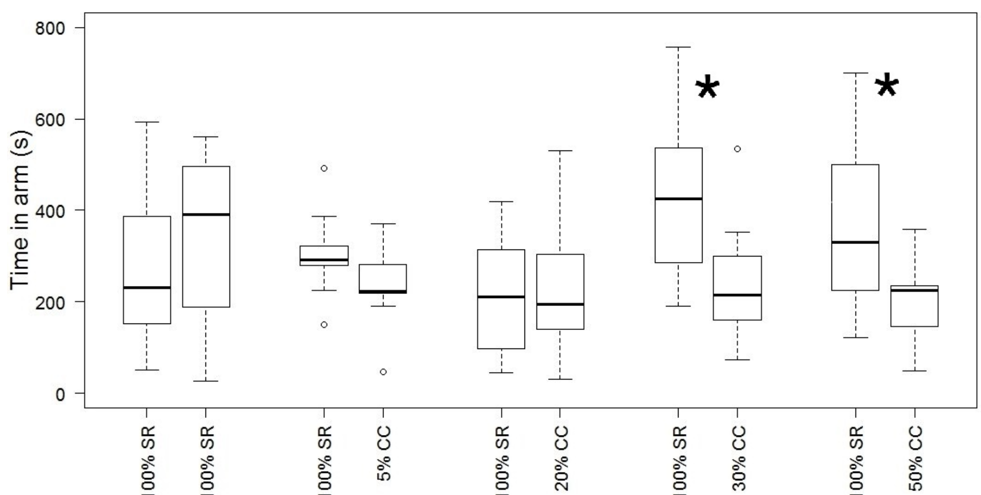

Figure 3-35: Time spent by Gates Creek sockeye salmon in each arm of the Y-Maze during water preference tests. 100% Seton River (SR) water was tested with control (100% SR) and 5, 20, 30 and 50% Cayoosh Creek (CC) dilution ratios. Upper, lower and middle box boundaries show the 75th and 25th percentiles

(interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicates a significant difference

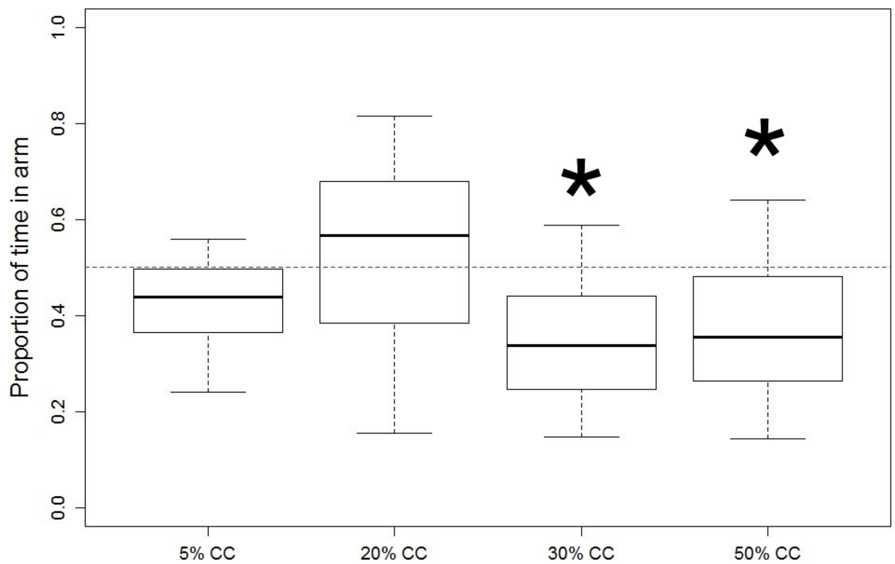

Figure 3-36: **The proportion of time spent by Gates Creek sockeye salmon in the dilution mixture arm of the Y-Maze during water preference tests. Dilution ratios of 5, 20, 30 and 50% Cayoosh Creek (CC) were tested against pure Seton River water. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicated a significant difference**

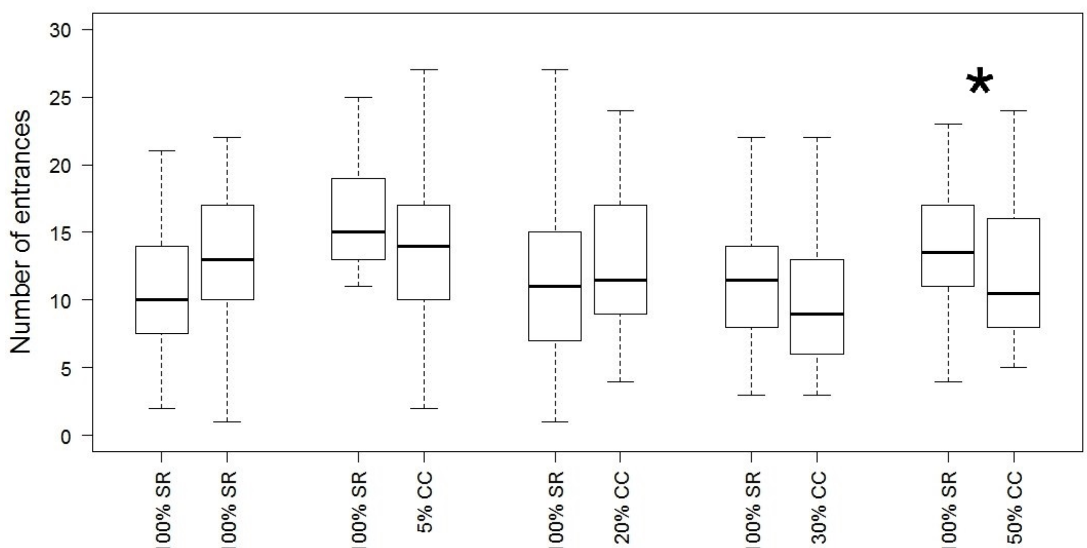

Figure 3-37: **The number of entrances into each arm on the Y-Maze by Gates Creek sockeye salmon in each arm of the during water preference tests. 100% Seton River (SR) water was tested with control (100% SR) and 5, 20, 30 and 50% Cayoosh Creek (CC) dilution ratios. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference**

3.8.2 Pink Salmon

In 2013, pink salmon were tested at a dilution ratio of 50% and showed a preference for the dilution mixture over 100% Seton River water. Pink salmon spent a significantly longer amount of time in the arm containing the 50% dilution ratio (Wilcoxon signed rank test: *n*=41, V=160, p<0.01) (Figure 3-38), and a significantly greater proportion of time (One sample t-test: µ=0.5, t=4.3369, p<0.01) (Figure 3-39). There was no difference in the number of entrances into each arm (Wilcoxon signed rank test: *n*=41, V=271.5, p=0.10) (Figure 3-40).

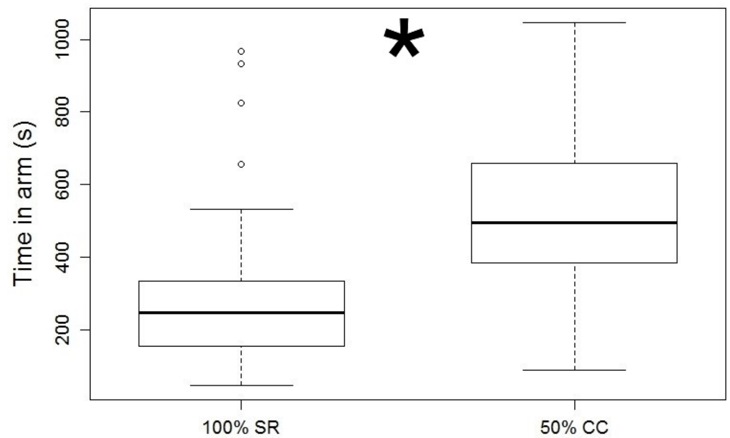

Figure 3-38: **Time spent by pink salmon in each arm of the Y-Maze during water preference tests. 100% Seton River (SR) water was compared with a 50% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicated a significant difference**

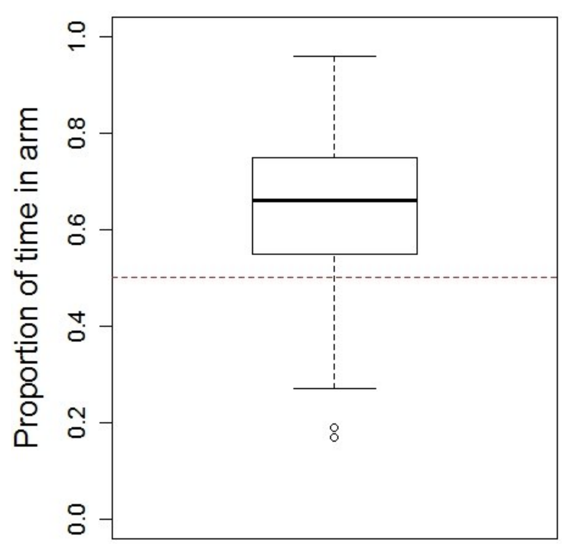

Figure 3-39: **The proportion of time spent by pink salmon in the dilution mixture arm of the Y-Maze during water preference tests. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers**

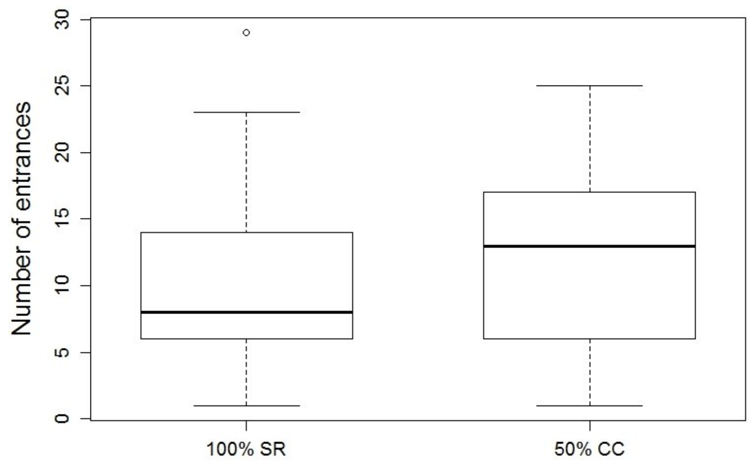

Figure 3-40: The number of entrances into each arm of the Y-Maze by pink salmon during water preference tests. 100% Seton River (SR) water was compared with a 50% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers. A (*) indicates a significant difference

3.8.3 Portage Creek Sockeye Salmon

Portage Creek sockeye did not exhibit a preference for Seton River water when tested at a dilution ratio of 10%. There was no difference in the time spent by fish in either the arm of the Y-maze (Wilcoxon signed rank test: *n*=35, V=337, p=0.73) (Figure 3-41) or the proportion of time spent in the arm containing the 10% dilution mixture (One-sample t-test: t=-0.6935, p=0.5) (Figure 3-42). In addition, fish did not enter either arm more frequently (Student's t-test: t=0.2253, p=0.82) (Figure 3-43).

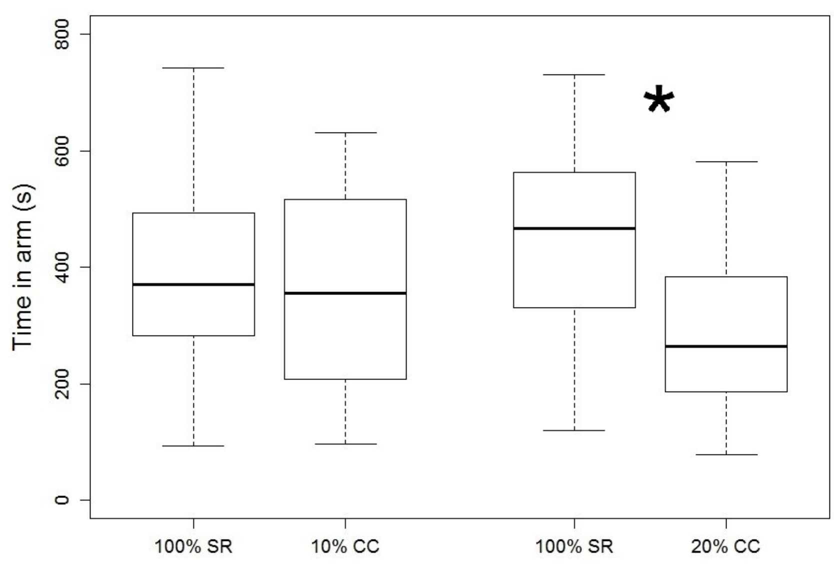

Figure 3-41: The time spent in each arm of the Y-Maze by Portage Creek sockeye salmon during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference

Portage Creek sockeye did exhibit a preference when tested with a dilution mixture of 20%, spending significantly more time in the arm with 100% Seton River water (Student's t-test: n=36, t=3.7966, p<0.01) (Figure 3-41) and a significant greater proportion of time in the arm containing pure Seton River water (One-sample t-test: μ=0.5, t=-3.4844, p=0.001) (Figure 3-42). However, there was no difference in the number of entrances into each arm (Student's t-test: t=0.8992, p=0.3747) (Figure 3-43).

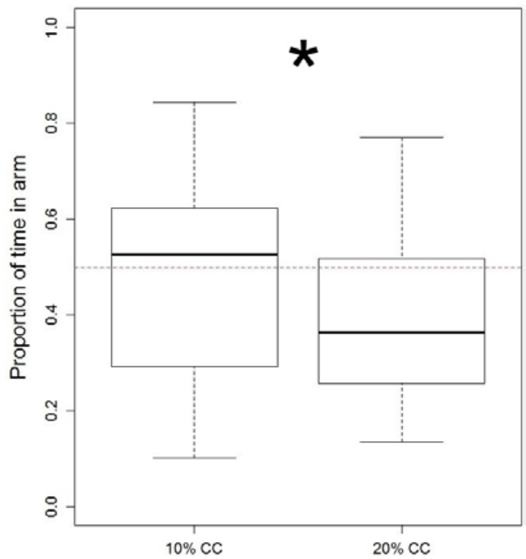

Figure 3-42: The proportion of spent in each arm of the Y-Maze by Portage Creek sockeye salmon during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. A (*) indicates a significant difference

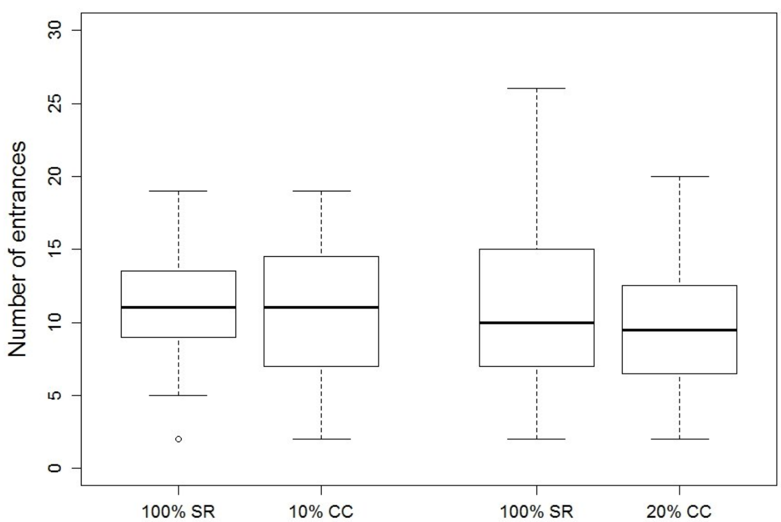

Figure 3-43: The number of entrances into each arm of the Y-Maze by Portage Creek sockeye salmon during water preference tests. 100% Seton River (SR) water was compared with a 10% and 20% Cayoosh Creek (CC) dilution ratio. The upper, lower and middle box boundaries show the 75th and 25th percentiles (interquartile range, IQR) and median. Whiskers show the range of data within 1.5x IQR. Circles represent outliers

4.0 DISCUSSION

4.1 Key Findings

4.1.1 Dilution

Water preference experiments in 2013-2014 found that Gates Creek and Portage Creek sockeye salmon demonstrated a preference for Seton River water when the dilution ratio exceeded the established 20% (Gates Creek) and 10% (Portage Creek) target ratios for each population (Fretwell 1989). While results of these experiments differed from those of Fretwell (1989) – with past results indicating water preference behaviour at slightly lower dilution ratios - the differences were likely a result of the methodologies used to assess water preference behaviour. Regardless, results of the current water preference experiments support maintaining the previously established dilution ratio targets during the Gates Creek and Portage Creek sockeye salmon migration periods.

River conditions in 2013-2014 did not allow Gates Creek sockeye salmon migration behaviour to be studied at above-target dilution ratios as nearly all fish experienced below-target dilution ratios in these two years. Radio telemetry studies designed to monitor in-river migration behaviour in 2013-2014 relied on natural variability in Cayoosh Creek flows to increase the dilution ratio. Elevated dilution ratios occurred during the Gates Creek sockeye salmon migration period in 2013, but coincided with extreme water temperatures and fish tagged during these conditions were not included in migration behaviour analyses due to poor survival. Further, no elevated dilution ratios occurred in 2014. As a result, Gates Creek sockeye salmon migration was studied over a limited range of below-target dilution ratios in 2013-2014 and model averaging found no effect of dilution on the migration behaviour of Gates Creek sockeye salmon in either year.

A planned increase in Cayoosh Creek flows in 2015 created above-target dilution ratios in the Seton River during the Gates Creek sockeye salmon migration period. Above-target dilution ratios of 28-29% were established in the second week of August and maintained for one week before Cayoosh Creek flows were decreased and below-target dilution ratios reestablished. Gates Creek sockeye salmon released during the above-target dilution ratios had increased wandering behaviour in the Fraser River and decreased survival to Seton Dam compared with fish released in the following week during below-target dilution ratios. However, the number of forays into the Seton Generating Station tailrace, time in the tailrace, and migration time to Seton Dam did not differ between these two weeks. Fish released in the last week of August, representing the latter-portion of the Gates Creek sockeye salmon migration period, spent significantly less time in Seton Generating Station tailrace and took significantly less time to reach Seton Dam than fish in the weeks prior, suggesting more directed migration later in the migration period. Changes in migration behaviour over the course of the migration period will be taken into account in future analyses. Migration behaviour data from 2014, where the dilution ratio did not significantly vary, will be a useful comparison to account for the timing of the 2015 dilution ratio experiment.

Dilution was found to have a significant effect on the in-river migration behaviour of Portage Creek sockeye salmon in 2013-2014. Model averaging results showed that increases in the dilution ratio increased both the number of forays fish made into the tailrace and the time fish spent in the tailrace. Although modeling did not identify a dilution ratio above which Portage Creek sockeye salmon would alter migration behaviour, all dilution ratio increases in 2014 caused the dilution ratio to exceed the 10% target ratio. Analyses to determine the effect of dilution on survival to Seton Dam have not yet been completed; however, survival to Seton Dam for radio-tagged Portage Creek sockeye salmon was high (88%) in 2014.

4.1.2 Fish Passage at Seton Dam

Passage success of Gates Creek sockeye salmon at Seton Dam remained high in 2015. Migrating fish benefitted from moderate water temperatures in August and Seton Dam discharges that remained low and constant throughout the migration period.

Conveyance structure use in 2015 followed routine BC Hydro operations (FWRG and SSV1 discharge) with overall passage success in 2015 (97%) equal to that during the alternative flow scenario in 2014 (98%) and greater than routine operations in 2014 (89%). While high passage success in 2015 indicates that Gates Creek sockeye salmon can effectively pass Seton Dam under routine conditions, discharge in early-August 2015 was ~6 $m^3 \cdot s^{-1}$ less than 2014 and was the lowest discharge to occur during BRGMON-14 studies. Low discharge in 2015 was due to an unexpected decrease in SSV1 discharge and conditions in early-August 2015 did not represent the discharge conditions normally present at Seton Dam at this time. Gates Creek sockeye salmon passage success could still be expected to be lower at greater discharges when conveyance structure discharge follows routine operations. Further, the carry-over effects of dam passage under the routine scenario in 2015 have not yet been examined.

Passage success in 2015 was similar across tag types and release locations but entrance delay continued to vary with release location. Radio-tagged fish released in the Fraser River in 2015 were again observed to have lower entrance delay than fish released from the Seton River fish fence. The difference in entrance delay is likely a result of downstream-released fish recovering in the Fraser River post-release while fence-released fish recovered in the Seton Dam tailrace. Lower entrance delay by radio-tagged fish suggest Fraser River West releases provide better absolute estimates of entrance delay. However, Upper Seton River releases still allow for relative comparisons of entrance delay across conditions with the increased probability of fish entering the Seton Dam tailrace while minimizing handling to provide the most-representative estimate of survival to spawning grounds.

4.1.3 Post-Passage Survival and Spawning Success

PIT-tagged Gates Creek sockeye salmon released from the Seton River fish fence in 2014 and 2015 had the greatest overall survival to spawning grounds following passage of Seton Dam (>80% in both years). Lower post-passage survival was observed for radio and PIT-tagged fish released in the Fraser River, likely due to the increased handling, transport, and added migration distance associated with downstream releases.

Survival from release to spawning grounds in 2014 for fence-released PIT-tagged Gates Creek sockeye salmon was significantly greater under the alternative flow scenario at Seton Dam than the routine flow scenario (86% vs. 72%). Post-passage survival for these tagging groups also increased under the alternative scenario (88% vs. 81%). Differences in post-passage survival indicate that only assessing passage success at Seton Dam is insufficient as these short-term measures do not incorporate the potential carry-over effects of dam passage on long-term survival. Further, larger differences in post-passage survival may have been observed had the fish that were released under both flow scenarios experienced comparable migration conditions prior to dam passage. The earlier timing of the alternative flow scenario meant fish arriving during this period were likely exposed to elevated Fraser River temperatures prior to arrival, whereas the later-timing of the routine scenario meant fish likely experienced cooler temperatures. Since estimating the prior migration experience of Gates Creek sockeye salmon is difficult, repeating the flow scenario trial with an alternative discharge scenario tested in both the early and latter portion of the Gates Creek sockeye salmon migration period would assist in distinguishing the effects of migration timing from the flow scenario experienced.

Models for the post-passage survival of radio-tagged fish found that tagging date, blood parameters, and sex were significant predictors of survival to spawning grounds with the time radio-tagged fish spent within the T_{opt} window found to be a significant predictor of both reproductive longevity and spawning success. As thermoregulatory behaviour is at least in part driven by fish condition, factors outside the Seton-Anderson watershed likely played a large role in the reproductive outcomes of Gates Creek sockeye salmon.

Spawning success of Gates Creek sockeye salmon in 2014 was found to be reduced under the alternative discharge scenario for radio-tagged females but not PIT-tagged females. Compared to PIT-tagged fish, radio-tagged females received additional handling during tagging including additional tags, sampling, and transport and release downstream in the Fraser River, which increased migration distance and duration to spawning grounds. Therefore, the PIT-tag dataset would be more reflective of the effects of dam discharge and the alternative flow scenario on subsequent reproductive success. However, despite improved survival to spawning grounds under the alternative flow scenario for PIT-tagged females, modeling results did not indicate differences in spawning success between the routine and alternative flow scenario. Indeed, maternal exposure to an acute stressor on spawning grounds has been shown to not affect spawning success of salmon (McConnachie et al. 2012) with results from 2014 PIT-tagged females suggesting the length of time on spawning grounds and date of arrival most influenced spawning success, as seen in other studies (Dickerson et al. 2005; Hruska et al. 2011). Although there were no differences observed in spawning success, the routine flow scenario effectively reduced the number of Gates Creek sockeye salmon reaching spawning grounds, potentially reducing the productivity of the population.

4.2 Future Directions

4.2.1 Migration Timing

Changes in Gates Creek sockeye salmon condition and migration behaviour were observed over the course of the migration period. In 2014 and 2015, the prevalence of gillnet injuries was greatest in the early portion of the migration period when Fraser River fisheries were active but also when Fraser River temperatures are elevated. In 2015, Gates Creek sockeye salmon migration behaviour was increasingly more-direct near the end of the migration period as migration rates to Seton Dam increased and exploratory behaviour in the Fraser River decreased. Accounting for changes in fish condition and behaviour while examining how changes in environmental conditions and operations alter behaviour and migration success will be required, given that modifications to both Seton Dam discharge (2014) and the dilution ratio (2015) occurred during specific time frames. If further studies are to take place that examine either Seton Dam operations or the dilution ratio, study design would benefit from multiple tests of alternative scenarios over the course of the migration period.

4.2.2 Fisheries Captures at Portage Creek

Survival estimates for Gates Creek sockeye salmon following passage at Seton Dam are critical for determining the carry-over effects of migration through Seton Dam. Sustenance fisheries at Portage Creek in 2015 captured tagged Gates Creek sockeye. While all known fisheries captures were removed from the analysis of post-passage survival, it is likely that other fish were captured but not reported. Determining the proportion of Gates Creek sockeye salmon removed at Portage Creek in 2015 is possible using telemetry data but in future years studies would benefit from upstream and downstream receivers at Portage Creek and a tag recovery program.

4.2.3 Coho Salmon and Chinook Salmon

The study of coho and Chinook salmon remained a challenge in 2015. From 2013-2015, few have been captured for study under the BRGMON-14 program. In 2014, a total of nine coho salmon were captured at the Seton River fish fence and zero Chinook salmon. Other BRGMON programs have reported similar difficulties capturing coho and Chinook salmon in the Seton River.

4.3 Management Questions

4.3.1 Question 1

1.1 Are the Cayoosh flow dilution requirements for Seton River derived by the IPSFC effective for mitigating delays in migrations of Gates and Portage Creek sockeye salmon populations?

1.2 How sensitive is Gates and Portage Creek sockeye migration behaviour to variations in the Cayoosh dilution rate?

Water preference tests found that Gates Creek sockeye salmon displayed a preference for Seton River water at a dilution target of 30%. However, no preference was observed at the current dilution ratio target of 20%. Portage Creek sockeye salmon displayed a preference for Seton River water at a 20% dilution ratio, but no preference was observed at the current dilution target of 10%. Together, these data suggest the dilution requirements derived by the IPSFC should be effective for mitigating delays in the migration of Gates Creek and Portage Creek sockeye salmon.

Gates Creek sockeye salmon migration behaviour – including time at the Seton Generating Station - was not significantly affected by the dilution ratio in 2013-2014. The dilution ratio did not exceed the 20% target ratio in these years suggesting that if the dilution ratio is maintained at <20%, migration behaviour will not be affected. In 2015, comparison of migration behaviour across weeks of high and low dilution found that fish released during above-target dilution ratios did not spend additional time at the Seton Generating Station tailrace or have increased migration time to Seton Dam. Wandering behaviour in the Fraser River did increase during above-target dilution ratios and was associated with increased straying. Further analyses are required to account for changing migration behaviour and fish condition before the effectiveness of IPSFC dilution requirements can be determined.

From studies in 2013-2014, increases in the dilution ratio were found to have a significant effect on Portage Creek sockeye salmon migration behaviour including time at the Seton Generating Station. Migration behaviour at above and below-target dilution ratios will be compared in future analyses to determine whether the IPSFC dilution ratio targets are effective.

4.3.2 Question 2

2.1 What are the effects of Seton powerhouse operation on the upstream migration of other salmon populations (pink, Chinook, coho) migrating to the Seton-Anderson watershed?

Water preference tests in 2013 found that pink salmon did not display a preference for Seton River water and preferred a 50% dilution ratio. This result suggests that pink salmon migrating to the Seton-Anderson watershed would likely not delay at the Seton Generating Station due to high dilution. However, analysis of telemetry data from 2013 is required to determine if the in-river migration behaviour of pink salmon corresponds to the water preference experiment results. Pink salmon were not studied in 2015.

Coho salmon were captured in limited numbers in 2013 and 2014. Effects of the Seton Generating Station on coho salmon migration cannot be determined due to the low number of fish tagged.

Chinook salmon migration to the Seton-Anderson watershed could not be studied in 2013 or 2014 due to the low abundance of this species.

4.3.3 Question 3

3.1 Does the operation of Seton Dam and fishway affect salmon passage upstream of Seton Dam?

3.2 What changes to the fishway or operation may mitigate salmon migration issues at Seton Dam?

Fish passage success at Seton Dam has varied across years, with total Seton Dam discharge, environmental conditions, and conveyance structure use all identified as important determining factors for fish passage. In 2014-2015, moderate water temperatures and the maintenance of WUP target discharges resulted in high (>95%) overall passage success for Gates Creek and Portage Creek sockeye salmon.

Results of an alternative flow scenario test in 2014 found that routine BC Hydro operations can impart delayed effects on fish that reduce survival to spawning grounds. Further, the alternative flow scenario tested in 2014 improved post-passage survival and already high passage success. However, passage success under routine operations in 2015 was equal to passage success under the alternative flow scenario in 2014, although discharge in 2015 was constant and the lowest yet observed. Current results suggest that fish passage at Seton Dam and survival to spawning grounds can be improved through the use of alternative conveyance structures or decreased discharge.

4.4 Monitoring Program Schedule

A schedule of activities outlining the tasks completed in Year 4 and the revised schedule of tasks to be completed in Year 4 to Year 5 is presented in Table 4-1.

Table 4-1: Tasks completed in Year 1 to Year 4 of the BRGMON-14 monitoring program and the tasks proposed for Year 5

Task	Year 1 (2012)	Year 2 (2013)	Year 3 (2014)	Year 4 (2015)	Year 5 (2016)
1) Project Coordination	X	X	X	X	X
2) Physical Parameter Monitoring					
i. Discharge and Dilution Ratio	X	X	X	X	-
ii. Water Temperature	X	X	X	X	-
iii. Water Chemistry	X	X	X	X	-
3) Adult Salmon Telemetry					
i. Radio Transmitters	-	X	X	X	-
ii. PIT Tags	-	X	X	X	-
4) Adult Sockeye Telemetry					
i. Radio Transmitters	X	X	X	X	-
ii. Accelerometer Loggers	X	X	-	-	-
iii. Accelerometer Transmitters	X	X	X	-	-
iv. PIT Tags	-	X	X	X	-
5) Salmon Dilution Sensitivity					
i. Olfactory Sensitivity Trials	X	-	-	-	-
ii. Water Source Preference Tests	-	X	X	-	-
6) Physiology and Injury Monitoring	X	X	X	X	-
7) Fishway Fish Counter	X	X	X	X	X
8) Final Reporting	-	-	-	-	X

5.0 RECOMMENDATIONS

5.1 Status of Year 3 Recommendations

The majority of the recommendations made in Year 3 of the BRGMON-14 monitoring program were implemented in Year 4. Notable recommendations that were adopted included:

- Re-build Seton Dam fish counter sensor tubes and install additional cameras and lighting to permit night time video recordings.
- Manipulate Cayoosh Creek discharge to increase Seton River dilution ratios while observing fish delay and behaviour at the Seton Generating Station.

5.2 Year 4 Recommendations

Based on findings in Year 1 to Year 4, the following recommendations are made for Year 5 of the BRGMON-14 monitoring program:

- Complete field work in Year 5 of the BRGMON-14 to address any uncertainties regarding the effectiveness of the alternative flow scenario at Seton Dam.
- Repeat the installation of a fish fence downstream of Seton Dam.

- Release radio-tagged and PIT-tagged fish from the Fraser River West site and the Seton River fish fence to estimate entrance delay at Seton Dam.
- Continue GSE screening all sockeye salmon to identify strays.
- Construct a second set of Seton Dam fish counter sensor tubes to allow the alternate set to be repaired.

6.0 REFERENCES

Barton, B.A., and Schreck, C.B. 1987. Influences of acclimation temperature on interregnal and carbohydrate stress responses in juvenile chinook salmon (*Oncorhynchus tshawytscha*). Aquaculture. 62: 299–310

BC Hydro, 2000. Bridge-Coastal Fish and Wildlife Restoration Program, Seton River Watershed Strategic Plan. Volume 2, Chapter 11. Burnaby, BC. 28pp.

BC Hydro. 2011. The Bridge River Power Development Water Use Plan, March 17, 2011, 31pp.

Burnham, K.P., and Anderson, D.R. 2002. Model selection and multimodel inference: A Practical Information-Theoretic Approach. Springer-Verlag New York, New York.

Caudill, C.C., Daigle, W.R., Keefer, M.L., Boggs, C.T., Jepson, M.A., Burke, B.J., Zabel, R.W., Bjornn, T.C., and Peery, C.A. 2007. Slow dam passage in adult Columbia River salmonids associated with unsuccessful migration: delayed negative effects of passage obstacles or condition-dependent mortality? Canadian Journal of Fisheries and Aquatic Sciences. 64:979–995

Crossin, G.T., and Hinch, S.G. 2005. A nonlethal, rapid method for assessing the somatic energy content of migrating adult Pacific salmon. Transactions of the American Fisheries Society. 134:184-191

Dickerson, B.R., Brinck, K.W., Wilson, M.F., Bentzen, P., and Quinn T.P. 2005. Relative importance of salmon body size and arrival time at breeding grounds to reproductive success. Ecology. 86:347-352

Eliason, E.J., Clark, T.D., Hague, M.J., Hanson, L.M., Gallagher, Z.S., Jeffries, K.M., Gale, M.K., Patterson, D.A., Hinch, S.G., and Farrell, A.P. 2011. Differences in thermal tolerance among sockeye salmon populations. Science. 332: 109-112

Eliason, E.J., and Farrell, A.P. 2016. Oxygen update in Pacific salmon *Oncorhynchus* spp.: when ecology and physiology meet. Journal of Fish Biology. 88(1):359-388

Fretwell, M.R. 1989. Homing behavior of adult sockeye salmon in response to a hydroelectric diversion of homewater at Seton Creek. International Pacific Salmon Fisheries Commission. Bulletin 25. 38pp.

Gelman, A. 2008. Scaling regression inputs by dividing by two standard deviations. Statistics in Medicine. 27(15):2865-2873

Goniea, T.M., Keefer, M.L., Bjornn, T.C., Peery, C.A., Bennett, D.H., and Stuehrenberg, L.C. 2006. Behavioral thermoregulation and slowed migration by adult fall Chinook salmon in response to high Columbia River water temperatures. Transactions of the American Fisheries Society. 135:408-419

Grueber, C.E., Nakagawa, S., Laws, R.J., and Jamieson, I.G. 2011. Multimodel inference in ecology and evolution: challenges and solutions. Journal of Evolutionary Biology. 24: 699-711

Hague, M., and Patterson, D.A. 2009. Predicting the magnitude and timeline of climate change effects on spawning migration success for major populations of Fraser River salmon and implications for fisheries: SEF Final Report. Prepared by Department of Fisheries and Oceans, Science Branch. 59pp.

Hansen, L.P., and Jonsson, B. 1994. Homing of Atlantic salmon: effects of juvenile learning on transplanted post-spawners. Animal Behaviour. 98:61-71

Harrell, F.E. 2001. Regression Modeling Strategies: With Applications to Linear Models, Logisitic Regression, and Survival Analysis. Springer, New York

Hawkins, J.M.B., Scholefield, D., and Braven, J. 2006. Dissolved free and combined amino acids in surface runoff and drainage waters from drained and undrained grassland under different fertilizer management. Environmental Science and Techology. 40:4887-4893

Hoar, W.S., D.J. Randall, and Farrell, A.P. 1992. The Cardiovascular System Part B, Fish Physiology Vol. VXII B. Academic Press, San Diego. 474pp.

Hosmer, D.W., and Lemeshow, S. 1989. Applied Regression Analysis. Wiley, New York.

Houston, A. H. 1990. Blood and circulation. *In* Methods for Fish Biology. *Edited by* Schreck, C.B., and Moyle, P.B. American Fisheries Society. Bethesda, MD. pp. 273–334

Hruska, K.A., Hinch, S.G., Patterson, D.A., and Healey, M.C. 2011. Egg retention in relation to arrival timing and reproductive longevity in female sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences. 68:250-259

Lee, C.G., Farrell, A.P., Lotto, A., MacNutt, M.J., Hinch, S.G., and Healey, M.C. 2003. The effect of temperature on swimming performance and oxygen consumption in adult sockeye (*Oncorhynchus nerka*) and coho (*O. kisutch*) salmon stocks. Journal of Experimental Biology. 206:3239-3251

Mathes, M.T., Hinch, S.G., Cooke, S.J., Crossin, G.T., Patterson, D.A., Lotto, A.G., and Farrell, A.P. 2010. Effect of water temperature, timing, physiological condition, and lake thermal refugia on migrating adult Weaver Creek sockeye salmon (*Oncorhynchus nerka*). Canadian Journal of Fisheries and Aquatic Sciences 67: 70-84

Martin, P., and Bateson, P. 2003. Measuring behavior: an introductory guide. 2nd Edition. Cambridge University Press, Cambridge, UK.

Martins, E.G., Hinch, S.G., Patterson, D.A., Hague, M.J., Cooke, S.J., Miller, K.M., Lapointe, M.F., English, K.K., and Farrell, A.P. 2011. Effects of river temperature and climate warming on stock-specific survival of adult migrating Fraser River sockeye salmon (*Oncorhynchus nerka*). Global Change Biology 17: 99-114

Martins, E.G., Hinch, S.G., Patterson, D.A., Hague, M.J., Cooke, S.J., Miller, K.M., Robichaud, D., English, K.K., and Farrell, A.P. 2012. High river temperature reduces survival of sockeye salmon approaching spawning grounds and exacerbates female mortality. Canadian Journal of Fisheries and Aquatic Sciences. 69:330-342

McConnachie, S.H., Cook, K.V., Patterson, D.A., Gilmour, K.M., Hinch, S.G., Farrell, A.P., Cooke, S.J. 2012. Consequences of acute stress and cortisol manipulation on the physiology, behavior, and reproductive outcome of female Pacific salmon on spawning grounds. Hormones and Behavior. 62: 67-76

Naughton, G.P., Caudill, C.C., Keefer, M.L., Bjornn, T.C., Stuehrenberg, L.C., and Peery, C.A. 2005. Late-season mortality during migration of radio-tagged adult sockeye salmon (*Oncorhynchus nerka*) in the Columbia River. Canadian Journal of Fisheries and Aquatic Sciences. 62: 30–47.

Nguyen, V.M., Martins, E.G., Raby, G.D., Donaldson, M.R., Lotto, A.G., Patterson, D.A., Robichaud, D., English, K.K., Farrell, A.P., Willmore, W.G., Rudd, M.A., Hinch, and S.G., Cooke, S.J. 2014. Disentangling the roles of air exposure, gillnet injury, and facilitated recovery on the post-capture and release mortality and behavior of adult migratory sockeye salmon (*Oncorhynchus nerka*) in freshwater. Physiological and Biochemical Zoology 87(1):125-135.

O'Brien, R.M. 2007. A caution regarding rules of thumb for Variance Inflation Factors. Quality and Quantity. 41(5): 673-690

Pon, L.B., Cooke, S.J., and Hinch, S.G. 2006. Passage efficiency and migration behaviour of salmonid fishes at the Seton Dam Fishway. Final Report for the Bridge Coastal Restoration Program, Project 05.Se.01. 105pp.

Pon, L.B., Hinch, S.G., Cooke, S.J., Patterson, D.A., and Farrell, A.P. 2009a. Physiological, energetic and behavioural correlates of successful fishway passage of adult sockeye salmon *Oncorhynchus nerka* in the Seton River, British Columbia. Journal of Fish Biology. 74: 1323-1336

Pon, L.B., Hinch, S.G., Cooke, S.J., Patterson, D.A., and Farrell, A.P. 2009b. A comparison of the physiological condition, and fishway passage time and success of migrant adult sockeye salmon at Seton River dam, British Columbia, under three operational water discharge rates. North American Journal of Fisheries Management. 29: 1195-1205

R Core Team. 2015. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Roscoe, D.W., and Hinch, S.G. 2008. Fishway passage, water diversion and warming temperatures: Factors limiting successful spawning migration of Seton-Anderson watershed sockeye salmon. Final Report for the Bridge Coastal Restoration Program, Project 07.BRG01. 101pp.

Roscoe, D.W., Hinch, S.G., Cooke, S.J., and Patterson, D.A. 2010. Behaviour and thermal experience of adult sockeye salmon migrating through stratified lakes near spawning grounds: the roles of reproductive and energetic states. Ecology of Freshwater Fish. 19: 51-62.

Roscoe, D.W., Hinch, S.G., Cooke, S.J., and Patterson, D.A. 2011. Fishway passage and post-passage mortality of up-river migrating sockeye salmon in the Seton River, British Columbia. River Research and Applications. 27: 693-705.

Shepard, B.G., and Bérézay G.F. 1987. Fish transport techniques in common use at salmonid enhancement facilities in British Columbia. Canadian Manuscript Report of Fisheries and Aquatic Sciences No. 1946. Prepared by Department of Fisheries and Oceans – Resource Enforcement Branch. Vancouver, BC. 28pp.

Thorstad, E.B., Okland, F., Kroglund, F., and Jepsen, N. 2003. Upstream migration of Atlantic salmon at a power station on the River Nidelva, Southern Norway. Fisheries Management and Ecology 10: 139–146.

Wendelaar Bonga, S. E. 1997. The stress response in fish. Physiological Reviews. 77:591–625.

Zuur, A.F., Ieno, E.N., and Elphick, C.S. .2010. A protocol for data exploration to avoid common statistical problems. Methods in Ecology and Evolution 1: 3-14.