Campbell River Project Water Use Plan

Quinsam and Salmon Rivers Smolt and Spawner Abundance Assessments

Implementation Year 5

Reference: JHTMON-8

Summary Report

Study Period: April 1, 2018 to March 31, 2019

Laich-Kwil-Tach Environmental Assessment Ltd. Partnership and Ecofish Research Ltd.

January 30, 2021

JHTMON-8: Quinsam River Smolt and Spawner Abundance Assessments

Year 5 Interim Summary Report

BC Hydro Water License Requirements
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EXECUTIVE SUMMARY

Water Use Plans (WUPs) were developed for BC Hydro's hydroelectric facilities through a consultative process. As the Campbell River Water Use Plan process reached completion, a number of uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources.

JHTMON-8 involves monitoring fish abundance and a range of environmental factors (Table i). Final data analysis will involve examining links between fish abundance and environmental factors to better understand what limits fish production. The main objective of this analysis is to understand whether BC Hydro operations, through changes to streamflow, were the primary cause of changes in fish abundance. The JHTMON-8 management questions, hypotheses and current status are presented in Table ii.

The JHTMON-8 monitoring program was initially developed to focus on the Salmon and Quinsam rivers, which have high fisheries values and include (or previously included) diversion structures that divert a portion of the total annual flow elsewhere in the Campbell River watershed for hydroelectric power generation. In 2017 (Year 4), BC Hydro decommissioned the Salmon River Diversion Dam, meaning that there is no longer a mechanism for BC Hydro operations to affect fish populations in the Salmon River. Consequently, the terms of reference for JHTMON-8 was revised by BC Hydro in 2018 (Year 5) to solely focus on the Quinsam River.

JHTMON-8 commenced in 2014 (Year 1) and five years of data collection (Table i) have now been completed, meaning that the ten-year study is now midway to completion. In Year 10, the three management questions in Table ii will be addressed by testing six null hypotheses that are designed to test whether juvenile fish abundance varies among years (*H_01*) and, if so, whether abundance is related to the following factors: habitat availability (*H_02*), water quality (*H_03*), floods (*H_04*), food abundance (*H_05*), and the abundance of returning adult fish (*H_06*). Species of primary interest are Chinook Salmon (*Oncorhynchus tshawytscha*), Coho Salmon (*O. kisutch*) and steelhead (*O. mykiss*), although the study involves compiling adult escapement data for a wider range of Pacific salmon species, as well as collecting abundance data for outmigrating juvenile life stages of a range of species at the Quinsam Hatchery salmon counting fence. below summarizes the field sampling programs that have been undertaken during Year 1–5 of JHTMON-8.

Table i. Summary of JHTMON-8 data collection methods.

River	Sampling program	Lead organization[1]	Method	Timing
Salmon (Year 1–4 only)	Adult Steelhead survey	LKT	Snorkel surveys	March – April
	Juvenile Steelhead abundance	LKT	Closed site multi-pass electrofishing	September
	Juvenile Coho abundance	LKT/DFO	Closed site multi-pass netting	October
	Salmon escapement surveys	DFO	Various	September – November
	Water quality sampling	LKT	*In situ* and laboratory analysis	May – October
	Invertebrate sampling	LKT	Drift sampling	May – October
Quinsam (Year 1–10)	Quinsam River Hatchery juvenile downstream migration	DFO/LKT	Fish fence	March – June
	Salmon escapement surveys	DFO	Various	September – November
	Water quality sampling	LKT	*In situ* and laboratory analysis	May – November
	Invertebrate sampling	LKT	Drift sampling	May – October

[1]LKT, Laich-Kwil-Tach Environmental Assessment Ltd. Partnership; DFO, Fisheries and Oceans Canada

As this is the mid-point of the program, this Year 5 Interim Summary Report provides a summary of all data collected to date. Therefore, data collected during Year 1–4 in the Salmon River and Year 1–5 in the Quinsam River are presented in this report, although the Salmon River will not be considered in future JHTMON-8 annual reports. The Discussion provides a summary of key progress so far and planned analysis tasks in relation to the six current management hypotheses, which focus on the Quinsam River.

Fish abundance data collected in Year 1–5 in the Quinsam River show that fish abundance has varied, including for the three primary species. An important task completed in Year 5 was the collation of historical data collected at the Quinsam Hatchery salmon counting fence since the 1970s, which involved securing, digitizing, and quality checking multiple files (electronic and hard copy) provided by DFO staff. Integrating this multi-decadal dataset into the JHTMON-8 analysis will substantially increase the statistical power to quantify variability in juvenile fish abundance in the Quinsam River. Interim analysis of these data shows that juvenile abundance varies among years by at least a factor of four for juvenile Chinook Salmon, Coho Salmon and steelhead.

In Year 5 we quantified the Weighted Usable Area (WUA; in m^2) to provide a measure of habitat availability *($H_0 2$)* for different life stages of priority species. This was undertaken using existing flow–habitat relationships that were developed to inform the WUP. Average annual estimates of WUA for the period 1975–2018 will be updated in Year 10.

Water quality data collected at an index site on the Quinsam River show that the river is fairly typical of streams in coastal BC watersheds with low nutrient concentrations (oligotrophic), near-neutral pH, and low turbidity during baseflow. Measurements of some water quality variables were, at times, outside of the biological optimum ranges for fish species present in the watershed. Specifically, maximum summer water temperatures in the Quinsam River exceeded 21°C, outside the prescribed range for suitable salmonid rearing conditions. Low Dissolved oxygen concentrations were occasionally recorded that were below guideline ranges for the protection of buried embryos/alevins of some species. A background water quality review undertaken in Year 2 and a screening analysis undertaken in Year 4 showed that interannual variability in many of the water quality variables was low, which may limit the power of the final analysis to quantify effects (if present) of water quality on fish abundance. It will therefore be important to continue to evaluate water quality results in the context of guidelines to support qualitative conclusions regarding $H_0 3$.

To test $H_0 4$ (floods), flow data collected by the Water Survey of Canada were used to calculate a range of hydrological metrics based on a subset of the Indicators of Hydrologic Alteration (Richter *et al.* 1996). These metrics will be used to examine whether hydrologic variability among years affects juvenile fish abundance. Key observations to date include the occurrence of notable floods (>80 m^3/s) in December 2014 and November 2016, and the occurrence of low discharge (<1 m^3/s) each year during the summer period when the diversion facility was not operating.

Invertebrate drift biomass on the Quinsam River generally tends to decline during the growing season, with distinct communities present early in the growing season (May and June) relative to later in the growing season. In Year 10, we will examine the relationship between invertebrate biomass (i.e., fish food) and juvenile fish abundance to test $H_0 5$. Interannual variability in invertebrate biomass has so far been generally low, despite seasonal patterns.

Pacific salmon escapement data collected by DFO have been compiled and analyzed each year to test $H_0 6$ (adult returns). Chinook Salmon escapement in the Quinsam River increased steadily over the four years from 2,366 fish to 9,131 fish. In contrast, Coho Salmon escapement decreased steadily over the four years from 14,883 fish to 5,865 fish. Another notable result was the occurrence of a record high Pink Salmon escapement (1.42 million) in Year 1 (2014). In Year 10, we propose to construct spawner-recruitment relationships for priority species to quantify the relationship between the abundance of adult fish and the subsequent recruitment of juvenile fish each year. Methods to derive spawner-recruitment relationships are scheduled to be developed in Year 6.

Table ii. Status of JHTMON-8 objectives, management questions and hypotheses after Year 5.

Study Objective	Management Questions	Management Hypotheses	Year 5 (2018/2019) Status
The objective is to address the management questions by collecting data necessary to test the impact hypotheses. Analysis is designed to understand whether BC Hydro operations, through changes to streamflow, are the primary cause of historical changes in fish abundance. This study will reduce uncertainty about factors that limit fish abundance in the Quinsam River.	1. What are the primary factors that limit fish abundance in the Campbell River System and how are these factors influenced by BC Hydro operations? The stream of interest in this monitor is the Quinsam River. 2. Have WUP-based operations changed the influence of these primary factors on fish abundance, allowing carrying capacity to increase? 3. If the expected gains in fish abundance have not been fully realized, what factors if any are masking the response and are they influenced by BC Hydro operations?	*$H_0$1: Annual population abundance does not vary with time (i.e., years) over the course of the Monitor*	-Juvenile fish have been sampled annually at the Qunsam Hatchery salmon counting fence to derive total outmigration estimates. In Year 5, we worked with DFO to secure data extending back to the 1970s. -Inter-annual variability has been observed in the abundance of priority species so we expect to reject this hypothesis in Year 10
		$H_0$2: Annual population abundance is not correlated with annual habitat availability as measured by Weighted Usable Area (WUA)	-In Year 5, we used existing flow-habitat relationships to estimate WUA of habitat for priority species for 1975-2017 -Spawning and rearing habitat availability for priority species has varied due to changes in flow, partly affected by BC Hydro operations -Analysis will be undertaken to test this hypothesis in Year 10
		$H_0$3: Annual population abundance is not correlated with water quality	-Water quality has been measured each year through the growing season at a single index site -Water quality is generally within ranges to support healthy salmonid populations, although there are some exceptions -Analysis will be undertaken to test this hypothesis in Year 10. Low variability in independent variables is expected to limit the statistical power of this analysis; comparisons with water quality guidelines will be an important line of evidence.

Table ii. Continued.

Study Objective	Management Questions	Management Hypotheses	Year 5 (2018/2019) Status
The objective is to address the management questions by collecting data necessary to test the impact hypotheses. Analysis is designed to understand whether BC Hydro operations, through changes to streamflow, are the primary cause of historical changes in fish abundance. This study will reduce uncertainty about factors that limit fish abundance in the Quinsam River.	1. What are the primary factors that limit fish abundance in the Campbell River System and how are these factors influenced by BC Hydro operations? The stream of interest in this monitor is the Quinsam River. 2. Have WUP-based operations changed the influence of these primary factors on fish abundance, allowing carrying capacity to increase? 3. If the expected gains in fish abundance have not been fully realized, what factors if any are masking the response and are they influenced by BC Hydro operations?	H_0*4: Annual population abundance is not correlated with the occurrence of flood events*	-Flow data collected by the Water Survey of Canada have been used to calculate flow metrics that will be used in the final analysis -Flow metrics have been variable throughout the monitoring period, affected by background hydrological factors and BC Hydro operations -Flood have occurred during the JHTMON-8 monitoring period during sensitive life history periods (Pacific salmon incubation) -Analysis will be undertaken to test this hypothesis in Year 10
		H_0*5: Annual population abundance is not correlated with food availability as measured by aquatic invertebrate sampling*	-Aquatic invertebrate biomass has been measured each year through the growing season at a single index site -Clear seasonal patterns have been observed but inter-annual variability in mean invertebrate drift biomass is less clear -Analysis will be undertaken to test this hypothesis in Year 10, although low inter-annual variability in invertebrate biomass may limit the statistical power of this analysis
		H_0*6: Annual smolt abundance is not correlated with the number of adult returns*	-Adult salmon escapement data have been compiled annually from DFO records and will be used to construct spawner-recruitment curves to test this hypothesis in Year 10.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF MAPS

LIST OF APPENDICES

1. INTRODUCTION

1.1. Background to Water Use Planning

Water use planning exemplifies sustainable work in practice at BC Hydro. The goal is to provide a balance between the competing uses of water that include fish and wildlife, recreation, and power generation. Water Use Plans (WUPs) were developed for all of BC Hydro's hydroelectric facilities through a consultative process involving local stakeholders, government agencies and First Nations. The framework for water use planning requires that a WUP be reviewed on a periodic basis and there is expected to be monitoring to address outstanding management questions in the years following the implementation of a WUP.

As the Campbell River Water Use Plan process reached completion, a number of uncertainties remained with respect to the effects of BC Hydro operations on aquatic resources. A key question throughout the WUP process was "what limits fish abundance?" For example, are fish abundance and biomass limited by available habitat, food, environmental perturbations or ecological interactions? Answering this question is an important step to better understanding how BC Hydro operations in the watershed affect fisheries, and to effectively manage water uses to protect and enhance aquatic resources. To address this uncertainty, monitoring programs were designed to assess whether fish benefits are being realized under the WUP operating regime, and to evaluate whether limits to fish production could be improved by modifying operations in the future. The *Quinsam River Smolt and Spawner Abundance Assessments* (JHTMON-8) is part of the wider suite of monitoring studies of the Campbell River WUP. JHTMON-8 focuses on monitoring fish populations and environmental factors that may influence fish abundance in the Quinsam River. Prior to Year 5, JHTMON-8 also focused on the Salmon River; however, this component of the program was removed following a revision to the terms of reference (BC Hydro 2018a) after the Salmon River Diversion Dam was decommissioned in 2017, meaning that there is no longer any mechanism for BC Hydro operations to affect fish populations in the Salmon River. As this is the mid-point of the 10-year program, this Year 5 Interim Summary Report provides a summary of all data collected to date. Therefore, data collected during Year 1–4 in the Salmon River are presented in the report, along with relevant background information about historical BC Hydro operations in the Salmon River watershed. As a consequence, some tables and figures in this report that show results of monitoring in the Salmon River are reproduced from the Year 4 report (Sharron *et al.* 2018). The Salmon River will not be considered in future JHTMON-8 annual reports.

1.2. BC Hydro Infrastructure, Operations and the Monitoring Context

1.2.1. Overview

The Salmon and Quinsam rivers are both located to the west of the city of Campbell River on the east coast of Vancouver Island, British Columbia. Both the Salmon River and the Quinsam River diversion facilities have historically diverted a portion of water from the river mainstems to generate hydroelectricity downstream at Ladore and John Hart generation stations (Map 1). Details of the diversion infrastructure and operations are summarized below based on the Campbell River System

WUP (BC Hydro 2012). In 2017, the Salmon River Diversion Dam was decommissioned and it therefore no longer diverts water from the river. Prior to this, the Salmon River Diversion facility was operational during JHTMON-8. As part of JHTMON-8, monitoring was undertaken on the Salmon River during Year 1 to 4, while monitoring was undertaken on the Quinsam River during Year 1 to 5. Monitoring will continue on the Quinsam River for the remainder of the program but further monitoring is not planned on the Salmon River as part of JHTMON-8 following a revision to the terms of reference (BC Hydro 2018a).

Project Overview

Legend
- Dam
- Stream

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 2 4 6 8 10 12 km

Scale: 1:300,000

NO.	DATE	REVISION	BY
1	12/03/2019	1230_SAM_QUN_Overview_Portrait_2019Mar12	CGA
2			
3			
4			
5			

Date Saved: 12/03/2019
Coordinate System: NAD 1983 UTM Zone 10N

ECOFISH RESEARCH

Map 1

Path: M:\Projects-Active\1230_JHTMON\MXD\Overview\1230_SAM_QUN_Overview_Portrait_2019Mar12.mxd

1.2.2. The Salmon River and Diversion

The Salmon River flows from headwaters in Strathcona Provincial Park in a general northwards direction to the ocean at Sayward. Major tributaries include Grilse Creek, the Memekay River and the White River, all of which drain the western side of the Salmon River watershed. The area of the watershed is approximately 1,300 km^2 and mean annual discharge near the mouth is 63 m^3/s (Burt 2010). The Salmon River has high fisheries values and the river supports a range of salmonid and non-salmonid fish species, including those that are both anadromous and resident (Burt 2010; see

Table for periodicity information). The Salmon River supports all five species of Pacific salmon (*Oncorhynchus* spp.) as well as both resident and anadromous Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarkii*) and Dolly Varden (*Salvelinus malma*). Lamprey (*Lampetra* spp.) and Sculpin (*Cottus* spp.) species are also present.

The Salmon River Diversion infrastructure was initially constructed in 1958. The diversion dam was a 69 m long rock-filled timber crib dam that diverted water into the Campbell River watershed. Water was diverted from the mainstem of the Salmon River via an intake channel, through a radial gate and into a concrete-lined canal that conveys water to Brewster Lake, which is upstream of Lower Campbell Lake Reservoir. Non-diverted water was returned to the mainstem downstream, either via the main spillway, an undersluice, a trimming weir, or the fishway.

Blasting was undertaken in 1975 and 1976 to remove a rock obstruction in a canyon at river km 38 that formed both a velocity and vertical obstruction to fish migrating upstream (Ptolemy *et al.* 1977 cited in Burt 2010). Subsequent surveys showed that juvenile steelhead were present upstream of the canyon where they were previously absent.

A fish (smolt) screen was installed in 1986 to prevent out-migrating smolts from being diverted into the Campbell River watershed. The fishway was installed in 1992 to aid upstream passage of fish past the diversion dam. Historically, there have been issues with the performance of both the fish screen and the fish way (Burt 2010). In summer 2017, BC Hydro decommissioned the diversion dam (Figure 1) and flow conditions in the river were unimpeded by the diversion infrastructure from September 10 onwards (Jay, pers. comm. 2018).

Prior to this, the Salmon River Diversion was operational in Year 1 to Year 3 of JHTMON-8. A total of 493.39 million m^3 was licensed to be diverted annually, and the 7.8 km diversion canal had a maximum design discharge capacity of 45 m^3/s. The Campbell River System WUP stipulates maximum down ramping rates for the Salmon River and the Diversion Canal (Table), maximum diversion flows to enhance fish screen efficiency (Table 3), and minimum flows that must be maintained in the Salmon River downstream of the diversion dam when sufficient flows are naturally available (4.0 m^3/s).

Table 1. Periodicity of important fish species found in the Salmon River (from BC Hydro files for Campbell River Water Use Plan, dated 2001).

Species	Life History Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chinook Salmon	Adult migration												
	Spawning									P P			
	Incubation												
	Emergence												
	Rearing												
	Juvenile migration												
Chum Salmon	Adult migration												
	Spawning												
	Incubation												
	Emergence												
	Juvenile migration												
Coho Salmon	Adult migration												
	Spawning										P P		
	Incubation												
	Emergence												
	Rearing												
	Juvenile migration				S								
Pink Salmon	Adult migration												
	Spawning								P	P			
	Incubation												
	Emergence												
	Juvenile migration												
Rainbow Trout	Spawning												
	Incubation												
	Emergence												
	Rearing												
Steelhead (winter run)[1]	Adult migration												
	Spawning			P P P	P								
	Incubation												
	Rearing												
	Juvenile migration				S								

Critical times

F = fry migration begins, S = smolt migration begins, P = peak spawning

[1] There are no summer run Steelhead in the JHTMON-6 study reach of the Salmon River.

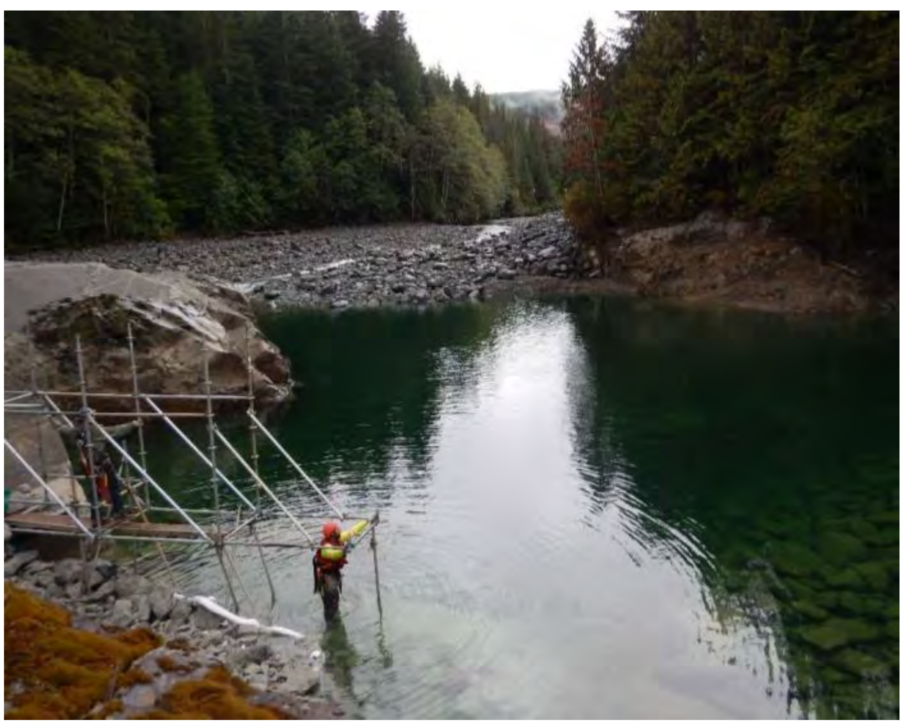
Table 2. Salmon River maximum permitted down ramping rates that applied prior to decommissioning (BC Hydro 2012).

Stream	Salmon River discharge (m^3/s)	Salmon River maximum down ramping rate ($m^3/s/h$)
Salmon River	< 8.0	1.0
	8.0 to 10.0	2.0
	>10.0	10.0
Salmon River Diversion	0 to 43.0	10.0

Table 3. Salmon River maximum permitted diversion flows that applied prior to decommissioning (BC Hydro 2012).

Date	Maximum diversion (m^3/s)	Fish screen operation
Jan 1 to Mar 31	43	N/A
Apr 1 to Dec 31	15	On

Figure 1. View at the site of the former Salmon River Diversion Dam, September 29, 2017.



1.2.3. The Quinsam River and Diversion

The Quinsam River is the only major tributary of the lower Campbell River, entering the Campbell River approximately 3.5 km upstream of the mouth. The Quinsam flows through a series of lakes and has a mainstem length of 45 km (excluding lakes), a watershed area of 283 km^2, and a mean annual discharge near the mouth of 8.5 m^3/s. The river has high fisheries values, supporting the same assemblage of native salmonid species that is found in the Salmon River (Burt 2003; see Table 4 for periodicity information). The Quinsam River Hatchery was constructed in 1957 and is located 3.3 km upstream from the confluence with the Campbell River. The hatchery has been active in the watershed, augmenting populations of Chinook Salmon, Pink Salmon, Coho Salmon and Cutthroat Trout since 2014 (Year 1), with Chum Salmon and steelhead also released in previous years (DFO 2016). Smolt and fry life stages that are ready for downstream migration to the ocean are released from the hatchery during the spring. In addition, juvenile Coho Salmon, steelhead and (less frequently) Chinook Salmon have been outplanted to the upper watershed since 1978 to promote adult returns upstream of the hatchery (Burt 2003).

The Quinsam River Diversion comprises a small concrete gravity storage dam, a concrete gravity diversion dam, a concrete flume and the natural waterways that convey water to Lower Campbell Lake Reservoir. Non-diverted water is conveyed to the Quinsam River via an undersluice gate or the free crest weir. The dams were both constructed in 1957.

A total of 100 million m^3 is licensed to be diverted annually and the design capacity of the Quinsam River Diversion is 8.50 m^3/s. The WUP stipulates maximum down ramping rates (Table 5) and minimum flows (when naturally available) in the Quinsam River downstream of the diversion dam (Table 6).

Table 4. Periodicity of important fish species in the Quinsam River system (from BC Hydro files for Campbell River Water Use Plan, dated 2001).

Species	Life History Stage	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Chinook Salmon	Adult migration												
	Spawning										P	P	
	Incubation												
	Emergence												
	Rearing												
	Juvenile migration				F	S							
Chum Salmon	Adult migration												
	Spawning											P P	
	Incubation												
	Emergence												
	Juvenile migration			F									
Coho Salmon	Adult migration												
	Spawning											P P P	
	Incubation												
	Emergence												
	Rearing												
	Juvenile migration			F	S								
Pink Salmon	Adult migration												
	Spawning									P			
	Incubation												
	Emergence												
	Juvenile migration			F									
Rainbow Trout	Adult migration												
	Spawning												
	Incubation												
	Rearing												
	Juvenile migration												
Sockeye Salmon	Adult migration												
	Spawning												
	Incubation												
	Emergence												
	Rearing												
	Juvenile migration			F									
Steelhead (winter run)[1]	Adult migration												
	Spawning			P P									
	Incubation												
	Emergence												
	Rearing												
	Juvenile migration				S								

Critical times

F = fry migration begins, S = smolt migration begins, P = peak spawning

[1] There are no summer run Steelhead on the Quinsam River.

Table 5. Quinsam River maximum permitted down ramping rates (BC Hydro 2012).

Stream	Discharge (m^3/s)	Maximum down ramping rate ($m^3/s/h$)
Quinsam River	> 4.0	8.5
	≤ 4.0	1.0
Quinsam Diversion	> 2.0	N/A
	≤ 2.0	1.0

Table 6. Minimum permitted discharge in the Quinsam River (BC Hydro 2012).

Date	Minimum discharge in Quinsam River (m^3/s)
Jan 1 to Apr 30	2.0
May 1 to Oct 31	1.0
Nov 1 to Dec 31	0.6

1.3. Background to Water Use Decision

The operating conditions (minimum flow requirements) prescribed in the WUP for the Quinsam Diversion (Table 6) match those of the "MinRisk 2c" option that was recommended by a Consultative Committee because it represented "the best trade off of all gains and losses" (Campbell River WUP CC 2004). This recommendation was based on evaluating a power/financial performance measure alongside the following four biological performance measures (Campbell River WUP CC 2004):

- Fish habitat risk: the average annual probability that Rainbow Trout and Chinook Salmon usable habitat will decline below 60% of the maximum available, calculated using a meta-analysis method);
- Fish passage (being considered in JHTMON-6);
- Fish overwintering success; and
- Drawdown in Upper Quinsam Lake/Wokas Lake, with the assumption that drawdown has a negative effect on fish and wildlife resources

The first two biological performance measures listed above were evaluated based on scores that were standardized to a scale from 0–1, whereas the second two measures were evaluated qualitatively by considering the direction of predicted change (Table 7-6 in Campbell River WUP CC 2004). The Quinsam Diversion operating conditions prescribed in the WUP are those that were evaluated to provide the best biological outcomes out of the options consider that involved flow diversion.

1.4. Management Questions and Hypotheses

The JHTMON-8 monitoring program aims to address the following three management questions:

1. What are the primary factors that limit fish abundance in the Campbell River System and how are these factors influenced by BC Hydro operations?
2. Have WUP-based operations changed the influence of these primary factors on fish abundance, allowing carrying capacity to increase?
3. If the expected gains in fish abundance have not been fully realized, what factors if any are masking the response and are they influenced by BC Hydro operations?

In addressing the questions, the monitoring program is designed to test the following five null hypotheses:

$H_0$1: Annual population abundance does not vary with time (i.e., years) over the course of the Monitor.

$H_0$2: Annual population abundance is not correlated with annual habitat availability as measured by Weighted Usable Area.

$H_0$3: Annual population abundance is not correlated with water quality.

$H_0$4: Annual population abundance is not correlated with the occurrence of flood events.

$H_0$5: Annual population abundance is not correlated with food availability as measured by aquatic invertebrate sampling.

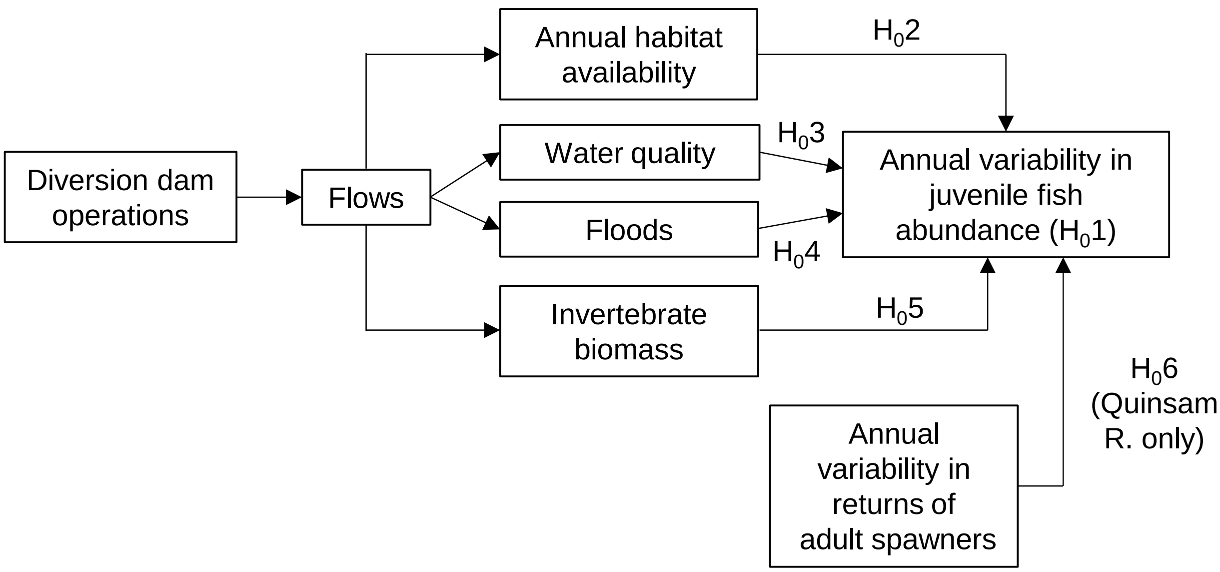
There is one additional null hypothesis to be tested for the Quinsam River System where adult escapement and smolt abundance data are collected separately for a wide range of species:

- $H_0$6: Annual smolt abundance is not correlated with the number of adult returns.

The basis of JHTMON-8 is outlined conceptually in Figure 2. The monitoring program is designed to first establish whether there is among-year variability in fish abundance ($H_0$1). The program is then designed to collect data to examine whether inter-annual variability in fish abundance is related to important environmental factors that could be influenced by BC Hydro operations, specifically: Weighted Usable Area (WUA) of habitat ($H_0$2); water quality ($H_0$3); an accumulated flood risk index during the spawning and incubation periods ($H_0$4), or; invertebrate abundance (food availability; $H_0$5). The study will also investigate whether annual variability in juvenile fish abundance is affected by annual variability in salmon spawner escapement ($H_0$6) – a factor that is influenced by marine survival and not by diversion dam operations.

The final step in the analysis will involve evaluating whether BC Hydro operations, via changes to flow, are the primary cause of any changes to environmental factors that are shown to be drivers of fish production. This step may require a mixture of quantitative and qualitative analysis as it will be easier to distinguish changes due to BC Hydro operations from those due to background variability for some factors (e.g., WUA) than others (e.g., invertebrate drift). To address Management Question 2, it will be necessary to compare pre-and post-WUP conditions, although this will not be possible for some components that lack pre-WUP data (e.g., invertebrate drift biomass). Such pre- and post-WUP comparisons will therefore focus on analyzing Quinsam River fish abundance, WUA, and flow data. We do not plan to compare changes in variables with targets that have been defined *a priori*, because we are not aware that these have developed[1]. Instead, conclusions about the biological significance of changes will be made based on multiple lines of evidence such as the effect size and, potentially, trends in other watersheds. Such conclusions may then inform decisions about whether changes to the WUP or alternative mitigation are necessary to achieve desired outcomes for fish.

Figure 2. Effect-pathway diagram showing the context of the six hypotheses that the JHTMON-8 monitoring program sets out to address.



1.5. Scope of the JHTMON-8 Study

1.5.1. Overview

The JHTMON-8 study has been designed to build upon monitoring that is already occurring in the Quinsam and Salmon watersheds. This allows the study to integrate established work programs and provides an opportunity to incorporate historical data into the analyses. Table 7 summarizes the field sampling programs that were undertaken during Year 4 of JHTMON-8.

[1] We recognize this is implied in Management Question 3 ("the expected gains"); however, we assume this relates to a general expectation that the WUP will qualitatively improve fish productivity in the Quinsam River.

Table 7. Summary of field sampling programs undertaken for JHTMON-8.

River	Sampling program	Lead organization[1]	Method	Timing
Salmon (Year 1–4 only)	Adult Steelhead survey	LKT	Snorkel surveys	March – April
	Juvenile Steelhead abundance	LKT	Closed site multi-pass electrofishing	September
	Juvenile Coho abundance	LKT/DFO	Closed site multi-pass netting	October
	Salmon escapement surveys	DFO	Various	September – November
	Water quality sampling	LKT	*In situ* and laboratory analysis	May – October
	Invertebrate sampling	LKT	Drift sampling	May – October
Quinsam (Year 1–10)	Quinsam River Hatchery juvenile downstream migration	DFO/LKT	Fish fence	March – June
	Salmon escapement surveys	DFO	Various	September – November
	Water quality sampling	LKT	*In situ* and laboratory analysis	May – November
	Invertebrate sampling	LKT	Drift sampling	May – October

[1]LKT, Laich-Kwil-Tach Environmental Assessment Ltd. Partnership; DFO, Fisheries and Oceans Canada

The species of primary interest on the Salmon River are anadromous Rainbow Trout (steelhead) and Coho Salmon; In Year 1–4, surveys were undertaken by LKT to enumerate juvenile Coho Salmon and both juvenile and adult steelhead in the Salmon River. Priority species for JHTMON-8 in the Quinsam River are Chinook Salmon, Coho Salmon and steelhead, although Pink Salmon is also of interest. Juvenile fisheries data for the Quinsam River are obtained via operation of a salmon counting fence at Quinsam River Hatchery to enumerate downstream juvenile migration of a range of species. In addition to these juvenile abundance datasets, adult escapement data obtained by Fisheries and Oceans Canada (DFO) for a range of Pacific salmon species during routine monitoring are also considered for both rivers as part of JHTMON-8.

Further information about the scope and objectives of specific sampling programs is provided in the text below, which also includes an overview of how impact hypotheses will be tested for the Quinsam River in Year 10. As further monitoring is no longer scheduled for the Salmon River (BC Hydro 2018a), JHTMON-8 hypotheses will not be tested for the Salmon River, although data collected to date are presented and described in this Year 5 Interim Report.

1.5.2. Fish Population Assessments

The JHTMON-8 juvenile fish sampling program was designed to ensure that the error associated with fish sampling methods is sufficiently small to assess between-year variability in fish abundance. The fish abundance data will first be used to test $H_0$1: '*annual population abundance does not vary with time (i.e., years) over the course of the Monitor*' (Section 1.4).

The program was designed to enumerate both adult and juvenile life stages to allow relationships between the numbers of adult spawning fish and juvenile recruitment to be examined. This enables testing of $H_0$6 '*annual smolt abundance is not correlated with the number of adult returns*' for the Quinsam River, which will help to tease apart the extent to which variations in abundance reflect either variations in adult returns (dependent on marine conditions and harvest) or variations in juvenile survival (dependent on freshwater conditions). Testing this hypothesis will therefore indicate whether the watershed is "fully seeded" for each species. This hypothesis will be tested for the Quinsam River, where the salmon counting fence is monitored to provide estimates of total juvenile fish out-migration. In Year 5, historical data collected at the Quinsam Hatchery salmon counting fence since the 1970s were collated, increasing the duration of the dataset available for this analysis. Testing $H_0 6$ will involve comparing the productivity of naturally-spawned Coho and Chinook salmon with the productivity of colonization programs that out-plant juvenile fish to areas in the upper Quinsam River watershed, e.g., Lower Quinsam Lake. This comparison will further help to examine whether spawning areas are fully seeded. This will need to consider the potential for lower fitness of hatchery-reared fish compared with wild fish, as has been observed during previous field studies in the watershed (Burt, pers. comm. 2016).

For at least some species and life stages, we anticipate that biologically significant interannual variability in juvenile fish abundance will be detected; i.e., after accounting for sampling error, we will be confident that variability among years in juvenile abundance occurred at the watershed scale. It will then be necessary to use these data to the remaining hypotheses to determine whether there are any relationships between the observed variability in fish abundance, and variations in key environmental factors, namely: habitat ($H_0 2$), water quality ($H_0 3$), floods ($H_0 4$) and food availability ($H_0 5$).

During Year 1–4, juvenile steelhead and Coho Salmon sampling on the Salmon River were undertaken during the low flow period in late summer to maximize capture efficiency and minimize the potential for results to be confounded by variability in discharge (and therefore habitat use by fish). Sampling was intended to provide an index of juvenile fish abundance that is representative of each age class for a specific year; data are not expected to reflect the potential effects of water management operations on the day of sampling. Prior to the decommissioning, the Salmon River Diversion was not generally operated during juvenile fish sampling because discharge in the mainstem is typically less than the minimum flow requirement of 4.0 m^3/s (Section 1.2.2) during late summer. For example, mainstem discharge in the upper watershed during juvenile steelhead sampling in Year 4 was <1.0 m^3/s (Section 3.1.2), which is representative of the flow conditions that are targeted for this work. Therefore, we do not expect that decommissioning of the diversion undermined the value of the juvenile fish abundance data collected in Year 4.

1.5.3. Weighted Usable Area (WUA) of Habitat

Changes to flow affect the width, depth and velocity of a stream, which in turn, affect the extent and suitability of fish habitat. Changes to these factors have the potential to limit juvenile fish production by either changing spawning habitat or, for stream-rearing species, changing instream rearing habitat conditions. As part of JHTMON-8, annual WUA metrics will be calculated for the Quinsam River to quantify how habitat varies among years for individual life stages of priority fish species. WUA will be calculated using existing flow–habitat relationships that were developed based on field work that was undertaken by D. Burt and Associates to inform WUP development[2], as described in Solander *et al.* (2004). Analysis will then be undertaken in Year 10 to examine whether variation in juvenile fish abundance is related to variation in applicable WUA metrics that are specific to individual species and life stages. Results of this analysis will be used to test $H_0 2$: *annual population abundance is not correlated with annual habitat availability as measured by Weighted Usable Area*.

In Year 5, we reviewed flow–habitat relationships, compiled flow data, and completed analysis to estimate a range of WUA metrics for the period since 1974, which matches the period for which juvenile fish abundance data have been compiled for the Quinsam River. In this Interim Report, we present our methods and results, with the intention that the WUA dataset will be updated in Year 10 and used to test $H_0 2$.

1.5.4. Water Quality

Healthy fish populations require water quality variables to be within confined ranges. This range of suitable conditions varies depending on the individual variable, fish species and life stage. The objective of the JHTMON-8 water quality monitoring is to measure biologically important water quality variables to provide data to test $H_0 3$: '*annual population abundance is not correlated with water quality*' (Section 1.4). An evaluation of how to incorporate the water quality data into final analysis was provided in the Year 4 Annual Report (Sharron *et al.* 2018) and complete analysis will be undertaken at the end of the ten-year monitor to examine whether there is a relationship between fish abundance and water quality. If a relationship is detected (i.e., the null hypothesis is rejected), then we will evaluate whether BC Hydro operations are likely to have adversely affected water quality. This will be done as part of this study to help address Management Question 1 and 2. If required, we expect this analysis to be predominantly qualitative and it will involve considering the pathways of effect by which BC Hydro operations may affect water quality.

Thus, a key objective of this aspect of the study is that water quality data are collected that suitably reflect variability of water quality in time and space and are representative of the conditions experienced by fish communities. A single mainstem index site was selected on each river that was assumed to be representative of water quality in the wider watershed.

1.5.5. Floods

High flows have potential to adversely affect fish populations due to a variety of mechanisms; these include: redd scour, delayed redd construction, redd desiccation due to spawning occurring along channel margins during high flows, sediment intrusion, physical shock, or reduced holding

[2] Note that, contrary to the revised TOR (BC Hydro 2018a), it is unnecessary to use information from JHTMON-6 as these relationships for the Quinsam River were developed prior to initiation of JHTMON-8. Developing flow-habitat relationships for the Salmon River was previously part of the scope of JHTMON-6; however, this is no longer applicable following decommissioning of the Salmon River Diversion. The current scope of JHTMON-6 includes quantifying flow-habitat relationships for the Quinsam River diversion route via Miller Creek, but not the Quinsam River mainstem (BC Hydro 2018b).

opportunities shortly after emergence (reviewed in Gibbins *et al.* 2008). Discharge data are collected at numerous sites on both study streams by the Water Survey of Canada. These data will be used to quantify the occurrence of high flow events during individual years to test $H_0$4: '*annual population abundance is not correlated with the occurrence of flood events*' (Section 1.4).

During Year 3, we evaluated suitable hydrological metrics to quantify key flow characteristics that have potential to influence fish productivity (Abell *et al.* 2017). Based on this, we quantified the maximum daily mean discharge each year that occurs during the spawning and incubation periods of key species on both study streams. In future years, we will consider calculating additional metrics (e.g., based on the duration of high flows), which can be easily calculated by modifying the existing code. Analysis will be undertaken in Year 10 to determine whether variability in these values explains variability in fish abundance, providing a test of $H_0$4. The proposed analysis will focus on the spawning and incubation life stages because these life stages have been shown to be particularly sensitive to the effects of high flows (e.g., Cattanéo *et al.* 2002). We recognize that there is a range of mechanisms by which high flows can affect these life stages (see list above); therefore, if $H_0$4 is rejected, it may be necessary to undertake further analysis to characterize the most sensitive periods and threshold flows at which high flow events adversely affect juvenile fish abundance. We also recognize that, although $H_0$4 specifically focuses on floods, other aspects of hydrological variability could affect juvenile fish productivity. For example, the occurrence of low flows during summer can potentially limit the abundance of juvenile fish species that rear in freshwater throughout the summer, e.g., Coho Salmon (Matthews and Olson 1980). Accordingly, we propose to calculate a range of annual minimum flow metrics for each stream so that this analysis can be extended to evaluate whether low flows affect juvenile fish abundance. Further details are provided in Section 2.3.

1.5.6. Invertebrate Drift

Invertebrates typically form the bulk of the diet of both juvenile and resident adult salmonids in rivers (Quinn 2005). Invertebrate populations can vary due to a range of factors and therefore variability in the abundance and biomass of invertebrates can limit the growth of salmonids in rivers. The objective of the JHTMON-8 invertebrate sampling is to provide data to test $H_0$5 *annual population abundance is not correlated with food availability as measured by aquatic invertebrate sampling* (Section 1.4). Analysis will be undertaken in Year 10 to examine whether there are any relationships between fish abundance and food availability, as inferred from invertebrate biomass. If a relationship is detected (i.e., the null hypothesis is rejected), then we will evaluate whether BC Hydro operations are likely to have adversely affected invertebrate drift biomass. This will be done as part of this study to help address Management Question 1 and 2. If required, we expect this analysis to be predominantly qualitative and it will involve considering the pathways of effect by which BC Hydro operations may affect invertebrate drift. These pathways relate to changes in flow and include changes to invertebrate habitat availability, in addition to changes to habitat suitability due to changes in flow velocity or sedimentation. These changes can affect total invertebrate biomass and thus food availability for fish. Further, effects may vary among invertebrate taxa, creating the potential for changes to invertebrate community structure and diversity, which can potentially influence the quality of food available for fish.

A key objective is therefore to collect invertebrate data that reflect variability in time and space of watershed invertebrate communities that are representative of the food available to salmonids. Invertebrate drift includes dislodged benthic invertebrates, terrestrial invertebrates entrained in the stream, and invertebrates originating from riparian areas. Johnson and Ringler (1980) studied the diets of Coho Salmon fry and steelhead fry and found that Coho Salmon fry fed more on terrestrial invertebrates than on aquatic invertebrates. The major terrestrial invertebrate groups that contributed to Coho Salmon fry diets were hymenopterans, coleopterans, homopterans, dipterans, and lepidopteran larvae. The main benthic groups were ephemeropterans, plecopterans, and trichopterans (EPT), as well as chironomids, and tipulids (both Diptera). Steelhead fry mainly fed on aquatic invertebrates, which were ephemeropterans, chironomids, trichopterans and tipulids. Based on Johnson and Ringler (1980), salmonids feed on a wide diversity of invertebrate taxa, including EPT taxa (indicative of good water quality) and other taxa such as dipterans that are more tolerant of disturbed environments. Other studies have also shown that a wide range of invertebrate taxa are present in drift and they provide an important food resource for salmonids, with all macroinvertebrates generally assumed to provide potential food for rearing salmonids once they are present in drift (e.g., Rader 1997) . Based on these studies, we expect that total invertebrate drift biomass provides a suitable metric of food availability to rearing salmonids in the Quinsam River.

A single mainstem index site was selected on each river that was assumed to be representative of the invertebrate communities present in the wider watershed. Invertebrate drift biomass is measured as a proxy for food availability, although invertebrate community composition is also examined to provide information on food quality. Drift sampling is undertaken during the growing season when rearing juvenile salmonid are actively feeding. In addition, a single kick net sample is collected in September. Kick sampling targets benthic invertebrates and is therefore less representative of the total abundance of food available to fish. However, kick sampling based on the CABIN protocol (Environment Canada 2012) has been used more widely to characterize stream invertebrate communities throughout Canada. Data collected using this method can be used to evaluate the wider ecological integrity of the streams, based on comparisons with the Environment Canada database of Georgia Basin reference sites (e.g., see Strachan *et al.,* 2009).

2. METHODS

2.1. Fish Population Assessments

2.1.1. Salmon River Adult Steelhead Survey

Annual spring snorkel surveys have generally been conducted as part of adult steelhead stock production monitoring on the Salmon River since 1998. These have historically been undertaken by British Columbia Conservation Foundation (BCCF) and Ministry of Environment (MoE) staff. Between 2014 (Year 1) and 2017 (Year 4), this work was led by LKT, with BCCF providing supervision until Year 2 to ensure ongoing consistency of methods. Following decommissioning of the Salmon

River diversion dam in summer 2017, snorkel surveys were not undertaken in Year 5 (2018) of JHTMON-8 and future snorkel surveys will not be undertaken as part of the JHTMON-8 program [3].

Surveys of an index reach ('Lower Index') are the primary stock assessment method, with surveys typically undertaken during the second week of March. Surveys of two additional index reaches ('Rock Creek' and 'Upper Index') have also been undertaken in April during most of the years since 2000. These reaches are upstream of the Lower Index reach: the Rock Creek reach extends upstream of the diversion dam and the Upper Index reach extends downstream of the dam (Map 2).

All three reaches were successfully surveyed in during Year 1–4, with survey timings consistent with historical surveys (see annual reports for precise survey dates). Each reach was snorkelled during a single day by two experienced technicians. Surveys were conducted in a downstream direction, with particularly steep and potentially dangerous sections bypassed on foot. Surveyors recorded the number, length and condition of adult steelhead, in addition to associated variables (Table 8). Incidental observations of other salmonids were recorded, although fish with fork length < 250 mm were not recorded.

Table 8. Variables measured during snorkel surveys of adult steelhead.

Variable	Unit/Classification
Weather	Observation
Air/water temperature	°C
Effective visibility	Measured or estimated (m)
Fish size class	fry/parr/adults; 150–250 mm, 251–350 mm, 351–450 mm, and > 450 mm
Fish species	Steelhead (ST)/Cutthroat Trout (CT)/resident Rainbow Trout (RB)
Fish condition	Bright/moderately coloured/mid-spawn/post-spawn/undetermined
Redd observations	Number

2.1.2. Salmon River Juvenile Steelhead Abundance

2.1.2.1. Field Methods

In Year 1–4, juvenile steelhead[4] populations in the Salmon River were sampled with multipass removal electrofishing at five sites upstream and five sites downstream of the Salmon River Diversion (Table 9; Map 2). Site locations were based on those historically sampled by BCCF during 1998–2013, with minor adjustments made to the positions of stop nets to account for changes in stream morphology.

[3] Snorkel surveys recommenced in spring 2019, led by BCCF (Damborg, pers. comm. 2019) Results from 2019 and future years will not be reported as part of JHTMON-8.

[4] For consistency with the historical sampling program, we use the term 'juvenile steelhead' to refer to juvenile (fry and parr) Rainbow Trout. We acknowledge that this may include resident and anadromous individuals.

Sites were historically selected to specifically target fry (not parr) habitat. The main criteria used to select sampling locations were:

- Water depth (maximum 1.0 m, average 0.1 to 0.4 m);
- Water velocity (maximum 1.0 m/s, average 0.1 to 0.5 m/s);
- Cover and substrate (non-embedded boulder, cobble, and/or gravel);
- Area of site (target 100 m^2); and
- Proximity to previous sampling location (as close as possible).

Table 9. Details of juvenile steelhead sampling sites in the Salmon River.

Location	Site	Historic Site #	Historic Site Name/Description	River km	Mesohabitat	UTM		
						Zone	Easting	Northing
Downstream of Diversion	SAM-EF01	1	Pallans (23.94 KM)	23.94	Riffle	10U	297922	5570705
	SAM-EF02	2	WSC Station (Kay Creek)	35.44	Riffle	10U	304030	5564241
	SAM-EF03	3	Memekay Mainline Bridge	52.60	Riffle	10U	309310	5556475
	SAM-EF04	4	Smolt Screen	58.02	Riffle	10U	309036	5552478
	SAM-EF07	7	Memekay River (lower bridge)	27.93	Riffle	10U	302056	5566097
Upstream of Diversion	SAM-EF05	5	Washout, old bridge 5km u/s/ diversion	67.73	Riffle	10U	304267	5548471
	SAM-EF06	6	Washout 500 m u/s of Grilse confluence	69.25	Riffle	10U	301417	5546997
	SAM-EF08	8	Grilse Ck. (100 m u/s of lower bridge)	70.77	Riffle	10U	300741	5547323
	SAM-EF09	9	Grilse Ck. (300 m d/s of upper bridge)	74.27	Riffle	10U	297133	5546961
	SAM-EF10	10	Grilse Ck. (500 m d/s of upper bridge)	75.91	Riffle	10U	296773	5546524

Fish were captured using closed-site multipass removal electrofishing methods in accordance with guidelines (Lewis *et al.* 2004; Hatfield *et al.* 2007). Sites were enclosed using stop nets (15.2 m long × 1.2 m deep, mesh size = 3.2 mm). Each pass consisted of two full circuits of the enclosure, and two to three passes were conducted at each site. Data collected included:

- Sampling effort (seconds) expended during each pass;
- The number, species, length (+/- 1 mm) and weight (+/- 0.01 g) of each fish caught per pass;
- Scales samples from a sub-sample of fish that were close to size/age class boundaries;
- Wetted width (three or four measurements) and site length; and
- Physical stream characteristics (cover types, substrate size, habitat type, stream gradient, compaction, sand in substrate, and roughness).

After electrofishing was complete, hydraulic habitat variables were measured along transects placed across the width of the sampling site. A minimum of ten wetted stations spaced a minimum of 0.25 m apart were placed along each transect. The following variables were measured at each station: distance from wetted edge, water depth, water velocity, available cover, and net locations. If a single transect was not long enough to accommodate 10 wetted stations, then an additional transect was completed at the site. Water temperature and conductivity were measured using *in situ* meters calibrated prior to sampling. Photographs from standardized locations were also taken at each sampling site.

2.1.2.2. Data Analysis

Individual Fish Data

For juvenile steelhead, we defined age class structure, described length-weight relationships, Fulton's condition factor (K), and length at age. Fulton's condition factor (K) was calculated for all captured fish as:

$$K = \text{weight} \times \text{length}^{-3} \times 100{,}000$$

Where weight was recorded in g and length in mm. Scale samples were examined under a dissecting microscope to age individual fish: representative scales were photographed, and apparent annuli were noted on a digital image. Fish age was determined by two independent observers using a double-blind methodology. The data produced by each observer were then compared to identify any discrepancies. Where discrepancies occurred, they were discussed, and final age determination was based on professional judgement of the senior biologist.

Fish were separated into age classes for fish abundance and biomass analysis. To define discrete age class size bins (size classes), the length-frequency histograms for fish captured during electrofishing were reviewed along with all of the length at age data from the scale analysis. Based on these data, discrete fork length ranges were defined for each of the following age classes: fry (0+), parr (1+), parr (2+) and adult (≥3+), although no 2+ parr or adult fish were captured during sampling in 2017. These discrete fork length ranges allow all fish to be assigned to an age class based on fork length for population analysis. Fork length ranges may differ from year to year and are therefore determined annually. Summary statistics of fish length, weight, and Fulton's condition factor were summarized by age class for both the upstream and downstream reaches.

Population Analysis

Total abundance and biomass were calculated for steelhead fry (0+) using removal depletion equations in MicroFish V3.0 (Van Deventer 2006). Fish abundance and biomass by age class at individual sites were then standardized to fish per 100 m^2.

Abundance and biomass estimates were also adjusted to account for differences in habitat suitability of each sampling site. The habitat suitability of each electrofishing site was determined based on depth and velocity measured at each transect data, and habitat suitability indices for steelhead fry (0+) developed for BC Water Use Planning projects (curves dated February 2001 provided by R. Ptolemy, MoE). Habitat suitability is expressed as a usability percentage, which is calculated by computing the weighted usable width of each transect within the sampling enclosures and dividing by the wetted width of the transect. The transect usability at each site was then used to adjust the fish density estimates. Results are expressed in terms of fish per unit area (FPU; fish/100 m^2), and are reported as both non-adjusted (FPU_{obs}) and usability-adjusted estimates (FPU_{adj}), and as non-adjusted and adjusted biomass per unit area (BPU_{obs} and BPU_{adj}; g/100 m^2). Abundance and biomass densities are presented for individual sites and as geometric mean values for upstream and downstream of the diversion reaches. Geometric mean values are used to compare results among years because these values are less sensitive to the influence of particularly low or high values than the arithmetic mean. The general equation for calculating a geometric mean ($\bar{X}_{geom}$) is

$$\bar{X}_{geom} \sqrt[n]{x_1 \cdot x_2 \cdot} \dots x_n$$

where *x* is an individual value (in this case, an abundance or biomass density for a single site) and *n* is the number of values (in this case, the number of sites).

Results were compared with historical data collected at the same sites by BCCF from 1998 to 2013, and by LKT and Ecofish in 2014 to 2016.

2.1.3. Salmon River Juvenile Coho Salmon Abundance

2.1.3.1. Field

The abundance of juvenile Coho Salmon has been measured in the Salmon River during the fall from 2008 to 2017, with the work undertaken by DFO prior to JHTMON-8 (i.e., during 2008–2014). No sampling occurred in Year 5 as part of JHTMON-8 because the Salmon River diversion was removed on September 10, 2017 and flows in the mainstem were restored, meaning that monitoring of juvenile Coho Salmon above and below the diversion was no longer required. However, in Year 5, DFO provided historical data collected during 2008–2014 (Anderson, pers. comm. 2018), which had not been previously reported in JHTMON-8 annual reports. Accordingly, in Year 5, these data were compiled with data collected during JHTMON-8 to provide a ten-year time series. This time series was analyzed to produce summary plots, which have been presented in the Results section. Field and analysis methods are described below to provide context to interpret the time series.

The program involved sampling at six sites, with three sites upstream of the diversion dam and three sites downstream (Map 2). Sites were representative of the juvenile Coho Salmon habitat generally present, typically ~ 20 m long, and comprised pools. As part of LKT's standardized approach to data collection and quality assurance, new site names were assigned to the sampling sites for data recording purposes in 2014. Correspondence between these and existing site names is shown in Table 10, although note that precise sampling areas have varied within stream reaches between years in response to differences in water levels and channel morphology. As discussed in the Year 4 monitoring report (Sharron *et al.* 2018), sites in mainstem Grilse Creek (SAM-BS03) and Big Tree Creek (SAM-BS06) were repositioned in 2016 and 2017 but are still representative of previous sites. Big Tree Creek was not sampled in 2008 and 2009. For the multiple year analysis, all repositioned sites were compared with the historical sites.

The sampling methods remained generally consistent among years. Sites were isolated using barrier nets placed at the upstream and downstream ends to form full enclosures that included the full width of the channel (Figure 3). Multi-pass beach and/or pole seine netting, depending on the site conditions, were then used to remove fish at five sites. In some years, including 2017, the water level at some sites was too low for seining so crews used multi-pass electrofishing. Two to four passes were undertaken with the objective of observing declining catches, permitting the estimation of capture efficiency and subsequent estimation of total fish abundance.

All captured fish were retained until sampling was complete. Fork lengths of all juvenile Coho Salmon were tallied using 1 mm size bins. Weight (g) of individual fish in each size bin was recorded, with a maximum of three measurements recorded per size bin for each pass. Fish scales were retained for a subsample of fish (n = ≤8 for each size class). Between 2014–2017, scales were analyzed at Ecofish's laboratory in Campbell River to establish fork length categories that corresponded to age classes.

The length of each site was measured and three width measurements were recorded at all six sites. Both wetted width and width of the channel with water depth > 10 cm were measured. The latter width measurements were used to calculate the area of each site when estimating fish density as they are more representative of the habitats used by juvenile Coho Salmon.

Table 10. Juvenile Coho Salmon sampling site details and correspondence with historical site names.

Location Relative to Diversion	Site	Historic Name	Stream	Coordinates (UTM)		
				Zone	E (m)	N (m)
Upstream	SAM-BS01	Crowned	Crowned Creek	10U	301818	5543950
Upstream	SAM-BS02	G02	Grilse Creek	10U	300117	5547376
Upstream	SAM-BS03C	Gmain	Grilse Creek	10U	300110	5547281
Downstream	SAM-BS04	Pater	Paterson Creek	10U	309986	5552605
Downstream	SAM-BS05	Mari	Marilou Creek	10U	307472	5557836
Downstream	SAM-BS06	BTCKFlCh	Big Tree Creek	10U	303387	5566520

Figure 3. Establishing stop nets at the Big Tree Creek juvenile Coho Sampling site (SAM-BS06) on September 20, 2017.

2.1.3.2. Data Analysis

Biomass Estimates

The weighted mean mass (g/fish, $\widehat{m}_j$) was calculated for each age class (0+, 1+ and 2+) at each site as:

$$\widehat{m}_j = \frac{\sum_{i_{min}}^{i_{max}} (n_{i,j} \cdot \bar{m}_{i,j})}{N_j}$$

where i_{max} is the maximum fork length (±1 mm) measured at a site, i_{min} is the minimum fork length (±1 mm) measured at a site, n_i is the number of fish recorded in size bin *i* for age class *j*, $\bar{m}_i$ is mean mass of fish in size bin *i* for age class *j* and N_j is the total number of fish caught at a site in age class *j*.

A total weighted mean mass (g/fish, $\widehat{M}$) at each site was calculated as:

$$\widehat{M} = \frac{\sum_{0+}^{2+} (\widehat{m}_j \cdot N_j)}{N}$$

where *N* is the total number of fish caught at a site.

Total juvenile Coho Salmon abundance ($\widehat{N}$) was estimated at each site using DFO's standard capture efficiency model for analyzing multiple pass removal data. Total biomass at each site (g/m^2) was subsequently estimated as:

$$Biomass = \frac{\widehat{N} \cdot \widehat{M}}{Area_{>0.1\,m}}$$

where $Area_{>0.1\,m}$ is the area (m^2) of the site with depth > 0.1 m.

Multiple-Year Comparisons

The estimated total biomass of juvenile Coho Salmon (g/m^2) in all of the sampled sites from 2008 to 2017 was compared among sites and years to identify changes in abundance over the ten-year period. The data collected from 2008 to 2013 (pre-JHTMON-8) were analyzed and quality assured by DFO, with no additional QA undertaken. Biomass of 0+ fry and 1+ parr was calculated using the actual catch data (n) instead of a population estimate ($\widehat{N}$), according to the previous DFO methodology. Biomass estimates for 1+ parr were not calculated before JHTMON-8 (2014) and 0+ biomass was not calculated before 2011.

2.1.4. Salmon and Quinsam River Salmon Escapement

Annual salmon spawner escapement counts have been undertaken on the Salmon and Quinsam rivers since the 1950s by DFO and its predecessors. Although these data are collected as part of wider salmon stock assessment work, they provide an important source of data to support the JHTMON-8 study. The results of summer and fall 2017 surveys were finalized during Year 5. These were obtained from DFO's New Salmon Escapement Database (nuSEDS) and are reported here alongside results from previous years. Data for the Quinsam River will support analysis scheduled for later during

JHTMON-8 to examine relationships between abundance of adult spawning fish and corresponding counts of juvenile fish in successive years.

Methods used in the 2017 surveys are summarized in Table 11 and Table 12 for the Salmon and Quinsam rivers respectively, based on information provided in the nuSEDS database (DFO 2018). Methods undertaken in previous years of JHTMON-8 are summarized in previous annual reports. Surveys of individual species conducted by DFO conform to one of six estimate classification types, ranging from Type-1 (most rigorous, almost every fish counted individually) to Type-6 (least rigorous, determination of presence/absence only). The estimate classification types are reported in the two tables of methods, with further general details about survey types provided in Table 13.

Table 11. Methods used during 2017 salmon spawner escapement counts on the Salmon River (DFO 2018). See Table 13 for descriptions of survey types.

	Salmon species				
	Chinook	Chum	Coho	Pink	Sockeye
Estimate classification	4	4	4	4	4
Number of surveys	18	18	12	12	0
Date of first inspection	Jul-14	Jul-14	Jul-14	Jul-21	Not Inspected
Date of last inspection	Oct-27	Oct-27	Oct-27	Oct-27	Not Inspected
Estimation method	Area under the curve	Peak live and dead	Area under the curve	Area under the curve	Peak live and dead

Table 12. Methods used during 2017 salmon spawner escapement counts on the Quinsam River (DFO 2018). See Table 13 for descriptions of estimate classes.

	Salmon species				
	Chinook	Chum	Coho	Pink	Sockeye
Estimate classification	2	3	2	2	3
Number of surveys	Unknown	Unknown	Unknown	Unknown	Unknown
Date of first inspection	Aug-08	Sep-01	Aug-13	Aug-01	Aug-02
Date of last inspection	Nov-30	Dec-15	Dec-15	Nov-03	Dec-15
Estimation method	Mark and recap.	Fixed site census	Fixed site census	Fixed site census	Fixed site census

Table 13. Summary of definitions of salmon spawner escapement estimate classification types reported in Table 11 and Table 12 (DFO 2018).

Estimate Classification Type	Abundance Estimate Type	Resolution	Analytical methods	Reliability (within stock comparisons)	Units	Accuracy	Precision
1	True	High resolution survey method(s): total, seasonal counts through fence or fishway with virtually no bypass	Simple	Reliable resolution of between year differences >10% (in absolute units)	Absolute abundance	Actual or assigned estimate; high	± 0%
2	True	High resolution survey method(s): high effort (5 or more trips), standard methods (e.g. equal effort surveys executed by walk, swim, overflight, etc.)	Simple to complex multi-step, but always rigorous	Reliable resolution of between year differences >25% (in absolute units)	Absolute abundance	Actual or assigned estimate; high	Actual estimate; high to moderate
3	Relative	Medium resolution survey method(s): high effort (5 or more trips), standard methods (e.g. mark-recapture, serial counts for area under curve, etc.)	Simple to complex multi-step, but always rigorous	Reliable resolution of between year differences >25% (in absolute units)	Relative abundance linked to method	Assigned range; medium to high	Assigned estimate; medium to high
4	Relative	Medium resolution survey method(s): low to moderate effort (1-4 trips), known survey method	Simple analysis by known methods	Reliable resolution of between year differences >200% (in relative units)	Relative abundance linked to method	Unknown; assumed fairly constant	Unknown; assumed fairly constant
5	Relative	Low resolution survey method(s): low effort (e.g. 1 trip), use of vaguely defined, inconsistent or poorly executed methods.	Unknown to ill defined inconsistent or poorly executed	Uncertain numeric comparisons, but high reliability for presence or absence	Relative abundance, but vague or no i.d. on method	Unknown; assumed highly variable	Unknown; assumed highly variable
6	Presence or absence	Any of above	N/A	Moderate to high reliability for presence/absence	Present or absent	Medium to high	Unknown

2.1.5. Quinsam River Hatchery Salmon Counting Fence Operations

2.1.5.1. Juvenile Outmigration Monitoring in Year 5

During spring of each year of JHTMON-8, technical staff provided by LKT worked under the instruction of DFO hatchery staff to enumerate fish at the Quinsam River Hatchery salmon counting fence. Each year, monitoring has been undertaken from March (range of start dates: March 11 to March 23) to mid June (range of end dates: June 9 to June 18). The methods described below for Year 5 are consistent with methods undertaken during previous years of JHTMON-8 (based on Ewart and Kerr 2014). Specific details for Year 5 (e.g., start/end dates, dates of mark-recapture studies) are based on information provided by the hatchery Enhancement Technician (Fortkamp, pers. comm. 2018); readers should consult previous annual reports for these details for previous years. Each year, data were collated, and quality assured by Quinsam River Hatchery.

The age of juvenile fish captured at the fence varies by species, reflecting differences in life histories. Coho Salmon, Cutthroat Trout, and steelhead are captured at the fence at the smolt stage and Chinook Salmon, Pink Salmon, and Chum Salmon at the fry stage. Pink Salmon and Chum Salmon emigrate from the river immediately or soon after emergence (Burt 2003). In the Quinsam River, Chinook Salmon migration from the rivers occurs either soon after emergence or a few months later. Those

Chinook Salmon that rear for a full summer and winter before smolting are believed to do so in the estuary (Burt 2003). The strategies adopted by steelhead, Cutthroat Trout and Coho Salmon are more variable, and emigration from the river varies from migrating during the first spring to emigrating three years after emergence.

In Year 5, sampling was undertaken from March 13 to June 18, 2018. Fish were caught using inclined plane traps (Wolf traps) that capture a proportion of the fish that migrate downstream through the fence, with the aim to capture salmonid fry and smolts as they out-migrate to the ocean (Figure 4). Traps were deployed continuously during the sampling period. Three traps are consistently used, but the number of openings varied during the sampling period. During the period of Pink Salmon fry migration, 16 openings were typically fished, while during the period of smolt migration five openings were fished (Forktamp, pers. comm. 2018). Pink Salmon fry typically migrate at night and therefore traps were set overnight from approximately 15:00 to 09:00 during sampling in March 13 to April 29. For the remainder of the sampling period, traps were set constantly during the times when fish were not being processed. Target species during this time were: steelhead (kelts and smolts), Coho Salmon (smolts), Chinook Salmon (fry), Chum Salmon (fry), Sockeye Salmon (fry), Cutthroat Trout (kelts and smolts) and Dolly Varden (smolts).

Total downstream migration estimates for individual species and life stages were calculated by dividing fish capture numbers by life stage specific (i.e., fry and smolt) capture efficiency coefficients. The capture efficiency coefficients were derived from mark-recapture studies in the Quinsam River. For Pink Salmon fry, capture efficiency was estimated based on the results of releases of wild fish marked with Bismarck brown dye. The fish were captured in the trap, marked with the dye, and released approximately 350 m upstream of the fence. A total of five releases were undertaken on March 23, March 27, April 4, April 16, and April 19; a total of 21,852 fish were released (3,675–5,010 per experiment). Capture efficiency coefficients were calculated for each experiment and the highest coefficient (0.024) was then used to estimate the abundance of Pink Salmon fry, and also to estimate the abundance of other species captured during the Pink Salmon fry trapping period (i.e., Sockeye Salmon, Chum Salmon, Chinook Salmon, Coho Salmon, steelhead, Cutthroat Trout, trout species, lamprey, and sculpin). Capture efficiency was calculated as k/K (where k is the number of marked fish recaptured and K is the total number of fish marked in the study).

Separate catch efficiency estimates were derived for Coho Salmon smolts based on two releases of wild Coho Salmon smolts marked with pelvic fin clips (alternating between right and left between experiments). As for fry, smolts were captured in the traps and released upstream of the traps. Releases were undertaken on May 7 (445 fish) and May 14 (441 fish), with a total of 886 fish released. Separate capture efficiency coefficients were calculated for each experiment and the highest coefficient (0.081) was used to estimate abundance of Coho Salmon smolts, as well as those of other species caught after April 30 (i.e., Pink Salmon, Chum Salmon, Chinook Salmon, Coho Salmon, steelhead, Cutthroat Trout, lamprey, and sculpin). Further details about the mark recapture methods are provided in Ewart and Kerr (2014).

For Coho Salmon and Chinook Salmon, separate counts were recorded for wild and 'colonized' smolts. Colonized refers to fish that were incubated at the hatchery and transplanted to the upper Quinsam River watershed as fry. All transplanted Coho Salmon were marked with an adipose fin clip. The abundance of colonized Coho Salmon and Chinook Salmon were estimated following the same protocol, and assuming equal catchabilities as wild fish.

Quinsam Hatchery staff have outplanted salmon fry during each year of JHTMON-8 (in addition to previous years; Table 14). During 2010 and 2011, approximately 100,000 Coho Salmon fry were released; during 2014-2017 approximately 150,000 Coho Salmon fry were released in the Upper Quinsam Lake. Chinook Salmon fry were released in the Lower Quinsam Lake in 2015 for the first time in 10 years; during 2015, 2017, and 2018 approximately 200,000 fry were released, while ~150,000 Chinook Salmon fry were released in 2016 (Table 14). These releases will be considered in the final JHTMON-8 analysis (see Section 4).

Figure 4. LKT technician undertaking a mark recapture study at Quinsam Hatchery salmon counting fence, June 2019.

Table 14. Number and dates of release of Coho and Chinook Salmon fry in the Quinsam watershed.

Species	Life Stage	Waterbody	Year	Date of release	Number released
Coho Salmon	Fry	Upper Quinsam River	2017	May 23-June 6	139,570
			2016	May 30-June1	146,547
			2015	Apr 29 - May 20	167,030
			2014	June 9 - June 13	157,661
Chinook Salmon	Fry	Lower Quinsam Lake	2018	May 7-May 8	215,952
			2017	May 9-unknown day in May	207,319
			2016	May12 - May 13	147,549
			2015	May 11 - May 12	217,603

2.1.5.2. Review of Historical Data

An Ecofish technical staff member visited the Quinsam River Hatchery in April 2018 and obtained all available historical records of juvenile outmigration monitoring. These data were in a mixture of paper and digital files. All paper files were photographed, and later digitized. Quality assurance/control procedures were followed, which involved an independent review by a second person. The data were secured at Ecofish's secure online database.

Abundance estimates by year and species were estimated by Fisheries and Oceans Canada personnel following protocols outlined in Section 2.1.5.1. Capture efficiency coefficients were estimated by year. In at least one case (2004), when no mark-recapture experiment for fry was carried out, coefficients for smolts were used in the calculations.

For Pacific Salmon and trout species, the time series extended from 1974 to 2018. There are some temporal gaps in the time series, the longest from 1990 to 1995 for all salmonid species, and from 1982 to 1986 for Chinook salmon. Data for Dolly Varden, Lamprey and Sculpin were also secured; these are shorter and began in the late 1990s or early 2000s (depending on species).

In addition, data from some of the missing years in the hatchery data was available in Table 12 in Burt (2003). There was some overlap between data secured from the hatchery and that available in Burt (2003). In all cases, values were either identical or very similar. Therefore, the time series were extended by obtaining data from the report. This covers years 1990-1992 for all species, and 1986-1988 for wild Coho Salmon smolts, and 1980, 1983, and 1986 for colonized Coho Salmon smolts.

For some years, records specified the origin of fish, i.e. it contained the words "Colonized" or "Wild", while other records had no specification regarding origin. Following inspection of the compiled data files, it was determined that records with no qualifier were related to wild fish. These records were used to derive a time series of outmigrating wild fish abundance.

2.2. Weighted Usable Area (WUA) of Habitat (Quinsam River)

As described in Section 1.5.3, WUA metrics for the Quinsam River will be used to examine whether lack of habitat limits juvenile fish abundance to test H_02. In Year 5, we identified flow-habitat relationships that were previously developed for the Quinsam River and used these to calculate annual WUA metrics to use during analysis in Year 10. WUA metrics were calculated using available flow data for the period since 1974, which is the start of the period encompassed by the historical juvenile fish abundance dataset collected at the Quinsam River Hatchery salmon counting fence (Section 2.1.5.2). At the time of completing the analysis, quality assured flow data were available until the end of 2017 and therefore the period of analysis was 1974–2017.

Flow habitat relationships for the Quinsam River were obtained from unpublished data collected during a biophysical assessment of the Quinsam River (Solander *et al.* 2004). We used relationships that relate usable width to percent of mean annual discharge, which were calculated by Solander *et al.* (2004). These relationships had been used to develop the relationships that relate percent usable width to flow (Figures 14 and 15 in Solander *et al.* 2004) that were used during WUP development. The data are based on sampling conducted along transects in multiple reaches of the Quinsam River, and habitat suitability curves that were used during WUP development (see Solander *et al.* (2004) for further details of data collection methods). Relationships were developed for individual species and life stages; specifically, rearing habitat relationships were developed for Rainbow Trout/steelhead fry and parr, and spawning habitat relationships were developed for Chinook Salmon, Pink Salmon, Coho Salmon and steelhead.

Applying relationships to calculate WUA required flow data that related to the reaches used by the species and life stages of interest. For steelhead rearing habitat metrics, WUA was calculated separately for the full rearing period (which spans a full year in the Quinsam River; Table 4) and the critical stream flow period, which is the period of lowest flow during the growing season. Survival of stream rearing salmonids on Vancouver Island can be particularly sensitive to lack of rearing habitat due to low flows during the critical stream flow period (Ptolemy and Lewis 2002); based on review of flow data, the critical stream flow period for the Quinsam River was determined to be August.

We generally followed the scheme specified by Solander *et al.* (2004) to estimate flow in individual reaches based on flow measured at Water Survey of Canada gauges (Map 3). Flow in reach 1 was estimated for the period 1975 to 2017, based on measurements at gauge 08HD005 (Quinsam River at the Confluence with Campbell River; Map 3). We assumed the flow within reach 1 was consistent throughout the reach, which is simpler than the approach taken by Solander *et al.* (2004) who accounted for inputs of water (~0.85 m^3/s) that occur midway in the reach from either Cold Creek or the hatchery. We recognize that our assumption that flow remains continuous throughout reach 1 may reduce the accuracy of the annual estimates of WUA; however, the focus of the JHTMON-8 analysis is on examining *relative* changes in WUA among years and therefore we expect results to be insensitive to this issue. Flow in reaches 2–5 was estimated based on flow measurements at gauge 08HD0027 (Quinsam River below Lower Quinsam Lake; Map 3), although data were unavailable for the period

1975–1996 and therefore this gap in the time series was filled by undertaking a monthly ranked regression using data for the two hydrometric gauges for the overlapping period of record (1997–2017).

A total of seven WUA metrics were calculated (Table 15). WUA metrics were calculated as follows:

1. Species and life stage specific flow-habitat relationships were used to calculate usable width for each day based on flow in applicable reaches (Table 16). Mean flow in each reach group was estimated based on the scheme shown in Table 16, with mean flow prorated based on reach length where necessary.
2. Estimated usable width (m) was multiplied by reach length (m) to estimate WUA for each day in m^2.
3. Daily WUA estimates were screened to remove values outside of the relevant life history periods based on periodicity information for the Quinsam River (Table 4).

To calculate the metrics applicable to Coho Salmon and steelhead, we used flow data for reaches 1–5, whereas Solander *et al.* (2004) used estimated flow data for reaches 1–7 to develop the relationships. This difference reflects that, to estimate flow in reaches 5–7, Solander *et al.* (2004) modelled flow using flow data collected at transects in those reaches; however, we were unable to use these methods as flow data for the time series of interest were unavailable. Our approach to use flow data for reaches 1–5 is deemed appropriate because data collected at transects in reaches 1–5 and 6–7 indicate that flow-habitat relationships are consistent between the two areas of the river (based on comparing coloured symbols in Figure 15 of Solander *et al.* (2004)). Further, we recognize that the extent of habitat use by fish is expected to vary among reaches, particularly in the case of spawning habitats (Burt 2003). We therefore recognize that this will reduce the accuracy of the annual estimates of WUA presented here; however, as described above, the focus of the JHTMON-8 analysis is on examining relative changes in WUA among years, which means we expect the JHTMON-8 results will be insensitive to this issue. Further, we recognize that analysis may be confounded by fish passage improvements undertaken in the lower and middle river that improve the potential for adult fish to migrate upstream of physical barriers. Most significantly, improvements were undertaken at cascades in 2005 and 2015 (reviewed by Marriner *et al.* 2016); these are expected to have most affected fish passage conditions for Pink Salmon, although they are also relevant to JHTMON-8 priority species. During analysis in Year 10, we propose to examine whether there is a statistically significant change in juvenile fish production associated with these works and, if so, seek to account for this effect in the analysis (e.g., by including as a fixed effect in statistical models).

Table 15. Weighted Usable Area metrics calculated for the Quinsam River.

Species	Life stage	Habitat type	Reaches[1] used in JHTMON-8 analysis	Reaches sampled by Solander *et al*. (2004)
Chinook Salmon	Adult	Spawning	1 to 4	1 to 4
Coho Salmon	Adult	Spawning	1 to 5	1 to 7
Pink Salmon	Adult	Spawning	1 to 4	1 to 2
Steelhead	Adult	Spawning	1 to 5	1 to 7
Steelhead	Fry	Rearing	1 to 5	1 to 7
Steelhead	Parr	Rearing	1 to 5	1 to 7
Steelhead	Fry	Rearing (CSFP)	1 to 5	1 to 7
Steelhead	Parr	Rearing (CSFP)	1 to 5	1 to 7

[1] See Solander *et al*. (2004) for reach breaks. For reference, Reach 2 extends to falls and cascades immediately downstream of Lower Quinsam Lake; Reach 4 extends to Lower Quinsam Lake; Reach 5 extends to the Iron River confluence, and; Reach 7 extends to the outlet of Middle Quinsam Lake.

Table 16. Methods to estimate flow in reaches of the Quinsam River to calculate Weighted Usable Area of habitat.

Reach	Upstream extent	Method to estimate mean daily flow
1	10.43 km upstream of the mouth at downstream-most set of cascades	Assumed equal to WSC gauge 08HD005 (Quinsam River at the Confluence with Campbell River)
2–5	Lower Quinsam Lake outlet	Assumed equal to WSC gauge 08HD027 (Quinsam River below Lower Quinsam Lake)

2.3. Water Quality

2.3.1. Water Chemistry

2.3.1.1. Salmon River and Quinsam River Water Chemistry Monitoring

One water quality site was established in the Salmon River (SAM-WQ; Map 2) and one in the Quinsam River (QUN-WQ; Map 3) in 2014 (Year 1). Both sites were selected based on the guidelines of the British Columbia Field Sampling Manual (Clarke 2013) and the Ambient Fresh Water and Effluent Sampling Manual (RISC 2003). SAM-WQ was monitored from Year 1 (2014) to Year 4 (2017); QUN-WQ was monitored from Year 1 to Year 5, with monitoring scheduled to continue on the Quinsam River for the remainder of JHTMON-8.

SAM-WQ (Figure 5) was located downstream of the historical Salmon River Diversion Dam, in a run immediately downstream of a braided section of the river with sandy banks. QUN-WQ (Figure 6) is located ~950 m downstream of the confluence with the Iron River, and downstream of the Quinsam Coal Mine and the salmon carcass nutrient enhancement site. Coordinates, site elevation, and sampling dates (*in situ* and laboratory samples) for both sites are provided in Table 17.

Table 17. Water quality index site details and sampling dates, Years 1 to 5.

River	Site Name	UTM Coordinates (Zone 10)		Elevation (m)	Study Year	Dates
		E (m)	N (m)			
Salmon River	SAM-WQ	309308	5556385	172	1	21-May-14; 17-Jun-14; 23-Jul-14; 18-Aug-14; 23-Sep-14; 03-Nov-14
					2	13-May-15; 16-Jun-15; 22-Jul-15; 12-Aug-15; 17-Sep-15; 15-Oct-15
					3	17-May-16; 14-Jun-16; 12-Jul-16; 16-Aug-16; 13-Sep-16; 11-Oct-16
					4	9-May-17; 13-Jun-17; 11-Jul-17; 8-Aug-17; 12-Sep-17; 10-Oct-17
Quinsam River	QUN-WQ	327433	5534757	193	1	3-May-14; 18-Jun-14; 22-Jul-14; 19-Aug-14; 24-Sep-14; 04-Nov-14
					2	12-May-15; 17-Jun-15; 23-Jul-15; 13-Aug-15; 16-Sep-15; 14-Oct-15
					3	18-May-16, 15-Jun-16, 13-Jul-16; 17-Aug-16, 14-Sep-16; 12-Oct-16
					4	10-May-17; 14-Jun-17; 12-Jul-17; 9-Aug-17; 13-Sept-17; 11-Oct-17
					5	10-May-18; 05-Jun-18; 04-Jul-18; 09-Aug-18; 12-Sept-18; 05-Oct-18

Figure 5. Looking upstream to SAM-WQ on September 13, 2017.

Figure 6. Looking upstream to QUN-WQ on June 5, 2018.

Water quality was monitored during Year 1 through Year 4 at SAM-WQ and during Year 1 through Year 5 at QUN-WQ. Water quality was monitored six times on a monthly basis from May through

October during each year. During all years, standard methods according to the procedures set out in the Guidelines for Designing and Implementing a Water Quality Monitoring Program in British Columbia (RISC 1997a) were employed to collect samples and measure *in situ* water quality parameters. Water chemistry variables were chosen based on provincial standards (Lewis *et al.* 2004). The variables measured in Year 5 are presented in Table 18 (*in situ*) and Table 19 (laboratory). Total gas pressure (TGP) was not sampled after Year 1, based on a recommendation made in the Year 1 Annual Report (Abell *et al.* 2015b). Laboratory method detection limits (MDL) occasionally differed (Table 19) due to matrix effects in the sample, or variations in laboratory analytical instruments.

Table 18. Water quality variables measured *in situ* and meters used in Year 5.

Parameter	Unit	Meter
Water temperature	ºC	YSI Pro Plus, YSI 85
pH	pH units	YSI Pro Plus
Salinity	ppt	YSI Pro Plus, YSI 85
Conductivity	µS/cm	YSI Pro Plus, YSI 85
Specific conductivity	µS/cm	YSI Pro Plus, YSI 85
Oxidation reduction potential	mV	YSI Pro Plus, YSI 85
Dissolved oxygen	mg/L	YSI Pro Plus, YSI 85
Dissolved oxygen	% Saturation	YSI Pro Plus, YSI 85

Table 19. Variables analyzed in the laboratory by ALS Environmental and corresponding units and method detection limit (MDL).

Parameter	Unit	MDL
General Water Quality		
Specific conductivity	µS/cm	2
pH	pH	0.1
Total suspended solids	mg/L	1 to 3
Total dissolved solids	mg/L	10 to 20
Turbidity	NTU	0.1
Alkalinity, Total (as $CaCO_3$)	mg/L	1 to 2
Nutrients		
Ammonia (as N)	µg/L	5
Nitrate (as N)	µg/L	5
Nitrite (as N)	µg/L	1
Total phosphorus	µg/L	2
Orthophosphate	µg/L	1

2.3.1.2. Quality Assurance/Quality Control

In situ water quality meters were maintained and operated following manufacturer recommendations. Maintenance included calibration, cleaning, periodic replacement of components, and proper storage. Triplicate *in situ* readings were recorded from each meter at each site on each sampling date.

For samples collected for laboratory analysis, sampling procedures and assignment of detection limits were determined following the guidelines of the BC Field Sampling Manual (Clarke 2013) and the Ambient Fresh Water and Effluent Sampling Manual (RISC 2003). Duplicate samples were collected on each sampling date at each site.

In Year 5 one field blank and one trip blank were collected on May 10, 2018. Values for all parameters for both blanks were below the respective MDLs. Overall for the sampling program, the total number of QA/QC samples collected over five years (92 out of 146 samples, or 63%) exceeded guidelines; the BC field sampling manual recommends that 20% to 30% of samples consist of QA/QC samples (Clark 2013), while the RISC (1997a) manual recommends a minimum of 10% of samples consist of QA/QC samples.

Samples for laboratory analysis were collected in clean 500 mL plastic bottles provided by a certified laboratory. Samples were packaged in clean coolers that were filled with ice packs and couriered to ALS Environmental in Burnaby within 24 to 48 hours of collection. Standard Chain of Custody procedure was strictly followed. ALS Environmental performed in-house quality control checks including analysis of replicate aliquots, measurement of standard reference materials, and method blanks. A summary of the quality assurance/quality control (QA/QC) laboratory results is provided in Appendix A.

It is a common occurrence in Vancouver Island streams to have concentrations of a number of variables (notably nutrients) that are less than, or near to, the MDL. When this occurs, there are several different methods to analyze these values. In this report, any values that were less than the MDL were assigned the actual MDL values and averaged with the results of the other replicates. In these cases, the "real" average is less than the average reported.

2.3.1.3. Comparison with Guidelines for the Protection of Aquatic Life

Water quality guidelines for the protection of aquatic life (WQG-AL) and typical ranges of water quality variables in BC waters that were considered for this report are provided in Appendix A. Any results for water chemistry variables that approximated or exceeded WQG-AL, or ranges typical for BC, are noted in Section 3.3.2.

For most water quality variables measured in this study, there are provincial WQG-AL. For total phosphorus, there are no provincial WQG-AL; however, there are federal guidelines (CCME 2004). For the remaining variables without provincial WQG-AL (i.e., orthophosphate, alkalinity, and specific conductivity) there are no federal guidelines either.

2.3.2. Water and Air Temperature

2.3.2.1. Salmon River and Quinsam River Temperature Monitoring

Water and air temperature monitoring was completed in Year 5 for the Quinsam River. Water temperature data have now been collected at the water quality index sites for the period May 2014 to October 2017 for the Salmon River and May 2014 to October 2018 for the Quinsam River. Air temperature has also been measured near-continuously throughout these periods.

Water temperature was recorded at intervals of 15 minutes using self-contained TidbiT v2 loggers (Onset, MA, USA). These TidbiT loggers had an operating range of -20°C to +70°C with an accuracy of ±0.2°C and have a resolution of 0.02°C. For most of the record duration, water temperature at each of the monitoring stations was logged using duplicate TidbiT loggers installed on separate anchors. This redundancy is intended to prevent gaps in the data if one of the loggers malfunctions or is lost; however, both TidbiT loggers were lost at SAM-WQ during high flows in late October 2014, and monitoring did not resume until May 2015.

Air temperature was measured using one HOBO Air Temperature U23 Data Logger (range of -40°C to 70°C, accuracy of ±0.21°C) at each water quality index site. The temperature loggers recorded air temperature at a regular interval of 15 minutes. The loggers were placed on trees that were close (< 100 m) to each site.

2.3.2.2. Data Analysis

Water temperature data were analyzed as follows. First, erroneous data were identified and removed. Sources of erroneous data include occasional drops in water level which can expose the sensors to the atmosphere, and high flows which can move sediment and bury the sensors. Second, the records from duplicate loggers (when available) were averaged and records from different download dates were combined into a single time-series for each monitoring station. The time series for all stations were then interpolated to a regular interval of 15 minutes, starting at the full hour.

Time series of water and air temperature data were plotted at 15-minute intervals; the hourly rates of change in water temperature were also plotted. Analysis of the water temperature data involved computing a range of summary statistics (Table 20) that were chosen based on the provincial WQG-AL (Oliver and Fidler 2001; Table 21). The following statistics were computed: mean, minimum, and maximum water temperatures for each month of the record; hourly rate of change of temperature; days with mean daily temperature >18°C, >20°C, and <1°C; the length of the growing season, and; the accumulated degree days in the growing season. The number of degree days in the growing season was not calculated for all years in the Salmon River due to a lack of temperature data for the start and end dates of the growing season (data were downloaded in October) as well as due to gaps in records (as mentioned above). Statistics were based on the data collected at, or interpolated to, intervals of 15 min.

Mean weekly maximum temperatures (MWMxT) were calculated for both datasets and compared to optimum temperature ranges for different fish species and their life stages as outlined in the provincial

WQG-AL (Oliver and Fidler 2001). The software used to calculate water and air temperature statistics was changed between Year 4 and 5. This resulted in small changes to some statistics; e.g., changes that could only be identified when numbers were expressed to one or more decimal places and likely reflected differences in how numbers were rounded during calculations. These differences were reviewed and found to be biologically insignificant.

Table 20. Parameters calculated based on water and air temperature data.

Parameter	Description	Method of Calculation
Monthly water- and air- temperature statistics	Average, minimum, and maximum temperatures on a monthly basis	Calculated from temperatures observed at or interpolated to 15-min intervals.
Rate of water temperature change	Hourly rate of change in water temperature	Calculated from temperatures observed at or interpolated to 15-min intervals. The hourly rate of cahange was set to the difference between temperature data points that are separated by one hour and was assigned to the avarage time for these data points.
Degree days in growing season	The beginning of the growing season is defined as the beginning of the first week that average stream temperatures exceed and remain above 5°C; the end of the growing season is defined as the last day of the first week that average stream temperature dropped below 4°C (as per Coleman and Fausch 2007).	Daily average water temperatures were summed over this period (i.e., from the first day of the first week when weekly average temperatures reached and remained above 5°C until the last day of the first week when weekly average temperature dropped below 4°C)
Number of days with extreme daily-mean temperature	>18°C , >20°C , and <1°C	Total number of days with daily-mean water temperature >18°C , >20°C , and <1°C
MWMxT	Mean Weekly Maximum Temperature	A 1-week moving-average filter is applied to the record of daily-maximum water temperatures inferred from hourly data; e.g., if MWMxT = 15°C on August 1, 2008, this is the average of the daily-maximum water temperatures for the 7 days from July 29 to August 4. MWMxT is calculated for every day of the year.

Table 21. Water temperature guidelines for the protection of freshwater aquatic life (Oliver and Fidler 2001).

Category	Guideline
All Streams	the rate of temperature change in natural water bodies not to exceed 1°C/hr
Streams with Known Fish Presence	temperature metrics to be described by the mean weekly maximum temperature (MWMT)
	mean weekly maximum water temperatures should not exceed ±1°C beyond the optimum temperature range for each life history phase of the most sensitive salmonid species present
Streams with Bull Trout or Dolly Varden	maximum daily temperatures should not exceed 15°C
	maximum spawning temperature should not exceed 10°C
	preferred incubation temperatures should range from 2°C to 6°C
	±1°C change from natural condition[1]
Streams with Unknown Fish Presence	salmonid rearing temperatures not to exceed MWMT of 18°C
	maximum daily temperature not to exceed 19°C
	maximum temperature for salmonid incubation from June until August not to exceed 12°C

[1] provided natural conditions are within these guidelines, if they are not, natural conditions should not be altered (Deniseger, pers. comm. 2009).

2.4. Hydrology

The Water Survey of Canada measures discharge at multiple gauges on both study streams (Table 22). Available discharge data collected since the start of the study were plotted to evaluate flow conditions at the following sites downstream of the diversion facilities: 'Salmon R. above Memekay R.', 'Quinsam R. near Campbell R.' and 'Quinsam R. at Argonaut Bridge' sites (Table 22). To provide historical context, discharge was plotted alongside summary statistics (10th, 50th and 90th percentiles) for the periods of record. At the time of reporting, quality assured historical data were only available until the end of 2017 (Year 4).

In addition, several annual hydrological metrics were calculated for each study stream to quantify key flow characteristics that have potential to influence fish productivity (Table 23). The metrics quantify the occurrence of high flows during biologically sensitive periods of the year to support analysis to test $H_0 4$, which relates to floods (Section 1.5.5). For Pacific Salmon species (fall spawners), the maximum discharge during the incubation period was calculated based on the discharge measured between the start of incubation in fall the previous year, and the end of incubation during spring of the current year. Low flow metrics were also calculated for each stream to support analysis to test whether low summer flows affect the abundance of juvenile salmonids that rear in freshwater through the summer (Coho Salmon and steelhead). All metrics are based on a subset (Group 2) of the Indicators of Hydrologic Alteration (Richter *et al.* 1996) that were developed to quantify the magnitude and duration of hydrological extremes. Metrics were either calculated based on annual records of mean daily discharge (m^3/s), or using records for the spawning and incubation periods of specific fish species, based on fish periodicity information reported by Burt (2010; Salmon River) and Burt (2003; Quinsam River). Metrics were calculated using the Indicators of Hydrologic Alteration package developed for R (R Core Team 2016) by The Nature Conservancy. For the Salmon River, metrics were calculated based on discharge data collected at the gauge above Memekay River (08HD007); for the Quinsam River, metrics were calculated based on discharge data collected at the gauges at Argonaut Bridge (08HD021) and near the confluence with the Campbell River (08HD005).

Table 22. Hydrometric gauges maintained by Water Survey of Canada on the two study streams. See Map 2 and Map 3 for site locations.

Stream	Site Name	Site Code	Period of Record		Position Relative to Diversion
			Start	End	
Salmon River	Salmon R. above Campbell Lake Diversion	08HD015	1981	Ongoing	Upstream
	Salmon R. below Campbell Lake Diversion	08HD032	1981	Ongoing	Downstream
	Salmon R. above Memekay R.	08HD007	1960	Ongoing	Downstream
	Salmon R. near Sayward	08HD006	1965	Ongoing	Downstream
Quinsam River	Quinsam R. at Argonaut Bridge	08HD021	1993	Ongoing	Downstream
	Quinsam R. below Lower Quinsam Lake	08HD027	1997	Ongoing	Downstream
	Quinsam R. near Campbell R.	08HD005	1957	Ongoing	Downstream

Table 23. Hydrological metrics calculated for each study stream.

Stream	Hydrological Metric	Data Period
Salmon River	Max. discharge during Coho Salmon incubation	Oct 1–April 15
	Max. discharge during steelhead incubation	March 1–June 30
	1-day minimum discharge	Calendar year
	7-day minimum discharge	Calendar year
	30-day minimum discharge	Calendar year
Quinsam River	Max. discharge during Chinook Salmon incubation	Oct 15–April 30
	Max. discharge during Coho Salmon incubation	Oct 15–April 22
	Max. discharge during steelhead incubation	Feb 15–June 15
	Max. discharge during Pink Salmon incubation	Sep 15–April 8
	1-day minimum discharge	Calendar year
	7-day minimum discharge	Calendar year
	30-day minimum discharge	Calendar year

2.5. Invertebrate Drift

2.5.1. Sample Collection

One invertebrate drift sampling site was established on the Salmon River (Map 2, Figure 7) and one on the Quinsam River (Map 3, Figure 8), both located close (<150 m) to the water quality index sites. Site locations were consistent among years. Sites were located in riffle or run habitats, upstream of any obvious source of debris that could clog the nets or areas that receive frequent sediment disturbance. Invertebrate sampling was conducted on a monthly basis from May to October, with weekly sampling conducted during September in Year 5 (the month that is sampled weekly is rotated among study years to quantify the variance of monthly data). Following removal of the Salmon River Diversion in the summer of 2017 (Year 4), invertebrate monitoring was not undertaken on the Salmon River in Year 5. In total, sampling occurred on nine dates on each river in Years 1–4 and nine dates in the Quinsam River in Year 5 (Table 24).

Invertebrate drift sampling followed methods recommended in Hatfield *et al.* (2007) and Lewis *et al.* (2013). Upon arrival at site, local areas with velocities of approximately 0.2 to 0.4 m/s were identified with a model 2100 Swoffer meter with a 7.5 cm propeller and a 1.4 m top-set rod. This range of velocities is ideal for sampling invertebrate drift as velocities are slow enough to prevent clogging of the nets. Due to flow conditions at the time of sampling, it was not always possible to deploy the nets in areas with velocities of 0.2 m/s to 0.4 m/s (as per Hatfield *et al.* 2007), and nets sampled higher or lower water velocities at times.

Five drift nets were deployed simultaneously across the channel. The mouth of each drift net was positioned perpendicular to the direction of stream flow, and nets were spaced apart to ensure that each individual net did not obstruct flow into an adjacent net. The drift net mouth dimensions were 0.3 × 0.3 m and the nets (250 μm mesh) extended 1 m behind the mouth. Nets were anchored such that there was no sediment disturbance upstream of the net before and during deployment. All nets were deployed so that the top edge of the net was above the water surface so that invertebrate drift in the water column and on the water surface could be sampled.

At the start of sampling, measurements were made of water depth in each net and the water velocity at the midpoint of the water column that was being sampled by each net. These measurements were repeated hourly so that the volume of water sampled with each net could be calculated. Any large debris (e.g., leaves) that entered the nets was periodically removed from the nets (after it had been washed of any invertebrates, which were returned to the nets). Nets were deployed for approximately four hours on each sample date (Table 24). Once the nets were removed, the contents of all five nets were transferred into sample jars (500 mL plastic jars with screw top lids) for processing as a single sample in Years 2–5. This is a method change from Year 1 (2014), when contents of each net were processed separately. Samples were preserved in the field with a 10% solution of formalin (formalin = 37-40% formaldehyde).

Additional invertebrate samples were collected using kick net sampling during September in most years (sampling was not conducted in Year 1 and Year 3 due to logistical issues). In Year 5, kick net sampling was undertaken on September 12, 2018 at QUN-IV. The CABIN standardized sampling method was followed (MoE 2009), with a single drift net (described above) used as a kick net. This required one crew member to hold the net flush with the stream bed immediately downstream of a second crew member undertaking the sampling. Sampling proceeded upstream for a timed period of 10 minutes, covering a horizontal distance of approximately 10 m. During sampling, the sampler kicked the substrate to disturb it to a depth of 5–10 cm, while also turning over any large cobbles or small boulders to dislodge invertebrates. Once sampling was complete, the contents were sieved (250 µm mesh), transferred into sample jars, and preserved in the same manner as drift net samples.

Table 24. Invertebrate drift sample timing and sampling duration at the Quinsam River site (QUN-IV) during Year 5. See annual reports for details of sampling in previous years.

Sample Date	UTM Coordinate (Zone 10)		Start	Finish	Sampling
	Easting	Northing	Time[1]	Time[2]	Duration[3,4]
10-May-2018	309,304	5,556,468	06:57	10:57	4:00
05-Jun-2018	309,304	5,556,468	06:29	10:29	4:00
04-Jul-2018	309,304	5,556,468	06:30	10:30	4:00
09-Aug-2018	309,304	5,556,468	07:06	11:06	4:00
04-Sep-2018	309,304	5,556,468	07:30	11:30	4:00
12-Sep-2018	309,304	5,556,468	07:54	11:55	4:01
21-Sep-2018	309,304	5,556,468	08:03	12:03	4:00
26-Sep-2018	309,304	5,556,468	08:16	12:16	4:00
05-Oct-2018	309,304	5,556,468	08:25	12:25	4:00

[1] When the first net was set

[2] When the last net was removed

[3] The duration between retrieving the first and last net

[4] For data analysis, start and finish times for individual nets were used to calculate the volume of water filtered for each net

Figure 7. View upstream towards SAM-IV, July 11, 2017.

Figure 8. View across the stream from river right towards QUN-IV, July 4, 2018.

2.5.2. Laboratory Processing

Samples were sent to Ms. Dolecki of Invertebrates Unlimited in Vancouver, BC for processing. Ms. Dolecki is a taxonomist with Level II (genus) certification for Group 2 (Ephemeroptera, Plecoptera, and Trichoptera (EPT)) and for Chironomidae from the North American Benthological Society.

The drift and kick net samples were first processed by removing the formalin (pouring it through a 250 µm sieve), followed by immediate picking and identification of the very large and rare taxa. Samples were split into subsamples if the number of invertebrates was over 1,000. The invertebrates were enumerated using a Leica stereo-microscope with 6 to 8 × magnification, with additional examination of crucial body parts undertaken at higher magnifications (up to 400 ×) using an Olympus inverted microscope where necessary. Individuals from all samples were identified to the highest taxonomic resolution possible and it was noted whether a taxon was aquatic, semi-aquatic, or terrestrial. Life stages were also recorded.

Digitizing software (Zoobbiom v. 1.3; Hopcroft 1991) was used to measure the length of a sub-sample of individuals. Length measurements were then used to calculate average biomass (mg dry weight) of each taxon using standard length–weight regressions from the literature. The regressions were developed using un-preserved individuals and therefore the estimates are unaffected by reduction in biomass that can occur due to preservation in alcohol and subsequent drying of tissues inside carapaces (the length measurements are unaffected by preservation). This method is considered more accurate than weighing the invertebrates because it is not influenced by loss of biomass caused by preservation or the presence of debris and does not require invertebrates to be dried. For abundant taxa, up to 25 randomly chosen individuals per taxon were digitized to address the variability in size structure of the group. For the rare taxa, all individuals in the taxon were measured. The damaged or partial specimens were excluded from the measurements. For pupae and emerging Chironomidae, up to 50 individuals were measured.

To provide QA/QC, all the samples were re-picked a second time to calculate the accuracy of picking. This assured that > 90% accuracy was attained, and the accuracy of the methods employed is expected to be over 95%.

2.5.3. Data Analysis

Variables were chosen and calculated as per Lewis *et al.* (2013), and all taxa (aquatic, semi-aquatic, and terrestrial) were considered. Density (# of individuals) and biomass (mg dry weight) of each sample were expressed as units per m^3 of water, where volume is the amount of water that was filtered through a single net during a set. Volume filtered by each net was calculated based on the duration that the nets were deployed, and the average discharge measured at each net. During Years 2–5, the analysis was undertaken for each combined sample that included the contents of all five nets. For Year 1 (when net samples were not physically combined), data for each net were combined into site-level samples prior to calculating biodiversity metrics (family richness, Simpson's diversity) so that results were directly comparable with the results for Year 2–5. Family richness and Simpson's diversity are both standard metrics used to quantify invertebrate biodiversity. Change in these metrics may indicate change in the quality of food available to rearing fish.

Family richness (i.e., the number of families present) was calculated for each sample as a metric of biodiversity. Simpson's diversity index (1-λ, Simpson 1949) was calculated from family level density data to provide a measure that reflects both richness and the relative distribution or 'evenness' of invertebrate communities (i.e., higher Simpson's diversity index values denote communities that have high family richness, with the total number of individuals also evenly distributed among families). The index value ranges between 0 (no diversity) and 1 (a hypothetical scenario of infinite diversity). A Simpson's diversity index closer to 1 is associated with greater diversity and, thus, potentially greater food quality for fish.

The Canadian Ecological Flow Index (CEFI) was calculated using family level data for aquatic taxa following Armanini *et al.* (2011). Taxa present in <5% of the samples were not excluded from the CEFI calculation (Armanini, pers. comm. 2013). Relative abundances of taxa at each site were calculated considering only aquatic taxa, and only aquatic taxa used to develop the CEFI were considered when calculating the index. The top five families contributing to biomass at each site on each date were also identified.

PRIMER (Plymouth Routines in Multivariate Ecological Research) v. 6 software was used to generate a Bray-Curtis similarity matrix for samples collected from each study stream. The similarity matrix was generated from square-root-transformed density data for aquatic, semi-aquatic, and terrestrial taxa at the highest taxonomic resolution available for each taxon. The square root transformation down-weights the effect of the most abundant taxa, allowing for a better representation of the invertebrate community as a whole, rather than having similarity measures dominated by only the most abundant taxa. The similarity matrix was generated by calculating a similarity coefficient for all possible pairs of sample dates with respect to the taxonomic composition and abundance of different taxa on both sample dates.

The resulting Bray-Curtis similarity matrices were then examined using cluster analysis dendrograms in PRIMER to detect similarities among samples, to help assess temporal variation in invertebrate community composition by identifying potential seasonal and interannual trends that may affect the quality of food available to fish. Specifically, the clustering method used is a hierarchical clustering with group-average linking. The method takes a Bray-Curtis similarity matrix as a starting point and successively fuses the samples into groups, and the groups into larger clusters. The method starts with the highest mutual similarities, and then gradually lowers the similarity level at which groups are formed. The significance level for clustering was set at 5% using the SIMPROF tool in PRIMER (1000 permutations were used to calculate the mean similarity profile and 999 to generate the null distribution of the departure statistic). Further discussion of the cluster analysis can be found in Clarke and Warwick (2001) and Clarke and Gorley (2006).

The Bray-Curtis similarity matrices were also examined using non-metric, multi-dimensional scaling (MDS) ordination plots in PRIMER to detect trends in similarity among samples. MDS uses an algorithm that successively refines the positions of the points (samples) until they satisfy, as closely as possible, the dissimilarity between samples (Clarke and Warwick 2001). This algorithm was repeated

1,000 times for each similarity matrix (i.e., with density from each site on each date as samples). The result is a two-dimensional ordination plot in which points that are close together represent samples that are very similar in community composition with respect to the taxa present and their abundances. Conversely, points that are far apart represent samples with a very different community composition. Further discussion of the MDS analysis can be found in Clarke and Warwick (2001) and Clarke and Gorley (2006).

3. RESULTS

3.1. Fish Population Assessments

3.1.1. Salmon River Adult Steelhead Survey

All adult steelhead count data collected during JHTMON-8 and previous years are shown in Figure 9 (Lower Index), Figure 10 (Upper Index), and Figure 11 (Rock Creek Index), which are reproduced from the Year 4 Annual Report (Sharron *et al.* 2018) The dataset is longest for the Lower Index reach (Figure 9), which is the primary index reach for steelhead stock assessment on the Salmon River. Steelhead abundance measured during JHTMON-8 for the Lower Index reach was low; e.g., total counts (39–72 fish) were close to the 25^{th} percentile for the dataset (53 fish). The Lower Index reach is 11.5 km long (Map 2) and therefore the JHTMON-8 counts equated to densities of 3.4– 8.2 fish/km. The counts for the Lower Index reach were lower during the JHTMON-8 program relative to the previous eight years. We do not believe this decline reflects sampling error associated with the change in program as BCCF staff (Kevin Pellett) worked alongside LKT and Ecofish crew members in Year 1 to ensure consistency in methods.

Steelhead abundance measured for the Upper Index reach (Map 2) was also low during JHTMON-8; counts during the four years of JHTMON-8 ranged from 16–73 fish, whereas counts during the preceding six years ranged from 103–206 fish. The Upper Index reach is also 11.5 km long (Map 2) and therefore the JHTMON-8 counts equated to densities of 1.4–6.4 fish/km.

The Rock Creek index reach is the only index reach upstream of the historical site of the diversion dam (Map 2). Prior to JHTMON-8, the Rock Creek index reach was surveyed irregularly during seven years (Figure 11). During the four years of JHTMON-8, counts in the Rock Creek index reach ranged from 0–13 fish, with 0 fish recorded during 2017 (Year 4). As described in the Year 4 Annual Report (Sharron *et al.* 2018), neither low visibility nor poor survey timing were considered to contribute to the count of 0 fish that year. Adult steelhead abundance was therefore particularly low upstream of the diversion dam site in 2017, although juvenile steelhead (0+) observations in fall 2017 (Section 3.1.2) indicated that a low number of steelhead did successfully spawn above the diversion dam site that year. Prior to JHTMON-8, counts recorded during seven of the nine surveys ranged from 0–14 fish, with substantially higher counts (64 and 70 fish) measured during counts in April 2011 and 2013.

As noted in Section 2.1.1, snorkel surveys were not undertaken in Year 5 (2018) of JHTMON-8 and future snorkel surveys will not be undertaken as part of the JHTMON-8 program.

Figure 9. Historical and 2017 adult steelhead counts for the Lower Index reach, Salmon River. Absence of bars for some years indicates that no survey was conducted. Historical data (pre-JHTMON-8) from Pellett (2013). Dashed horizontal lines denote percentiles.

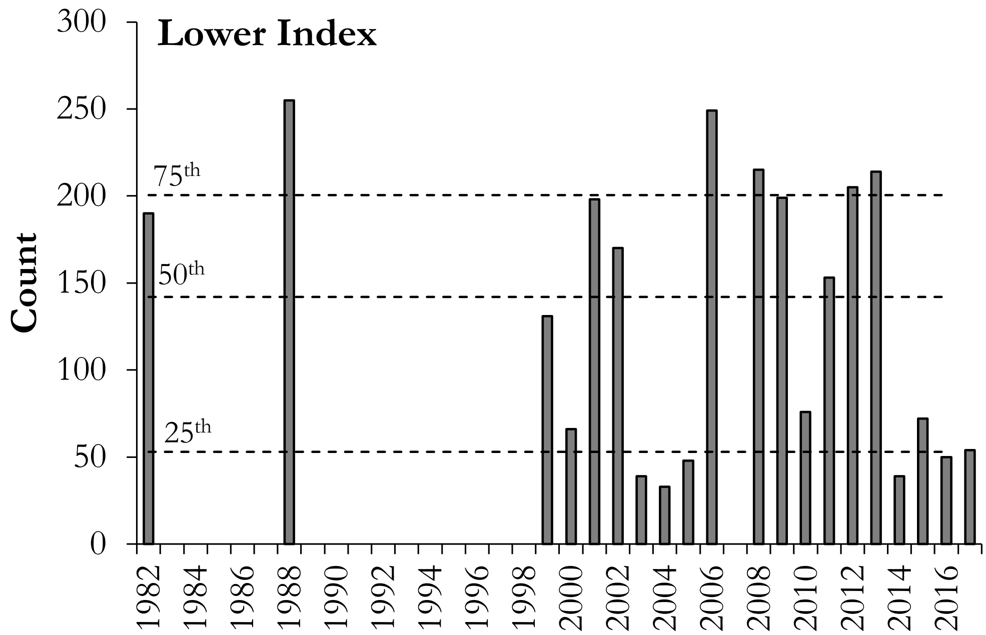


Figure 10. Historical and 2017 adult steelhead counts for the Upper Index reach, Salmon River. All data relate to surveys undertaken in April. Dashed horizontal lines denote percentiles.

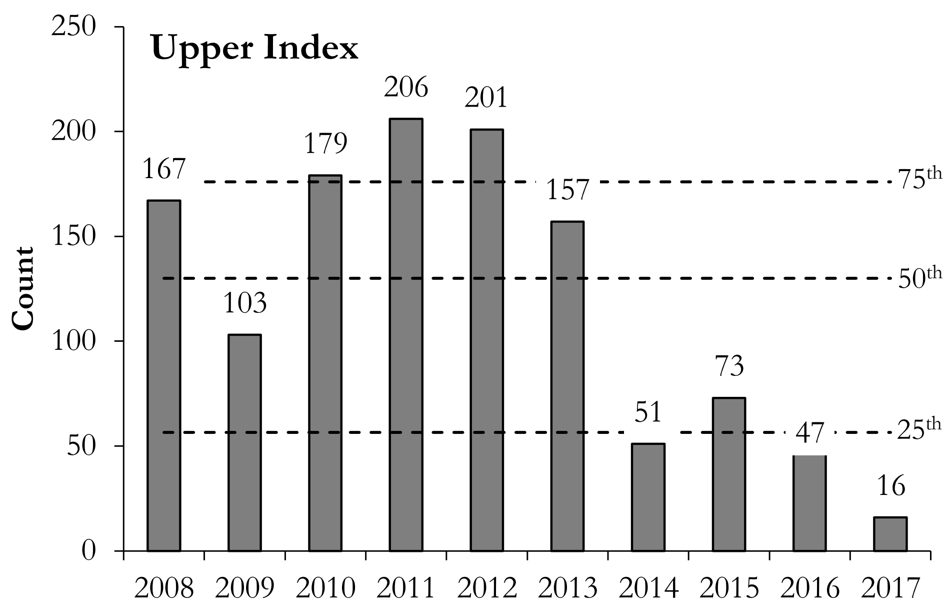
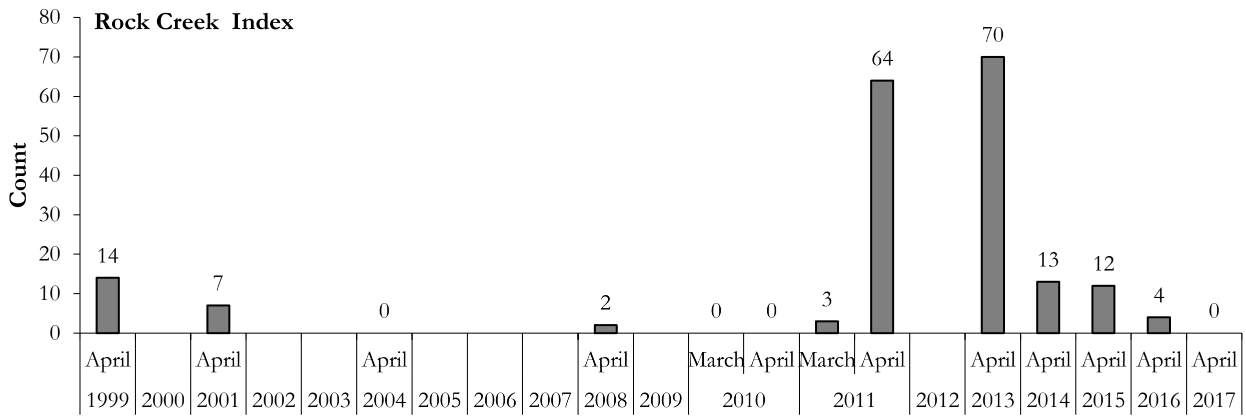


Figure 11. Historical and 2017 adult steelhead counts for the Rock Creek index reach, Salmon River. Absence of bars for some years indicates that no survey was conducted, unless labelled '0'. Pre-JHTMON-8 data from Pellett (2013).



3.1.2. Salmon River Juvenile Steelhead Abundance

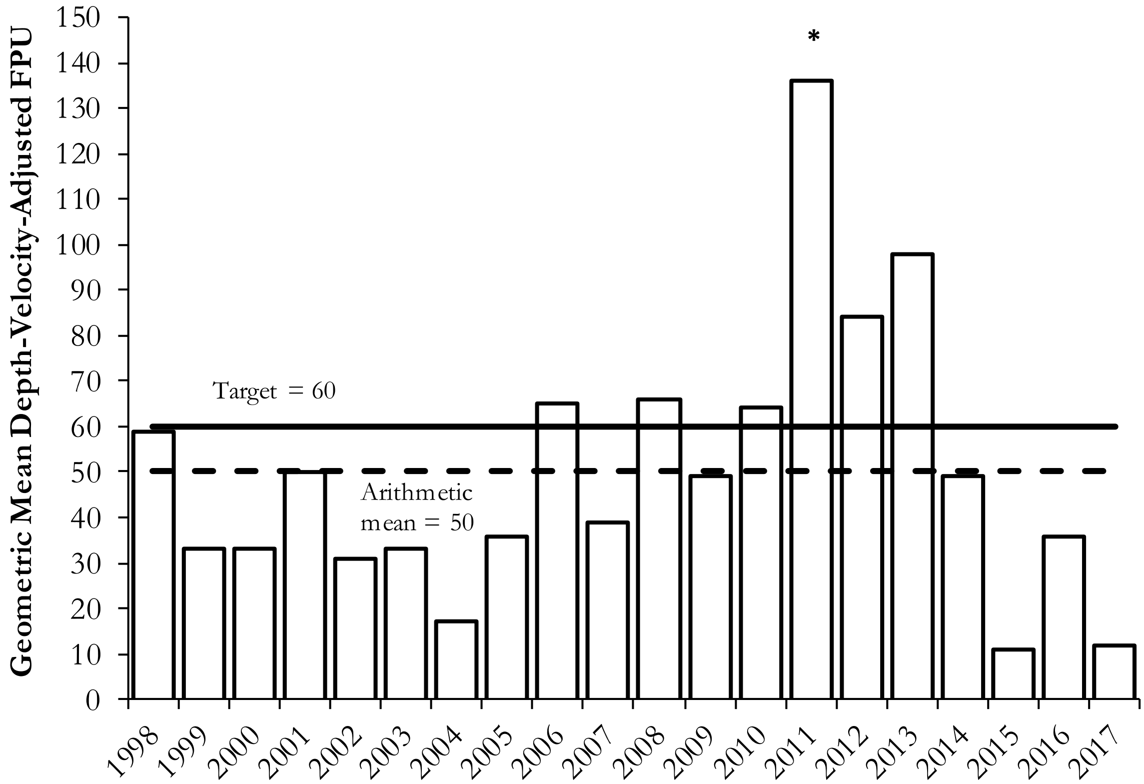
Geometric mean values are used here to compare results among years because these values are less sensitive to the influence of particularly low or high values than the arithmetic mean. The geometric mean values were calculated based on sampling at the 10 sites, with values standardized based on depth and velocity measured at each site. Over the four years of monitoring, the geometric mean juvenile steelhead abundance was consistently below the arithmetic mean for the period of record (1998–2017; 50 FPU) (Figure 12). The geometric mean values were also below the precautionary target of 60 FPU set for the watershed by provincial biologists, which was based on a predicted juvenile Rainbow Trout/steelhead capacity of 162 g/100 m^2 (Lill 2002) and assumes a mean fry weight of 2.7 g (Pellett 2014). The highest geometric mean value was measured in 2014 (Year 1; 49 FPU); the values measured in 2015 (Year 2; 11 FPU) and 2017 (Year 4; 12 FPU) were the two lowest values in the 20-year dataset.

Comparison of sites upstream and downstream of the diversion dam site (Figure 13) shows that geometric mean juvenile steelhead abundances measured in the two sections of the river were most similar in 2014 (Year 1; 45 FPU below diversion, 54 above diversion) and 2016 (Year 3; 33 FPU below diversion, 39 above diversion). In 2015 (Year 3) and 2017 (Year 4), the differences between the values for the two sections of the river were greater, with higher abundance measured downstream of the diversion dam site in both years.

Figure 14 shows geometric mean adjusted densities of steelhead fry compared with corresponding peak adult steelhead counts from the 11.5 km Lower Index reach on the Salmon River (Kay Creek to Pallans). The general positive relationship between the two variables throughout the range of the x-variable (i.e., no distinct "plateau") indicates that spawning and rearing habitats are not at carrying capacity, i.e., years with high peak adult density are associated with high fry density in the subsequent summer, indicating that habitats are not fully seeded. Figure 14 further highlights that both juvenile and adult (Section 3.1.1) steelhead abundances were low during JHTMON-8. The figure also suggests that 0+ steelhead survival during incubation and/or post emergence was lower in 2015 and 2017 than in 2014 and 2016.

Detailed information about sampling effort, fish size, fish age, and habitat characteristics at the 10 sites (e.g., site length, width, gradient, depth, substrate) are provided in previous annual reports.

Figure 12. Geometric mean depth-velocity-adjusted-abundance of steelhead fry (fry per unit, FPU) sampled in the Salmon River watershed in 1998–2017.



* Only sites upstream of the diversion dam were sampled in 2011

Figure 13. Geometric mean depth-velocity-adjusted juvenile steelhead (all age classes) fish per unit area (FPU) at sites upstream and downstream of the Salmon River Diversion, 1998–2017.

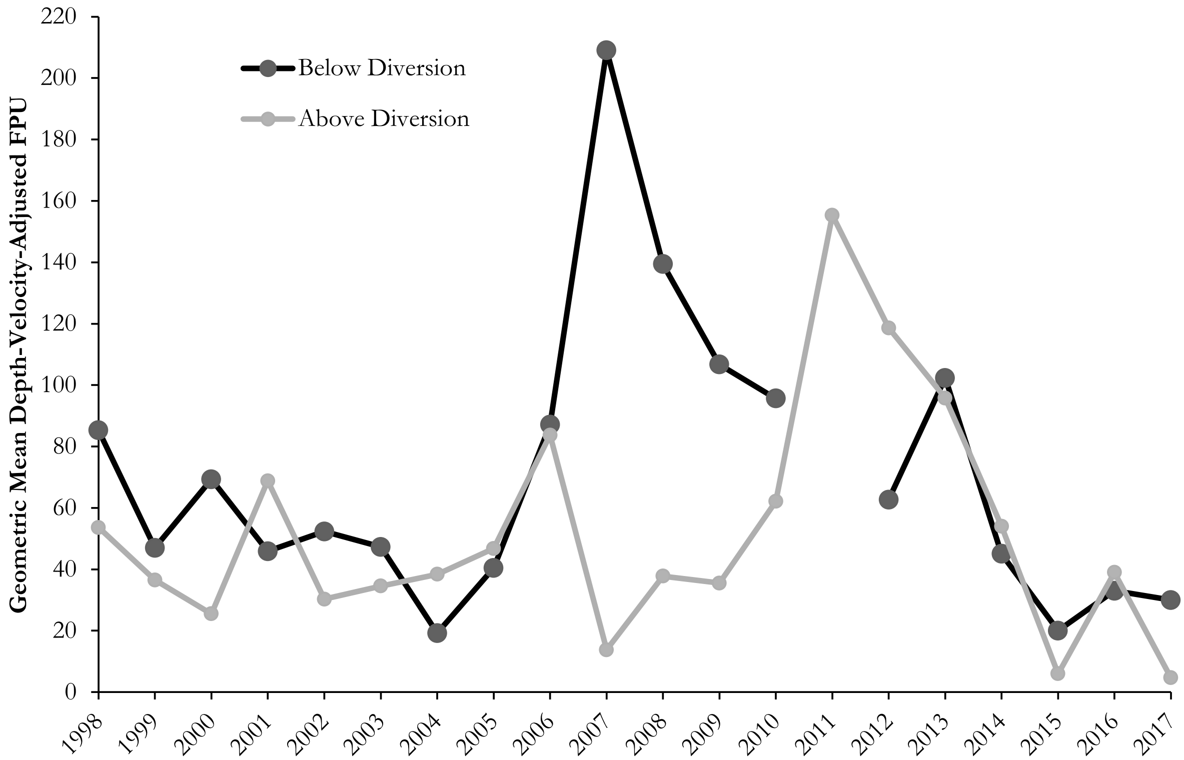
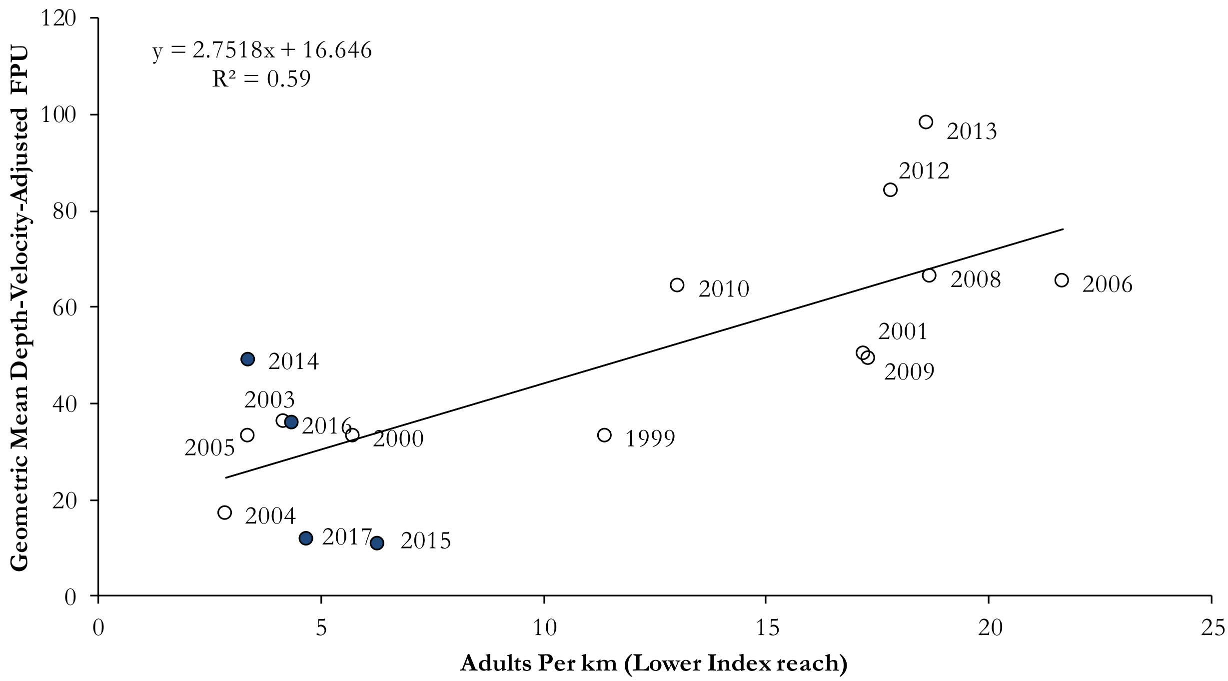


Figure 14. Geometric mean annual juvenile steelhead fish per unit (FPU) vs. adult steelhead counts in the Lower Index reach during the previous spring, Salmon River. Coloured symbols denote JHTMON-8 study years.



3.1.3. Salmon River Juvenile Coho Salmon Abundance

Juvenile Coho Salmon biomass was most variable at sites above the diversion (range of values: 0–7.09 g/m^2), compared with sites downstream of the diversion (range of values: 0.69–5.91 g/m^2; Table 25, Figure 15). No fish were captured at the Crowned Creek site, except for in 2009 when four Coho fry were captured. The overall average biomass estimates were similar among sites (1.94–2.85 g/m^2), with the exception of Crowned Creek (0.01 g/m^2; Table 25). Interannual variability in biomass at each site was high; e.g., there was at least a three-fold difference among years in average biomass at most sites (Figure 15).

When data were pooled separately for sites upstream and downstream of the diversion, average juvenile Coho Salmon biomass was more consistent among years at sites downstream of the diversion than at sites upstream of the diversion (Figure 16). Upstream of the diversion, average juvenile Coho Salmon biomass increased from 2008 (1.02 g/m^2) to 2014 (3.67 g/m^2; Year 1 of JHTMON-8), before declining to lower average values in 2015 to 2017 (0.55–0.81 g/m^2). This decline reflected low biomass at the two Grilse Creek sites, particularly SAM-BS03 in 2015 and 2017. This marked decline occurred in Year 2 of JHTMON-8; therefore, it cannot be attributed to differences in methods between the DFO-led and LKT-led programs.

The average biomass estimates for 0+ Coho Salmon below the Salmon River diversion were similar between 2011 and 2017 (Figure 17). At the sites upstream of the diversion, a similar decline in

0+ Coho biomass was observed in 2015 as for the total juvenile biomass (Figure 16). Coho Salmon aged 1+ were infrequently sampled and this age class was not consistently captured at each site, or during each year (Figure 18). This is reflective of the life history of Coho Salmon in the Salmon River, which typically out-migrate from the river during spring as one-year-old smolts (Burt 2010); i.e. several months before the sampling is undertaken in the fall. There was substantial variation in the average biomass of 1+ Coho Salmon at sites downstream of the diversion between 2011 and 2017 (Figure 18). No 1+ Coho were captured downstream of the diversion in 2016; upstream of the diversion, no 1+ Coho were captured from 2015–2017.

Table 25. Summary of the juvenile Coho Salmon biomass at the size sampling sites from 2008-2017.

Location Relative to Diversion	Stream	Site Name	Historic Name	Sampling Years	Juvenile Coho Biomass (g/m^2)		
					Min	Max	Avg
Upstream	Crowned Creek	SAM-BS01	Crowned	10	0.00	0.05	0.01
	Grilse Creek	SAM-BS02	G02	10	0.75	5.49	2.83
	Grilse Creek	SAM-BS03	Gmain	10	0.00	7.09	2.11
Downstream	Paterson Creek	SAM-BS04	Pater	10	1.02	5.14	2.85
	Marilou Creek	SAM-BS05	Mari	10	0.69	5.91	1.94
	Big Tree Creek	SAM-BS06	BTCKFlCh	8	1.17	4.42	2.77

Figure 15. Total estimated Juvenile Coho Salmon biomass for each site for all sampling years (2008-2017).

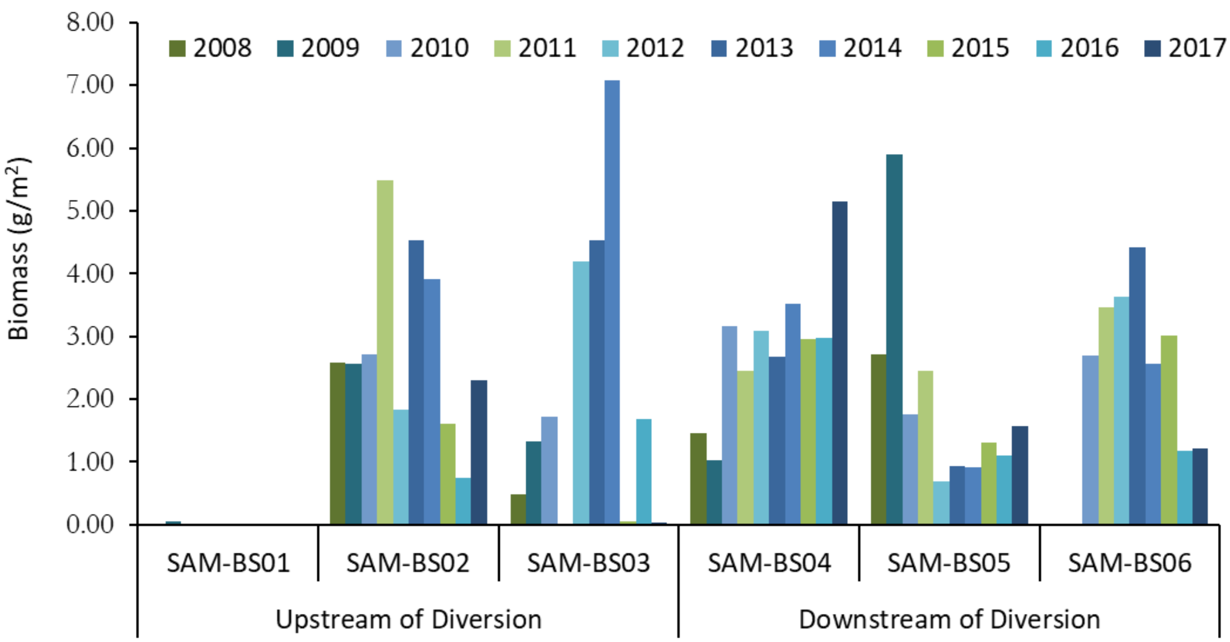


Figure 16. Average estimated Juvenile Coho Salmon biomass in sites above and below the Salmon River diversion for all sampling years (2008–2017). Vertical bars denote plus 1 standard error.

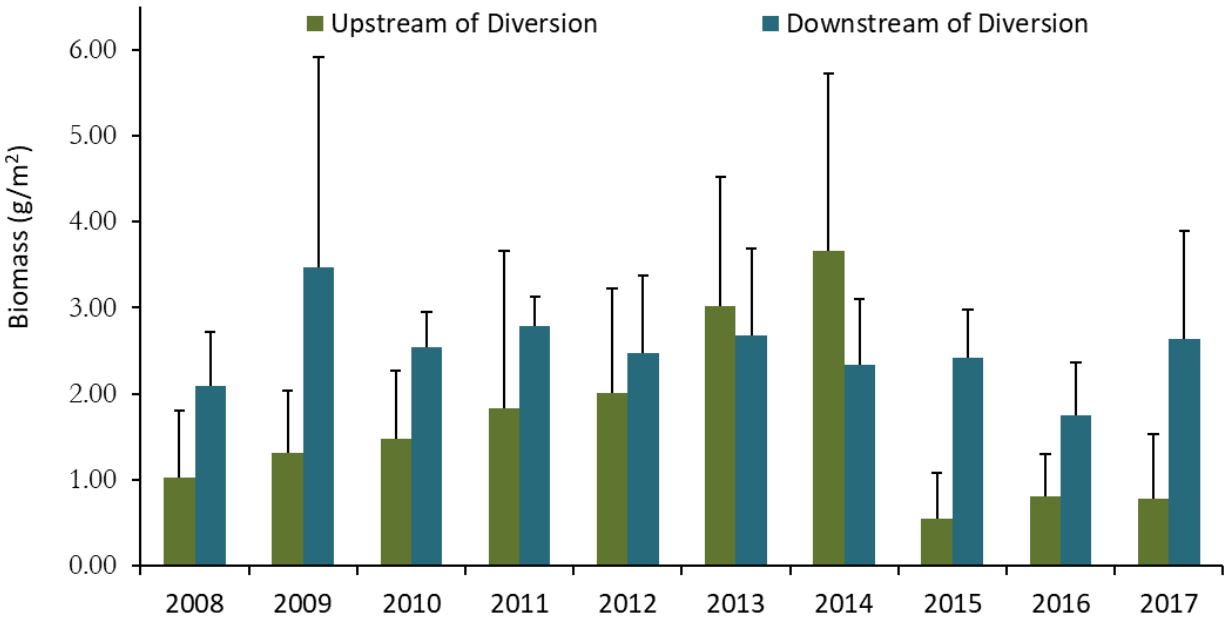


Figure 17. Average estimated 0+ Coho Salmon biomass in sites above and below the Salmon River diversion for all sampling years (2011–2017). Vertical bars denote plus 1 standard error.

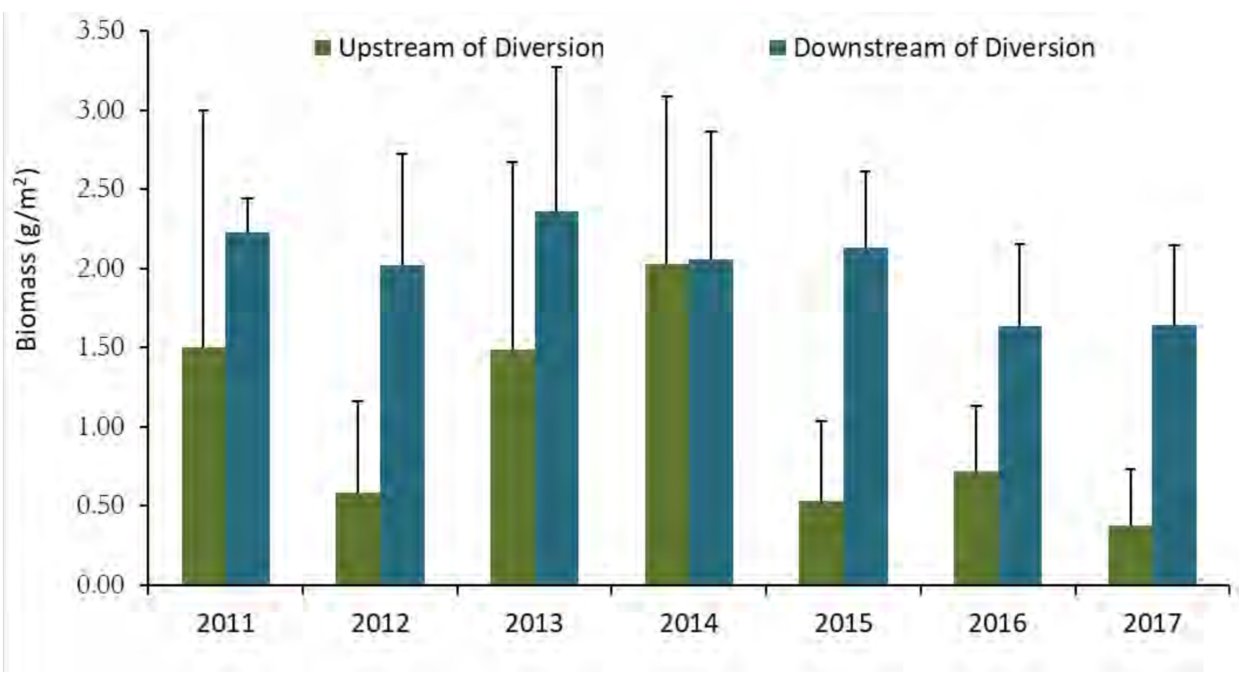
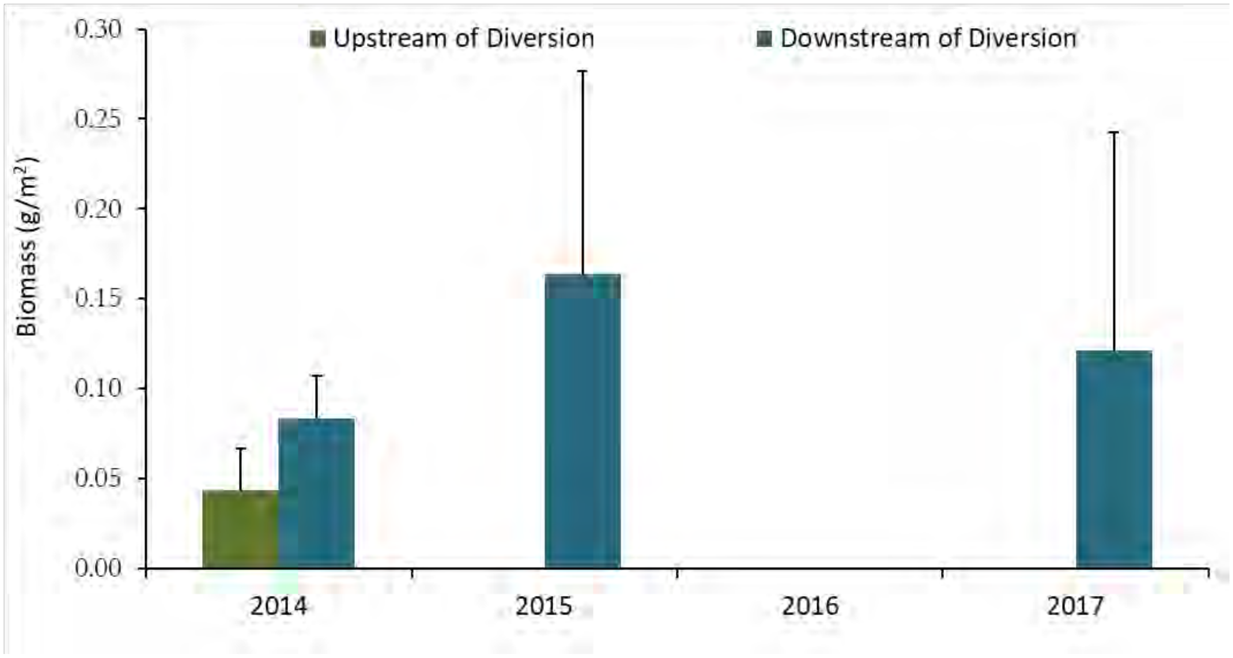


Figure 18. Average estimated 1+ Coho Salmon biomass in sites above and below the Salmon River diversion for all sampling years (2014–2017). Vertical bars denote plus 1 standard error.



3.1.4. Salmon River and Quinsam River Salmon Escapement, 2016

Salmon escapement data for 2017 (Year 4) for the Salmon and Quinsam rivers are presented in Table 26. Summary statistics for the period of record are also provided in this table to provide points of reference. Figure 19 and Figure 20 present salmon escapement data for the periods of record for the Salmon River and Quinsam River respectively. These plots include all available data for the JHTMON-8 study period.

Pink, Coho and Chinook salmon were the dominant returning species in 2017 (Table 26). In the Salmon River, the estimated escapement values of Pink, Coho and Chinook salmon in 2017 were each greater than the median (50th percentile) values for the period of record (1953–2017). Coho Salmon escapement in the Salmon River (6,156) was particularly high relative to historical counts, with the 10th highest count recorded in the 64-year dataset. Escapement of Chum Salmon and Sockeye Salmon in the Salmon River in 2017 was low for both species (2 and 5 fish, respectively). Chum Salmon low counts at least partly reflect that the last survey date (October 27; Table 11) was less than midway through the spawning period for this species, which spans from the start of October through mid December (Table 1). Estimated escapement of Sockeye Salmon in the Salmon River was 5 fish in 2017 and escapement of this species has been consistently low (90th percentile = 100 fish) throughout the period of record.

For the Quinsam River, escapement of Chinook Salmon in 2017 (9,131) was high, with the 6th highest count recorded in the 49-year dataset. Estimated values of escapement of Coho (5,865) and Chum

(50) salmon in 2017 were both less than the median (50th percentile) values for these species for the period of record (1953–2017). The estimated Chum Salmon escapement was particularly low, with the 5th lowest count recorded in the 58-year dataset. Unlike the Salmon River, survey timing did not seemingly contribute to this low count (the final inspection date was December 15; Table 12). Pink Salmon escapement in the Quinsam River in 2017 (110,101) was approximately equal to the mean value (130,278) for the period of record (1953–2017) and substantially exceeded the median (50th percentile) value (31,073) for the period of record. The estimated escapement of Sockeye Salmon in 2017 (17) was lower than the average and median values for the dataset.

The four years of available data for the JHTMON-8 study period show that Chinook Salmon escapement on the Salmon River has been relatively low during JHTMON-8, with the exception of 2017. Coho Salmon escapement has also been generally low on the Salmon River during JHTMON-8, although 2017 was again somewhat of an exception (Figure 19). Chum Salmon escapement on the Salmon River has been very low during JHTMON-8 (only detected in 2017), although there is uncertainty regarding this result due to the survey timing issue described above, which also applies to previous years of JHTMON-8. On the Quinsam River, the most notable result during JHTMON-8 was the occurrence of a record high Pink Salmon escapement (1.42 million) in Year 1 (2014). Chinook Salmon escapement in the Quinsam River increased steadily over the four years from 2,366 fish to 9,131 fish. By contrast, Coho Salmon escapement decreased steadily over the four years from 14,883 fish to 5,865 fish.

Table 26. 2017 salmon escapement data for the Salmon and Quinsam rivers (DFO 2018).

River	Statistic	Salmon species				
		Chinook[1]	Chum	Coho[1]	Pink	Sockeye
Salmon	2017 count	1,073	2	6,156	12,664	5
	Mean (1953-2017)	889	921	3,310	30,431	30
	Median (1953-2017)	736	400	2,000	7,608	2
	10th percentile (1953-2017)	200	0	288	1,380	0
	90th percentile (1953-2017)	1,500	3,100	7,500	85,257	100
	Percent of years sampled (1953-2017)[2]	95	94	98	100	55
Quinsam	2017 count	9,131	50	5,865	110,101	17
	Mean (1953-2017)	4,219	487	12,200	130,278	53
	Median(1953-2017)	3,356	281	9,007	31,073	25
	10th percentile (1953-2017)	25	66	1,500	1,500	7
	90th percentile (1953-2017)	9,461	1,500	32,384	428,437	133
	Percent of years sampled (1953-2017)[2]	80	95	98	98	75

[1] Priority species for JHTMON-8

[2] "Percent of years sampled" is approximate; uncertainty in data recording means that a count of zero is not always distinguished from a record of "not measured"

Figure 19. Salmon escapement for the Salmon River (1953–2016; DFO 2018).

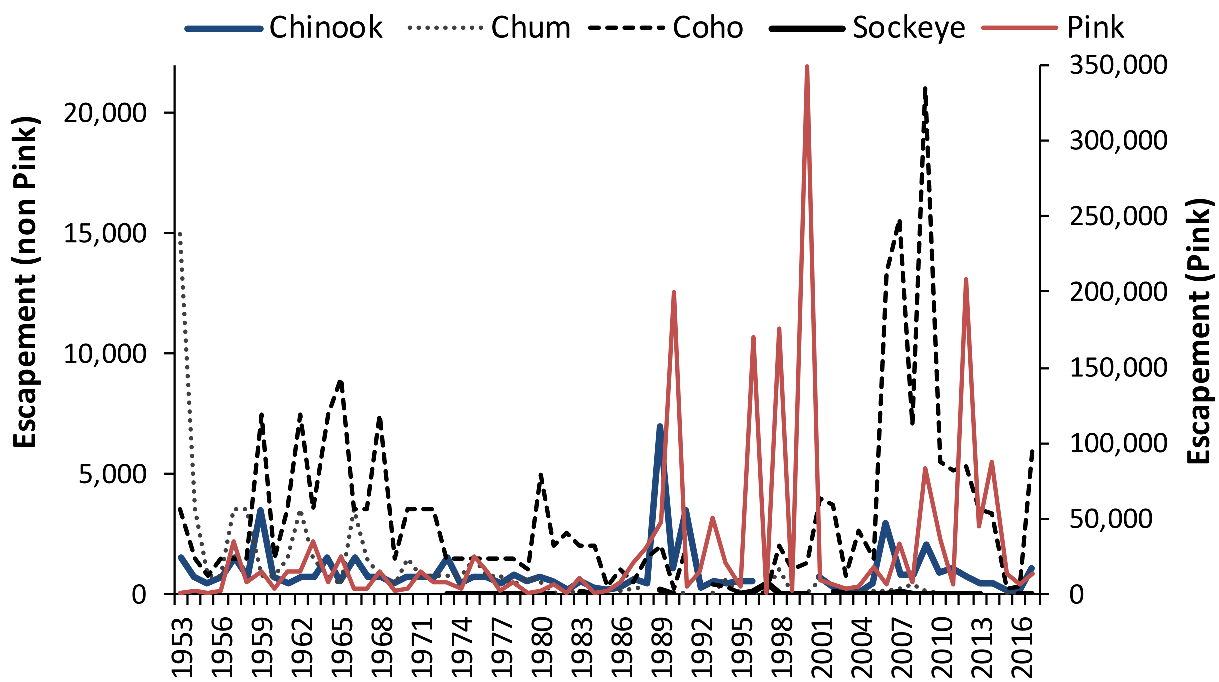
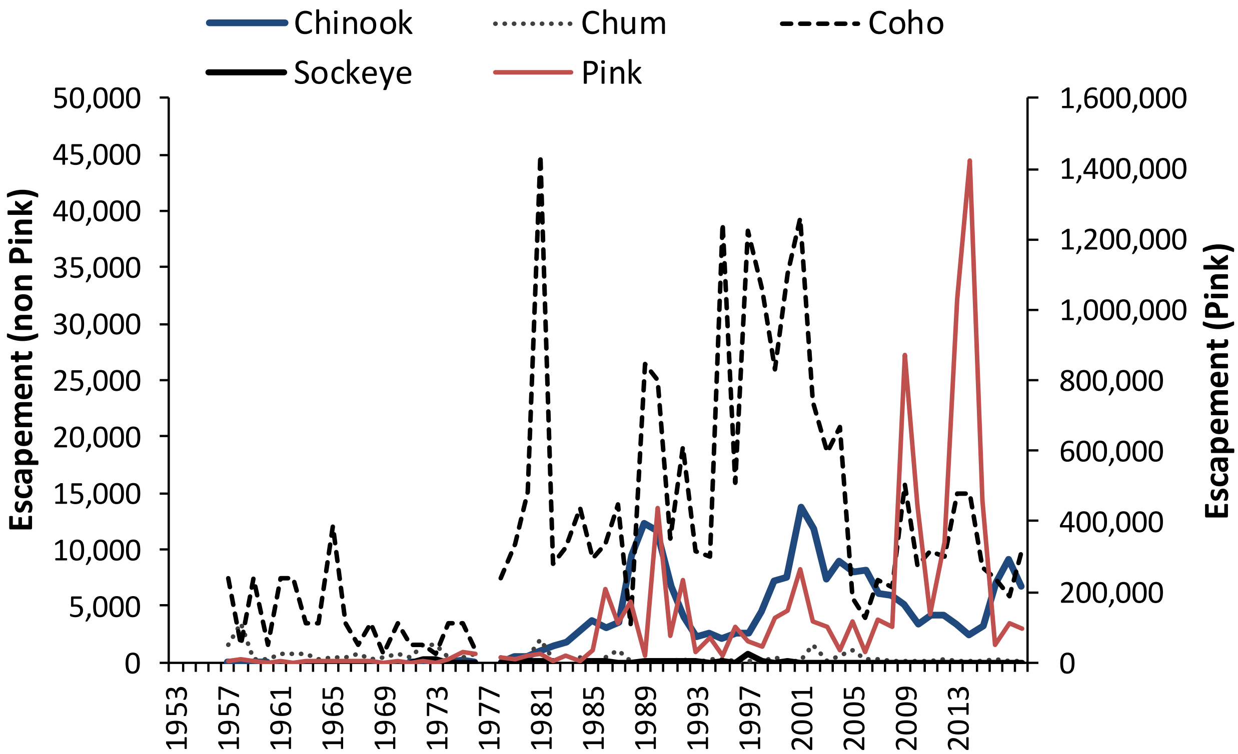


Figure 20. Salmon escapement for the Quinsam River (1957–2017; DFO 2018).



3.1.5. Quinsam River Hatchery Salmon Counting Fence Operations

3.1.5.1. Juvenile Outmigration Monitoring in Year 5

Data collected at the salmon counting fence are summarized in Table 27. The traps were monitored continuously from March 13 to June 18 and fish were sampled from the traps each day.

The monitoring period provided good coverage of the Pink Salmon fry migration period in 2018, although low numbers of fry were captured on the first day of sampling, suggesting that the migration period started slightly prior to March 13. The migration was largely complete by April 30 (only 99 Pink Salmon fry were captured after this date). Total estimated migration of Pink Salmon fry has been highly variable in the five years of the monitoring program and was 10.7 million in 2018 (Year 5) (Table 27). Estimates varied by an order of magnitude every year since 2014; 22 million in 2014, 2.7 million in 2015, 9.2 million in 2016, 1.5 million in 2017, and 10.7 million in 2018.

Total migration estimates for the three JHTMON-8 priority species in the Quinsam River (Coho Salmon smolt, steelhead smolt, and Chinook Salmon fry) are presented in Figure 21. Total abundances of colonized fish (28,371 Coho Salmon, and 160,382 Chinook Salmon) were similar to those of 2017. In contrast, the abundance of wild fish differed substantially from those of 2017: 46,679 wild Coho Salmon smolts (~190% the abundance in 2017), 8,672 wild steelhead smolts (~170% the abundance in 2017), and 45,148 wild Chinook Salmon smolts (~40% the abundance in 2017).

The survival of out-planted juvenile salmon was estimated as the percentage of outmigrating juvenile colonized salmon that comprise the total number of fish out-planted (Figure 22). After a break of approximately 10 years, Chinook Salmon outplanting operations resumed in 2015, and therefore estimates of survival rate are available for 2015–2018 (Years 2–5 of this monitoring program). Estimated survival of colonized juvenile Chinook Salmon in Year 5 was 74%; identical to that of Year 4 and higher than Year 3 (28%) and Year 2 (66%). Note that colonized Chinook Salmon were still outmigrating in low numbers on June 18 when the sampling finished, indicating that the survival estimate may be biased low[5]. Estimated survival of colonized juvenile Coho Salmon in Year 5 was 20%; identical to that of Year 4 and higher than Years 3 and 2 (13% survival both years), and similar to survival in Year 1 (21%). Note that the estimates for Coho Salmon assume that fish outmigrate at age 1+, although a small number of 2+ smolts were recorded at the fence[6].

Table 27. Summary of downstream migration data and total migration estimates from sampling at the Quinsam River Hatchery salmon counting fence, March 13 to June 18, 2018.

Species	Life Stage	Total Counts	Total Estimated Migration[1]	Peak Migration	Migration Period	Comments
Coho Salmon (Colonized)	Smolt	2,288	28,371	May 10	May 1 - Jun 18	
Coho Salmon (Wild)	Smolt	3,732	46,679	May 13	Apr 06 - Jun 18	
Coho Salmon (2-year)	Smolt	0	0	n/a	n/a	
Coho Salmon	Fry	1,102	34,342	April 8	March 13 - Jun 18	
Steelhead	Smolt	697	8,672	May 16	Apr 15 - Jun 9	
Steelhead	Fingerling	810	10,943	May 16	Apr 04 - Jun 18	
Steelhead	Kelts	0	0	n/a	n/a	
Cutthroat	Fingerling	52	1,080	April 16	Apr 14 - Jun 18	
Cutthroat	Smolt	44	546	May 11	May 1 - Jun 14	
Cutthroat	Kelts	15	215	May 8	Mar 17 - May 19	
Trout species	Fry	13	422	April 13	Apr 8 - Jun 15	
Chinook Salmon	Fry	3,496	45,148	May 21	Apr 8 - Jun 18	Still migrating on Jun 18th
Chinook Salmon (colonized)	Fry	12,934	160,382	May 21	May 10 - Jun 18	Still migrating on Jun 18th
Chum Salmon	Fry	19	468	April 2	Apr 25 -Jun 18	
Sockeye Salmon	Fry	10	414	March 16	Mar 15 - Mar 17	
Pink Salmon	Fry	257,463	10,656,097	April 8	March 13 - May 16	
Dolly Varden	Smolt	0	0	n/a	n/a	
Lamprey (2 species)	all	114	1,501	May 7	Apr 16 - Jun 18	
Sculpin	all	182	2,982	April 11	Apr 9 - Jun 17	

[1] Based on capture efficiency measured for Pink Salmon and Coho Salmon
"n/a" indicates no peak or migration period identified

[5] Outmigration records of juvenile Chinook Salmon in the Quinsam River extend until the third week of July (Burt 2003).

[6] Estimated outmigration of 2+ Coho Salmon was 120 fish. Burt (2003) suggests that 2+ smolts represent fish that were trapped in off-channel habitats, preventing them from out-migrating the previous year.

Figure 21. Total estimated outmigration of priority species on the Quinsam River during Years 1–5 (2014–2018). Coho Salmon and steelhead were captured at the smolt stage and Chinook Salmon at the fry stage.

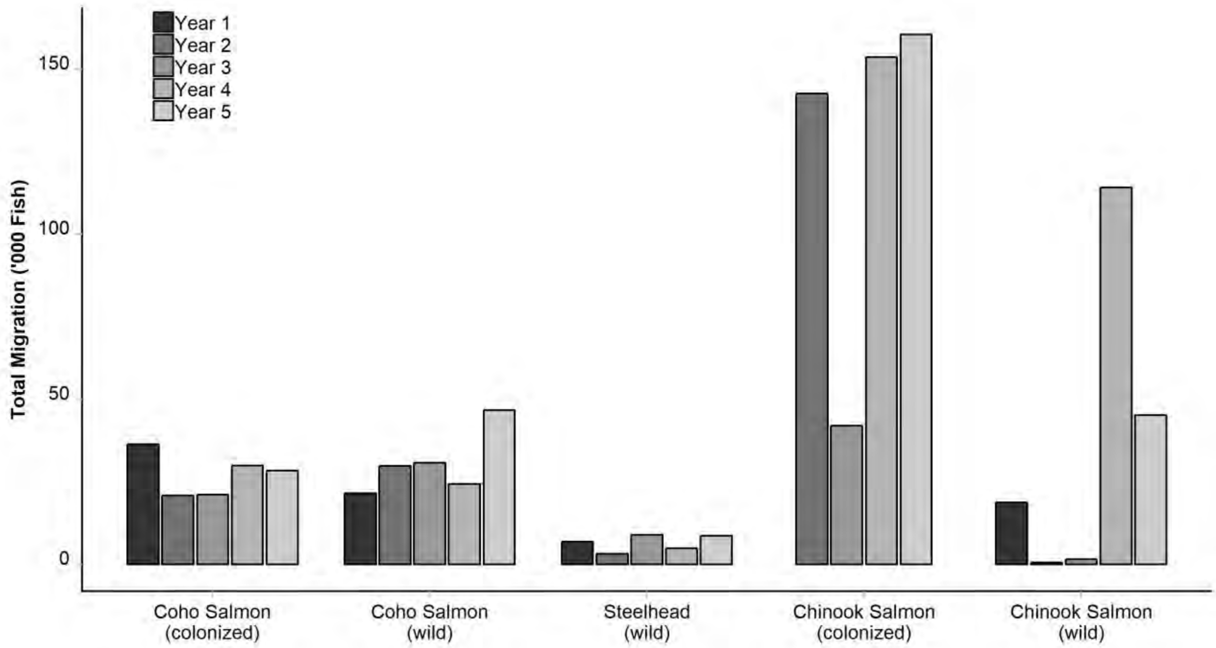
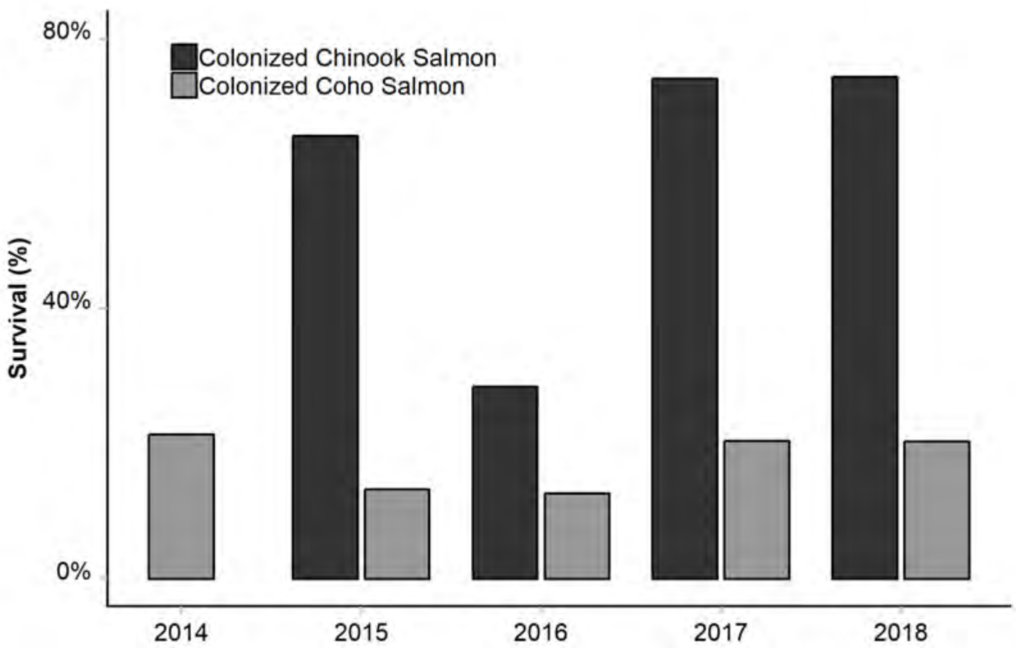


Figure 22. Estimated survival of out-planted salmon raised at the hatchery, based on the proportion of out-planted fish estimated to outmigrate at the salmon counting fence. Outmigrating Chinook Salmon were out-planted during spring (May) of the same year; outmigrating Coho Salmon were out-planted the previous year.



3.1.5.2. Review of Historical Data

The historical dataset secured from the Quinsam Hatchery starts in 1974 and includes data corresponding to most years until the present. There is a data gap in the time series for all species from 1989 to 1995, and a second gap common to all time series in 2005 and 2007. The reasons for the first (and longest) data gap include a paucity of data from 1993 to 1995 when no trapping was carried out due to budget constraints (Burt 2003). Data for some years were not present in the hatchery files, despite monitoring being undertaken. For these years, data were extracted from a table in Burt (2003). These data correspond to years 1990–1992 for the five species of Pacific Salmon and steelhead, and years 1991–1992 for Cutthroat Trout. In addition, data for years 1980 and 1983–1988 were obtained for Coho Salmon.

The species with the longest time series are Pink Salmon, Coho Salmon, and steelhead. The other species have additional data gaps of varying duration, but the time series have been nearly continuous since 1996 (Figure 23). The completeness of these records (% of years with data) for the JHTMON-8 priority species over the period 1974–2018 was: Chinook fry (62%, 28 years), Coho Salmon smolts (87%, 39 years), and steelhead smolts (82%, 37 years).

Figure 23 shows the abundance of outmigrating fish (by species) on the Quinsam River for the available time series (see Section 2.1.5 for a detail of the variation among species of ages sampled). Pink Salmon are the most abundant salmonid in the Quinsam River, reaching abundance in excess of 22 million outmigrating fry in some years (Figure 23). Chinook Salmon and Coho Salmon were the second-most abundant species, with estimated abundances in the order of hundreds of thousands of outmigrating fish, followed by Chum Salmon, with maximum abundance of just over 100,000 outmigrating fish. Trout species were much less abundant, with steelhead smolt abundance reaching a maximum abundance of about 15,000 in the late 1980s, and Cutthroat Trout smolts reaching a maximum abundance of 800 outmigrating fish in 2009 (Figure 23).

The estimated abundances of outmigrating fish were variable throughout the time series (Figure 23). Temporal trends were evident for some species the uncertainties in the datasets should be considered (Section 3.1.5.3) when evaluating possible trends. Abundance of Chum Salmon fry was highly variable, with no clear trends over time. Numbers of Chinook Salmon and Pink Salmon fry remained relatively low until the late 1990s/early 2000s, when there was an increase in the number of outmigrating fry. In contrast, numbers of Coho Salmon, steelhead, and Cutthroat Trout smolts increased during a period that spanned from the 1980s until the late1990s/early 2000s, when the three species started to decline, most notably Coho Salmon and steelhead. It is also noteworthy that there seems to be some synchrony among species in fluctuations in abundance, better seen when there were peaks (e.g., 1999, 2009, 2013) or nadirs (e.g., 1982, 2003, 2011) (Figure 23).

Estimated outmigration of priority species on the Quinsam River, discriminated by origin, are presented in Figure 24. Estimates of colonized Chinook Salmon fry are only available during 2015–2018, the time series for colonized Coho Salmon starts in 1980, and the time series for colonized steelhead starts in 1998. Estimates of outmigrating colonized Coho Salmon followed a similar pattern as that of wild Coho Salmon and, particularly during the last 10 years, these two estimates have been almost equal with a few exceptions. The abundance of out-migrating colonized steelhead was generally lower than that of wild fish for the years when hatchery-raised steelhead were out-planted (1998 to 2009).

Estimates of survival of outplanted salmon raised at the Quinsam Hatchery since 1999 are presented in Figure 25 When comparing survival estimates during the span of JHTMON-8 (2014–2018) to the historical data (1999–2012), survival of Coho Salmon has been less variable and in generally slightly lower recently than in the past. For Coho Salmon, mean survival prior to JHTMON-8 was 0.22, compared to 0.18 for 2014–2018. For Chinook Salmon, mean survival has been higher since JHTMON-8 commenced (mean survival of 0.37 versus 0.48 for the two periods) (Figure 25).

Figure 23. Total estimated fish outmigration in the Quinsam River during 1974–2018. Coho Salmon, Cutthroat Trout, and steelhead were captured at the smolt stage and Chinook Salmon, Pink Salmon, and Chum Salmon at the fry stage.

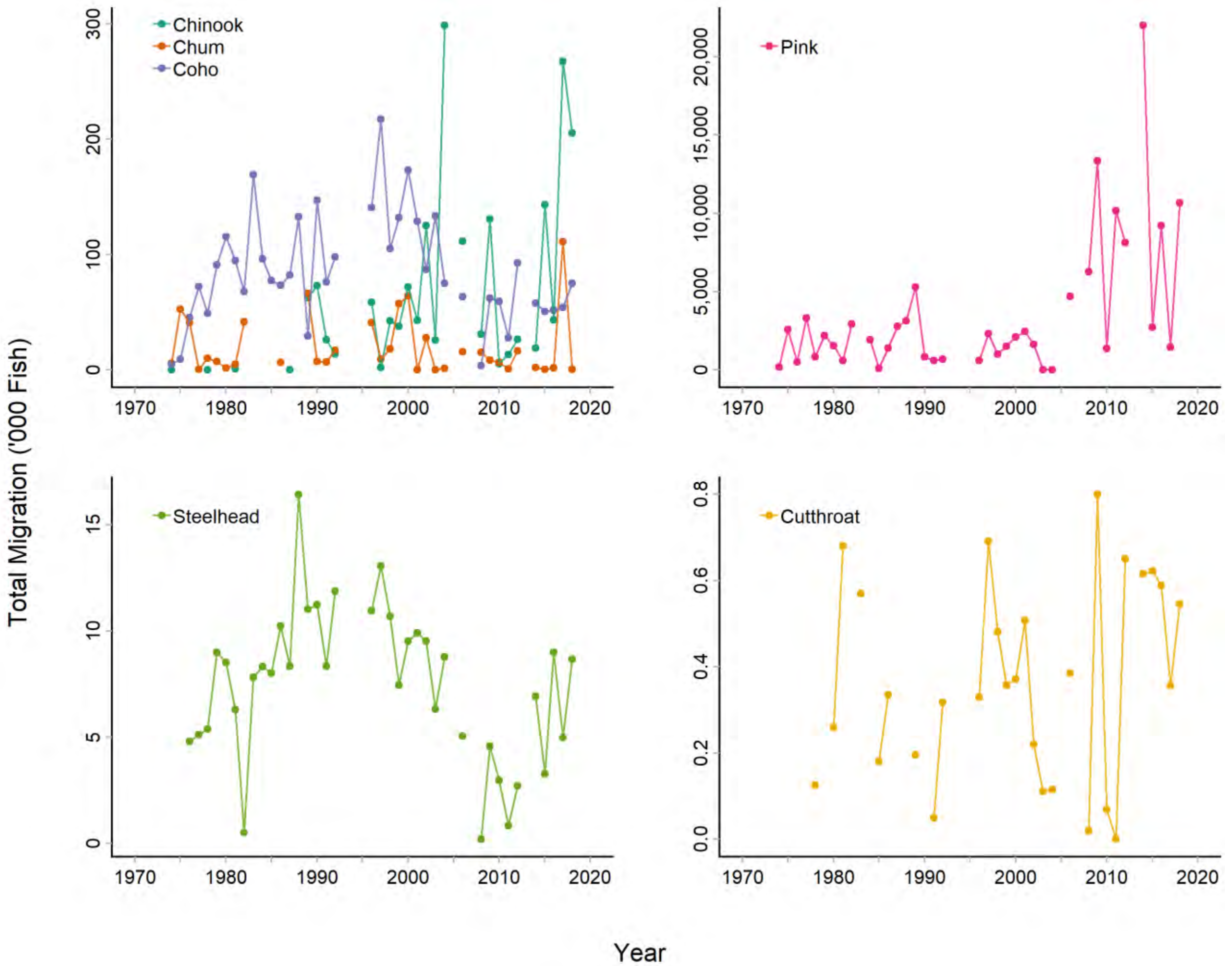


Figure 24. Estimated outmigration of priority species on the Quinsam River during 1979–2018, discriminated between colonized and wild fish. Coho Salmon and steelhead were captured at the smolt stage and Chinook Salmon at the fry stage.

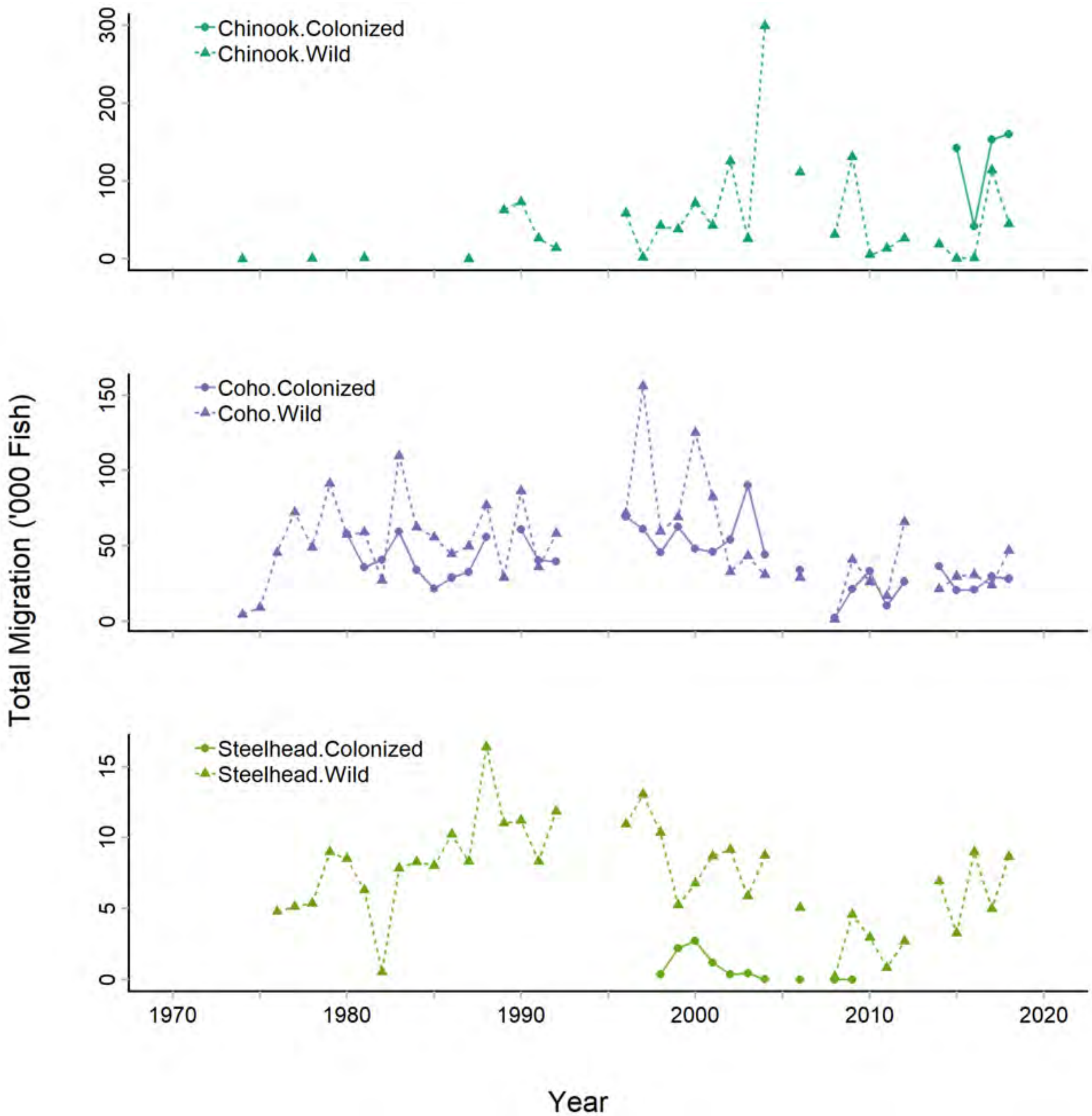
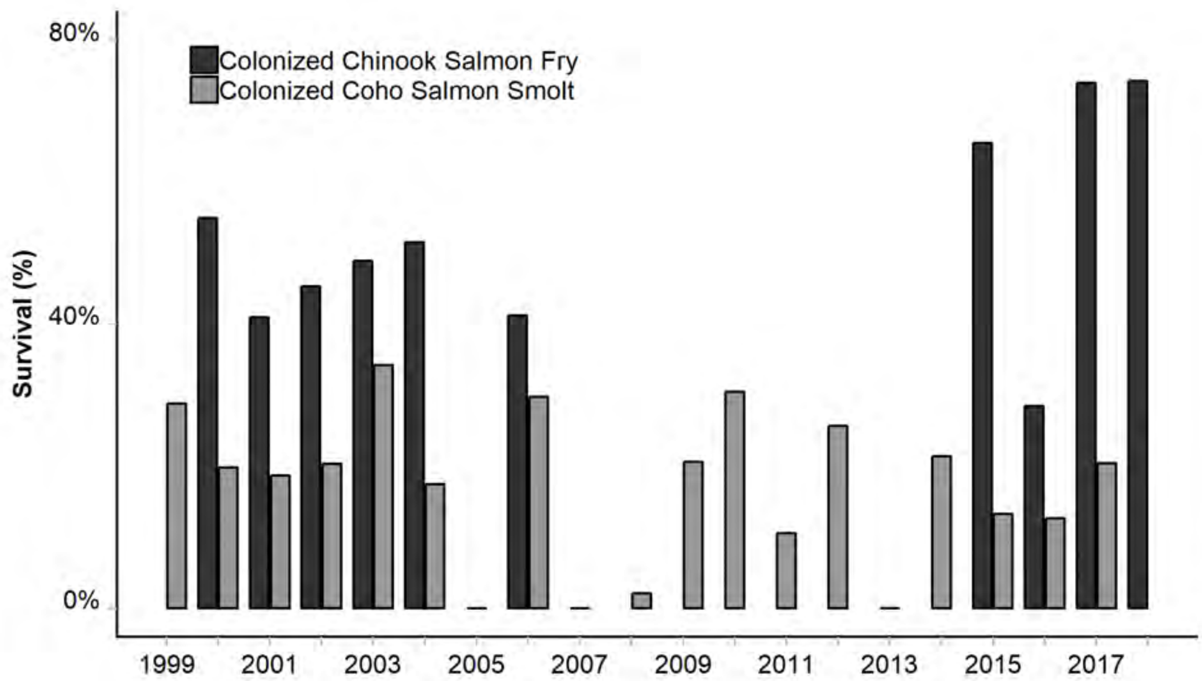


Figure 25. Estimated survival of out-planted salmon raised at the hatchery, based on the proportion of out-planted fish estimated to outmigrate at the salmon counting fence. Outmigrating Chinook Salmon were out-planted during spring (May) of the same year; outmigrating Coho Salmon were out-planted the previous year.



3.1.5.3. Sources of Uncertainty

The additional work undertaken in Year 5 to secure and analyze this multi-decadal dataset is expected to improve our ability to answer the JHTMON-8 management questions; however, as with many long-term monitoring programs, there are several sources of uncertainty that relate to differences in methods among years or incomplete records. Here, we describe the main sources of uncertainty and provide options of additional tasks that could reduce uncertainty.

A source of uncertainty in the estimates of outmigrating fish is the accuracy of the capture efficiency coefficients used by DFO to extrapolate the abundance of captured fish to the total abundance of outmigrating fish. Given that these are used as denominators in the calculations, the estimates of the total numbers of outmigrating fish are highly sensitive to these values. The coefficients used during 1975–1989 were not recorded in the data secured from the Quinsam Hatchery. Capture efficiency coefficients were estimated during most years by undertaking mark-recapture experiments specific for life stages. Due to lack of funding, no fry mark-recapture experiments were carried in 2003 or 2004, and no smolt mark-recapture experiments in 2002, 2003, 2006, 2008, or 2011. Mark-recapture experiments of fry were carried out using Pink Salmon, and assumed to be applicable to other salmonid species, while mark-recapture experiments for smolts were carried out using Coho Salmon, and assumed to be applicable to other salmonid species. Given that coefficients of capture efficiency were usually estimated annually, an implied assumption is that interannual variability in capture efficiency is more important than interspecific variability.

In addition, in at least one year (2004) when no mark-recapture experiment was carried out for Pink Salmon fry, the capture efficiency coefficient for Coho Salmon smolts was applied to all captured fishes by DFO. This likely led to an underestimation of outmigrating fishes, given that a typical value for fry capture efficiency coefficient is ~0.025, while a typical value for smolts is ~0.1.

A literature review of variability among estimates of species-specific capture efficiency coefficients could help to understand the potential error associated with this uncertainty. If bias is suspected, then it may be possible to adjust capture efficiency coefficients by applying a species-specific weighting. Alternatively, species-specific mark-recapture experiments could be undertaken to improve the accuracy of capture efficiency estimates for species that have not previously been used in experiments.

A second source of uncertainty is the magnitude of fish production that occurs downstream of the hatchery counting fence, given that fish produced in 3.7 km reach are not sampled. Burt (2003) reported this source of uncertainty and noted that estimates for Coho Salmon are likely a reasonable approximation of total Coho Salmon production since most spawn above the counting fence. In contrast, estimates reported for wild Chinook Salmon highly underestimate total production from the Quinsam River as most fish spawn below the counting fence (Burt 2003). Burt (2003) did not report on the spatial differences in spawning habitat use among other species. In theory, surveys to measure the distribution of spawning salmon in the river could be used to adjust the data to partly account for this source of uncertainty. However, as the focus of the JHTMON-8 analysis is on interannual trends (rather than the precise magnitude of abundance in an individual year), this extension is not considered high priority.

A third source of uncertainty relates to the coexistence of migratory and resident forms of juvenile Rainbow and Cutthroat Trout. Numbers of juvenile trout presented in this report are not differentiated between resident and anadromous forms, and it is possible that these are confounded. We expect that the effect of this source of uncertainty on the results is low and it is notable that the raw data show a clear "pulse" (data not shown) during the monitoring period, consistent with the assumption that the data relate to outmigrating trout smolts.

3.2. Weighted Usable Area (WUA) of Habitat (Quinsam River)

Median WUA for steelhead spawning was generally consistent throughout the steelhead spawning period (mid February to mid April; Table 4), although there were large (e.g., 400-fold) differences among years in this WUA metric on individual days (Figure 26A). There was a clear seasonal pattern in WUA for steelhead fry rearing, with highest values occurring during mid to late summer, reflecting a preference for low stream velocities by this life stage (Figure 26B). Steelhead parr WUA was generally highest during May through November, although there was generally a decline in mid-summer (Figure

26C). Annual average WUA for steelhead life stages varied throughout the dataset, with variability highest for steelhead spawning WUA (Figure 27).

For Pink Salmon and Coho Salmon, median spawning habitat WUA remained fairly consistent throughout the respective spawning periods, while Chinook Salmon median spawning habitat WUA increased in late October, midway through the spawning period (Figure 28). Variability in annual average spawning habitat WUA was similar among the three Pacific salmon species, with maximum differences among years of approximately 100% (i.e., approximately two-fold differences; Figure 29).

Figure 26. **Daily Weighted Usable Area (WUA) for steelhead life stages in the Quinsam River, 1975–2017. Grey dots denote daily values for individual years; coloured lines show percentiles (see legend).**

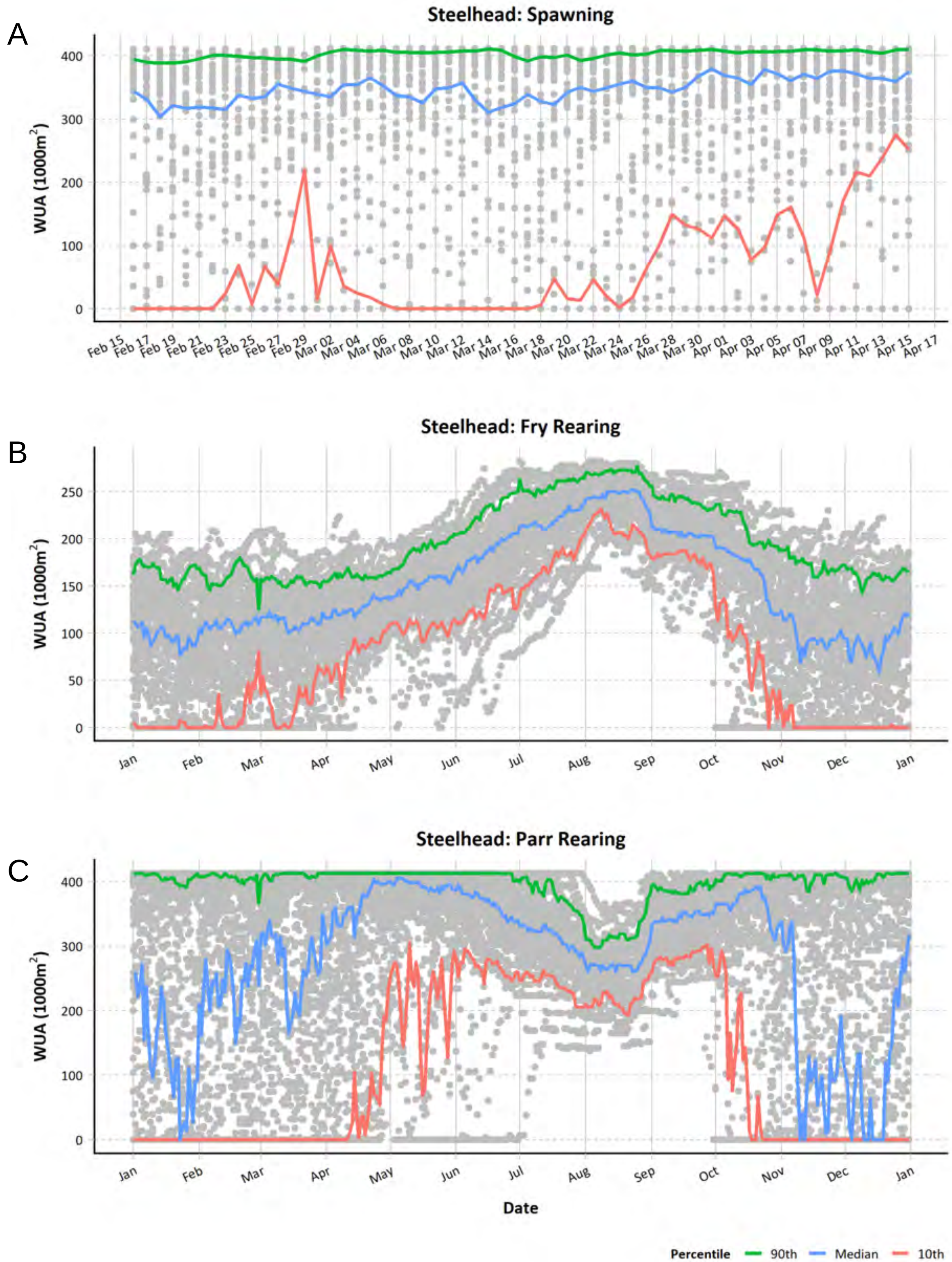


Figure 27. Annual average Weighed Usable Area (WUA) for steelhead life stages in the Quinsam River, 1975–2017. Mean annual rearing habitat WUA is calculated separately for the critical stream flow period (CSFP; August) and the full rearing period.

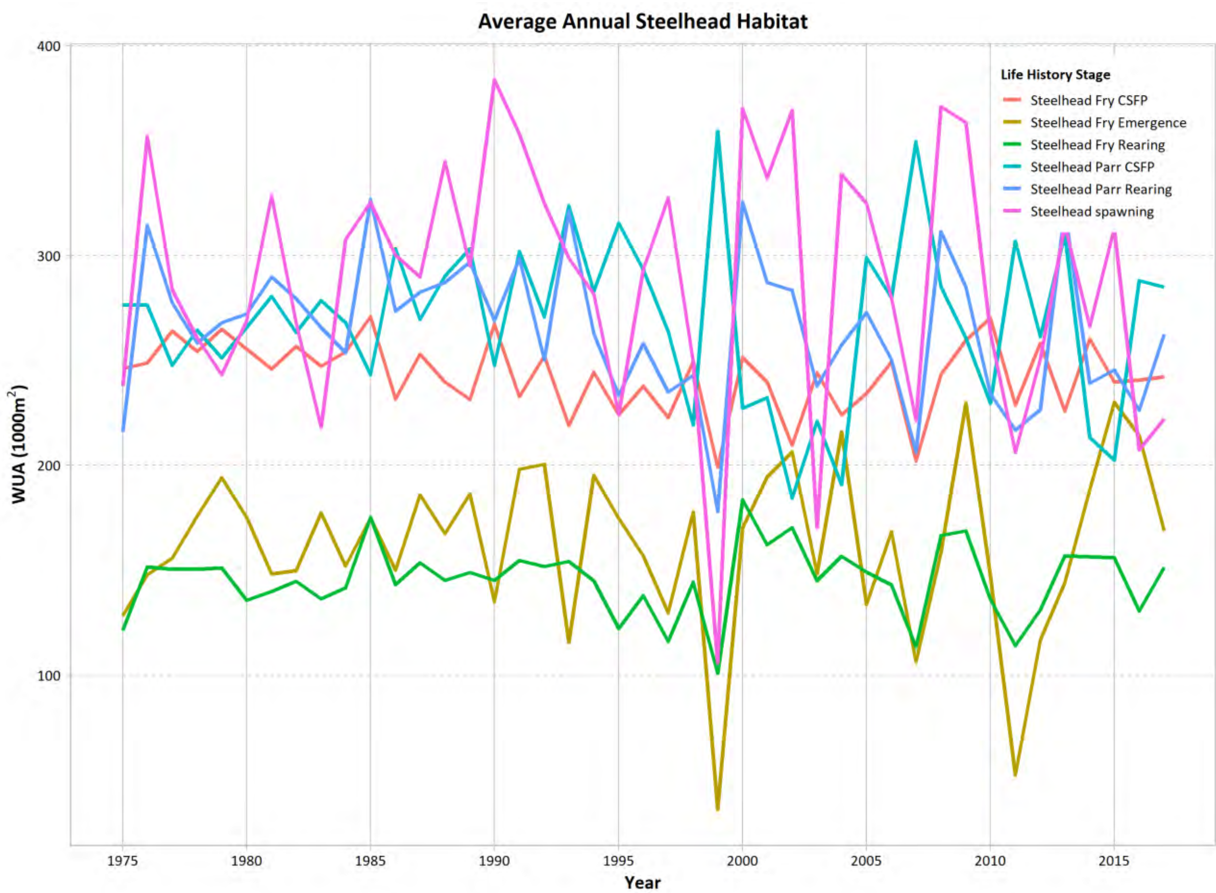


Figure 28. Daily Weighted Usable Area (WUA) of spawning habitat for JHTMON-8 priority Pacific salmon species (plus Pink Salmon) in the Quinsam River, 1975–2017. Grey dots denote daily values for individual years; coloured lines show percentiles (see legend).

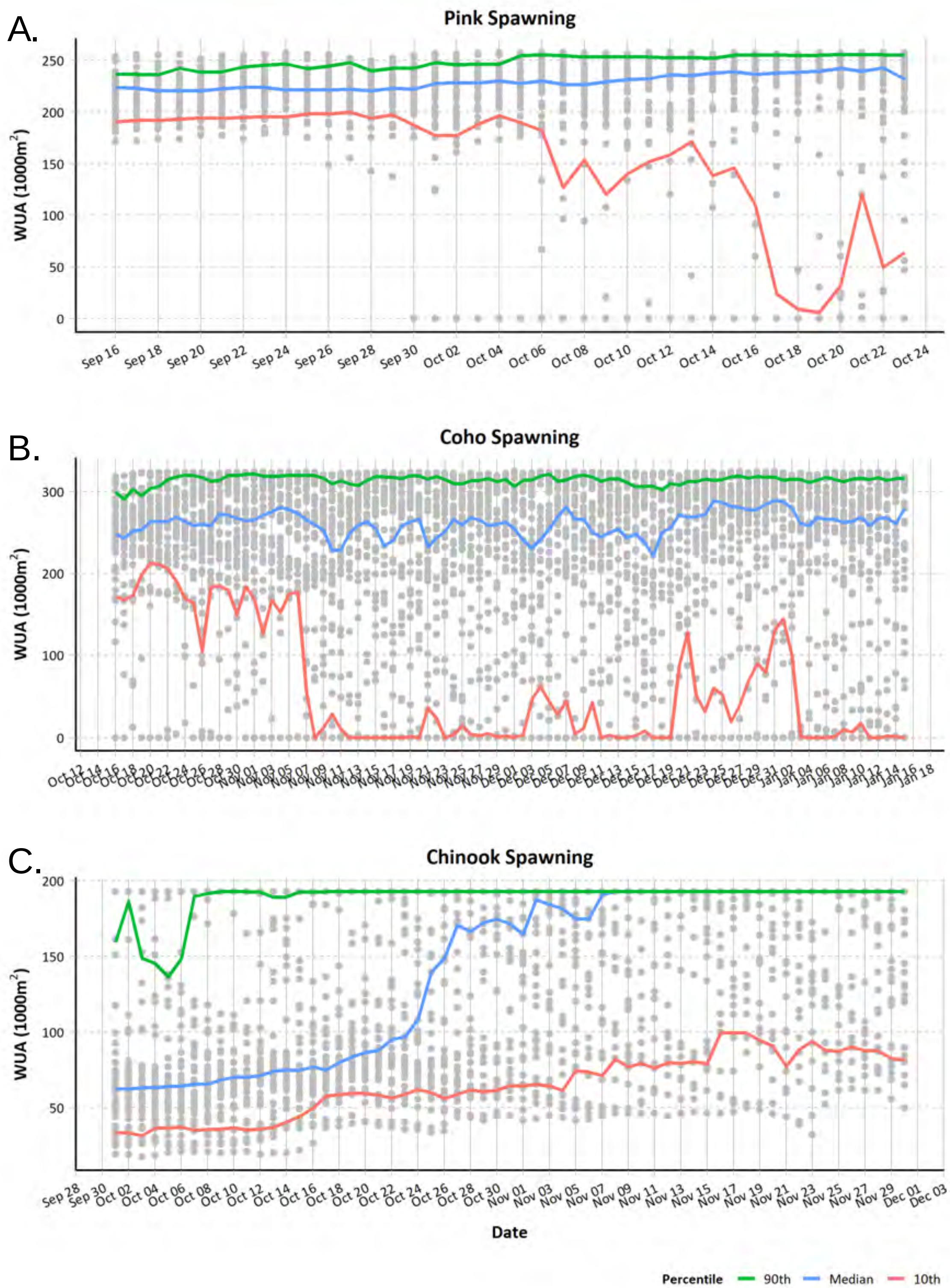
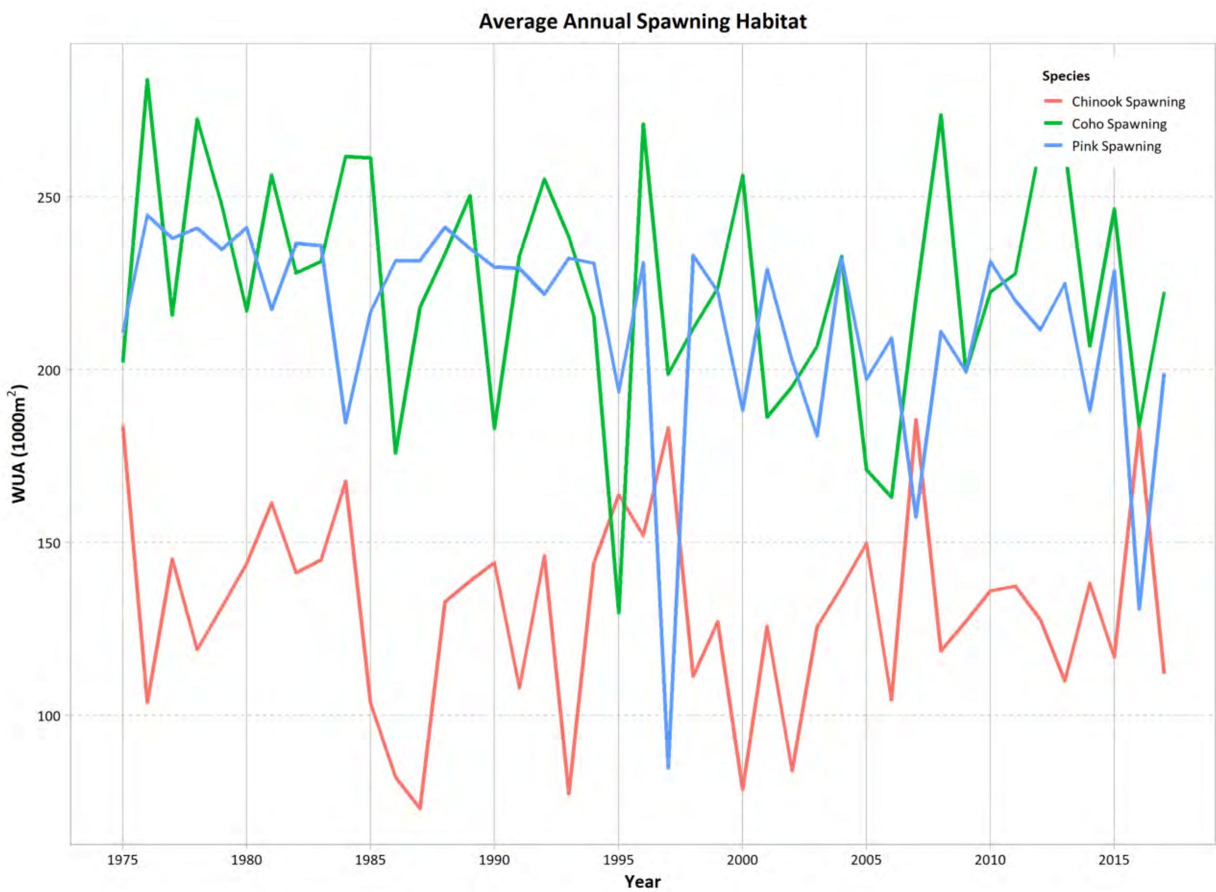


Figure 29. Annual average Weighed Usable Area (WUA) of spawning habitat for JHTMON-8 priority Pacific salmon species (plus Pink Salmon) in the Quinsam River, 1975–2017.



3.3. <u>Water Quality</u>

3.3.1. Year 1 to Year 5 Water Quality Data

Tabulated results from Years 1 to 5 (2014 to 2018) of water quality monitoring are presented in Appendix A. Results for the Salmon River collected during Years 1–4 are described and discussed below in Section 3.3.2.2. Year 5 (2018) results for the Quinsam River are described below in Section 3.3.2.1, which includes discussion of Year 5 results and how they compare with previous years. Analytes for which measurements were consistently below or close to the MDL are not plotted.

3.3.2. Water Chemistry

3.3.2.1. Year 5 QA/QC Results

All laboratory analyses were conducted within the recommended hold times (see Appendix A), with the exception of nitrate analysis of the sample collected on May 10, 2018 and all pH values. The hold time for the nitrate sample was five days, thus exceeding the recommended hold time of three days.

The potential for this measurement to be affected by this hold time exceedance is discussed in Section 3.3.2.1.

All pH samples from QUN-WQ exceeded the recommended hold time of 0.25 hours, as occurred in all previous years and is inevitable given the sampling location. Both laboratory and field data for pH are presented in the following sections.

Clark (2013) and RISC (2003) recommend that results for duplicate samples should have relative percent difference or relative standard error values of 20% or less (provided that the concentrations are greater than five times higher than the MDL), otherwise it can indicate a potential issue with the sample. Contamination is suspected when the relative variability between duplicates exceeds 50% (Clark 2013).

In 2018, considering only parameters with concentrations five times higher than the MDL, only turbidity measurements for samples collected on August 9, 2018 at QUN-WQ had duplicate values with > 20% relative standard error (measured values were 0.52 and 0.75 NTU). Variability between all other duplicate samples for all other parameters was below the 20% threshold. It is unlikely that the high variability in the turbidity measurement for this set of duplicates was due to contamination of the sample since values for other parameters measured in the same samples do not show high variability. Instead, it is possible that the variability in the duplicates was the result of environmental heterogeneity; the turbidity values in both duplicate samples were relatively low and are within the range measured at the QUN-WQ site in Years 1 through 5.

One field and one trip blank were collected in 2018. Values for all parameters were below the respective MDLs for both blanks. Values of pH were slightly higher in the field blank (5.53) than the travel blank (5.33).

3.3.2.2. Salmon River

Overview

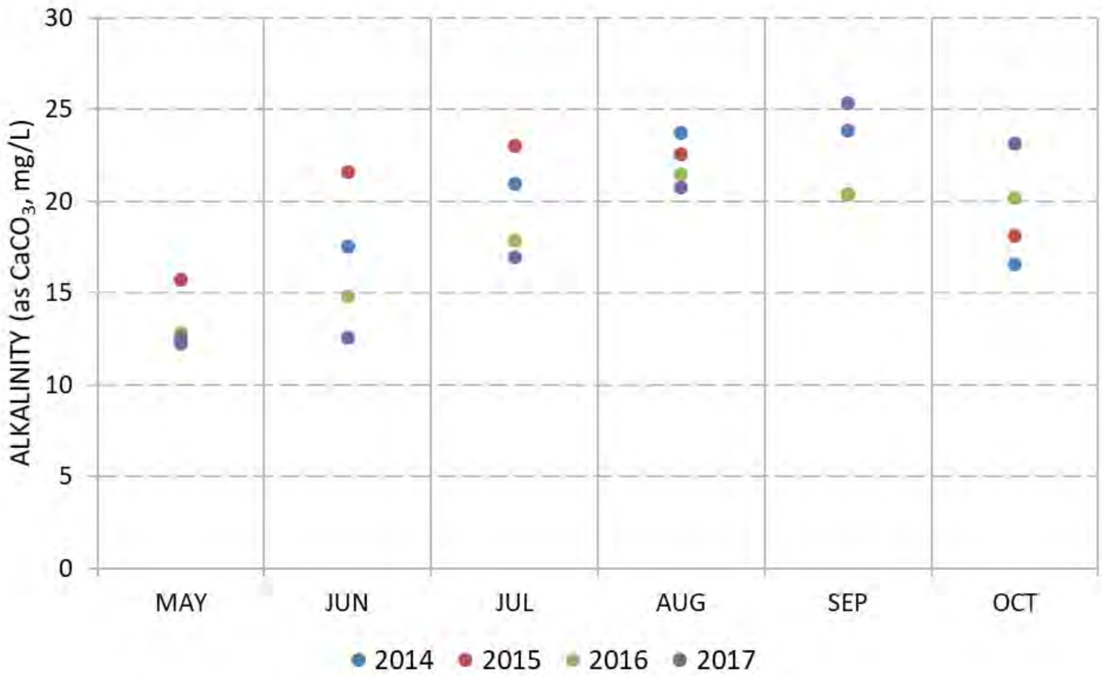
Water quality monitoring of the Salmon River was completed in Years 1–4 and results are summarized for individual analytes in the following sections. All *in situ* and lab water chemistry results for the Salmon River at SAM-WQ are tabulated in Appendix A.

Alkalinity

Alkalinity (as $CaCO_3$) varied throughout the study period within the range 12.2 mg/L to 25.4 mg/L (Figure 30). Concentrations showed a strong seasonal cycle with lower values occurring at the start of each growing season and higher values occurring in late summer. The mean value for all samples was 19.0 mg/L with a standard deviation of 3.9 mg/L; no clear trend over the four years was observed. Alkalinity concentrations less than 10 mg/L in streams indicate sensitivity to acidic inputs, or poor buffering capacity. Alkalinity in the range of 10 mg/L to 20 mg/L indicates that the watercourse is moderately sensitive to acidic inputs, whereas values greater than 20 mg/L suggest a low sensitivity

(RISC 1997b). Thus, the Salmon River is moderately sensitive to acidic inputs during the majority of the growing season.

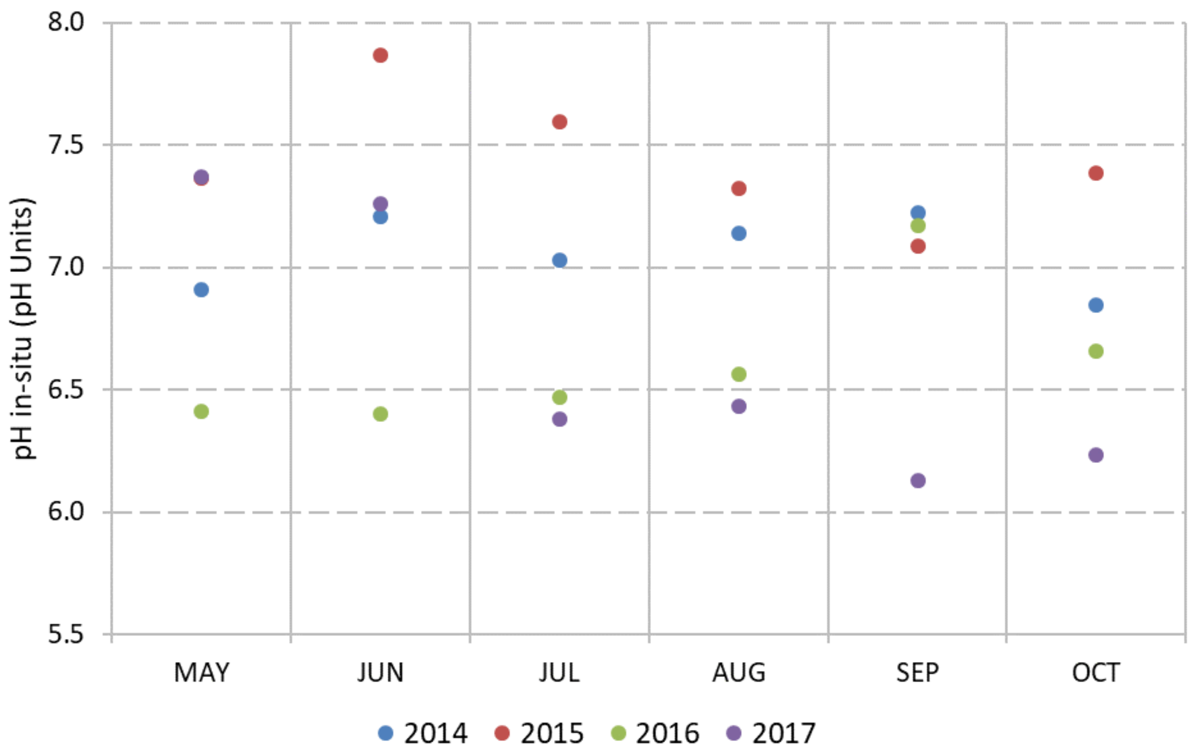
Figure 30. Alkalinity (as $CaCO_3$ mg/L) in the Salmon River.



pH

pH values measured in the laboratory ranged from 7.31 to 7.88 with a mean of 7.56 and a standard deviation of 0.15 whereas *in situ* pH ranged from 6.10 to 7.88 with a mean of 6.96 and a standard deviation of 0.46. Because lab-based pH exceeded hold times, the *in situ* data should be considered to be more accurate. No strong seasonal pattern was observed; however, a slightly decreasing trend was noted over the course of the four years (Figure 31). Natural fresh waters have a pH range from 4.0 to 10.0; BC lakes tend to have a pH ≥ 7.0, and coastal streams commonly have pH values of 5.5 to 6.5 (RISC 1997b). The pH values measured *in situ* and in the lab are within the range expected for natural fresh waters in BC.

Figure 31. pH measured in the Salmon River.



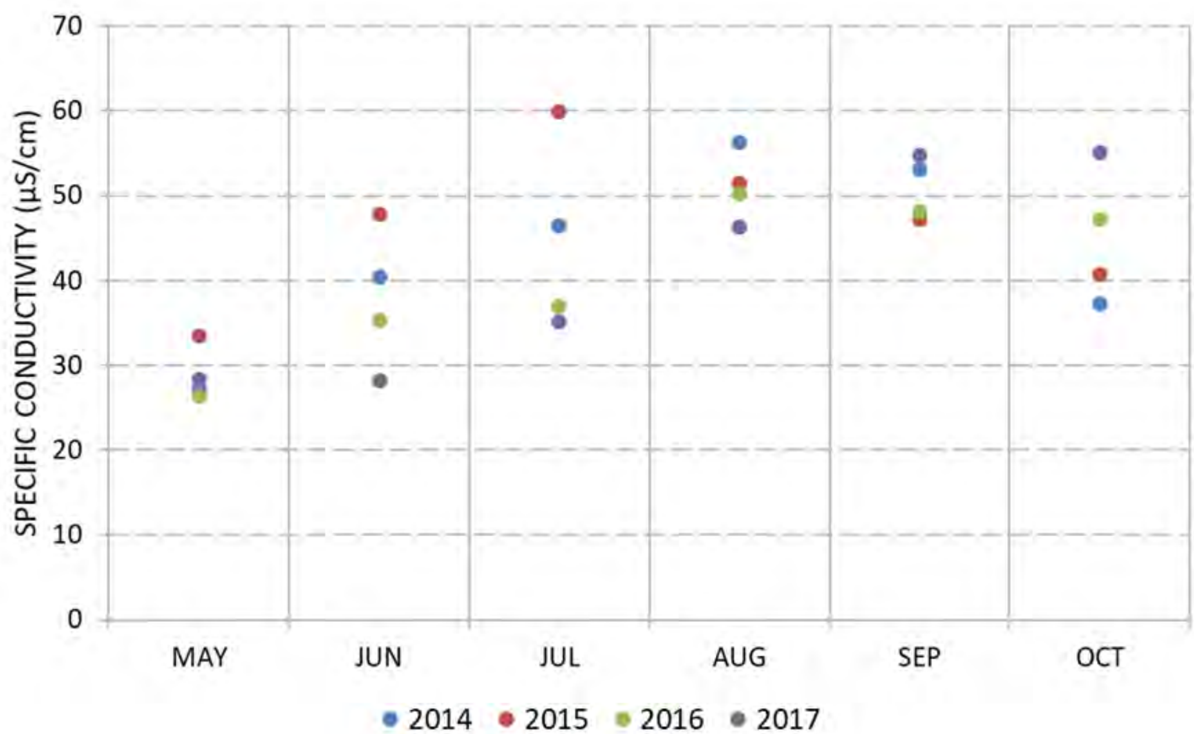
Specific Conductivity and Total Dissolved Solids

Specific conductivity (i.e., conductivity normalized to 25°C) measured by laboratory analysis varied between 26.3 µS/cm and 64.8 µS/cm, with a mean of 43.0 and a standard deviation of 10.1 µS/cm. Like alkalinity, a strong seasonal cycle (likely due to dilution effects) was observed with low values occurring at the start of the growing season and highest values in late August. There was no trend over the four years of monitoring.

In situ measurements showed the same seasonal pattern but values were slightly lower and more variable, ranging between 16.6 µS/cm and 65.0 µS/cm, with a mean of 36.6 and a standard deviation of 12.8 µS/cm. Coastal BC streams generally have a specific conductivity of ~100 µS/cm (RISC 1997b). Thus, with a mean *in-situ* specific conductivity of 36.6 µS/cm, the Salmon River has a relatively low specific conductivity and thus a low concentration of dissolved ions.

Concentrations of total dissolved solids measured in the lab for the Salmon River ranged from 19 mg/L to 53 mg/L, with a mean value of 34.5 mg/L. Values tended to increase as the growing season progressed with highest values occurring the late summer.

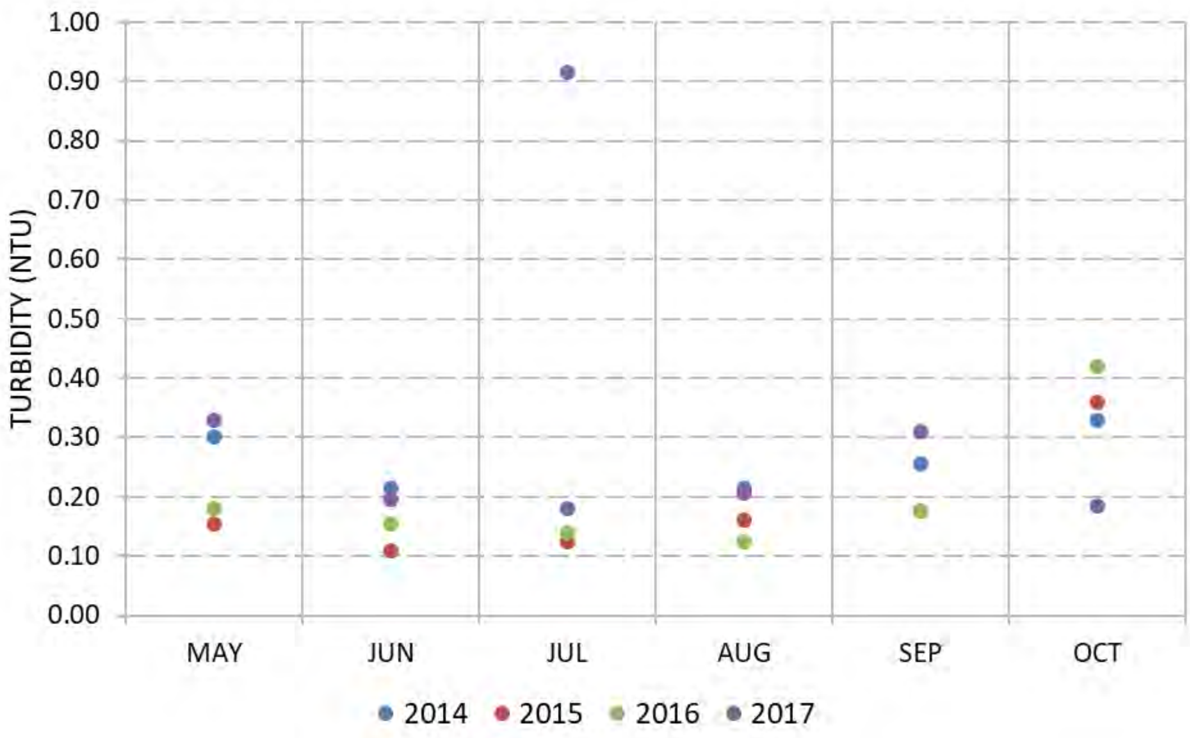
Figure 32. Specific conductivity in the Salmon River as measured by lab analysis.



Turbidity and Total Suspended Solids (TSS)

Turbidity measured in the Salmon River at SAM-WQ (Figure 33) was low throughout the monitoring program. Values ranged from 0.11 to 0.92 NTU with a mean of 0.25 and a standard deviation of 0.17 NTU. Turbidity values tended to be highest at the start and end of each monitoring year with lowest values occurring in mid-summer (Figure 33). The highest turbidity value was measured on July 23, 2014, with measurements consistent between both duplicate samples. Concentrations of TSS were constantly low; e.g., 43 of 48 samples were below the MDL of 1.0 mg/L.

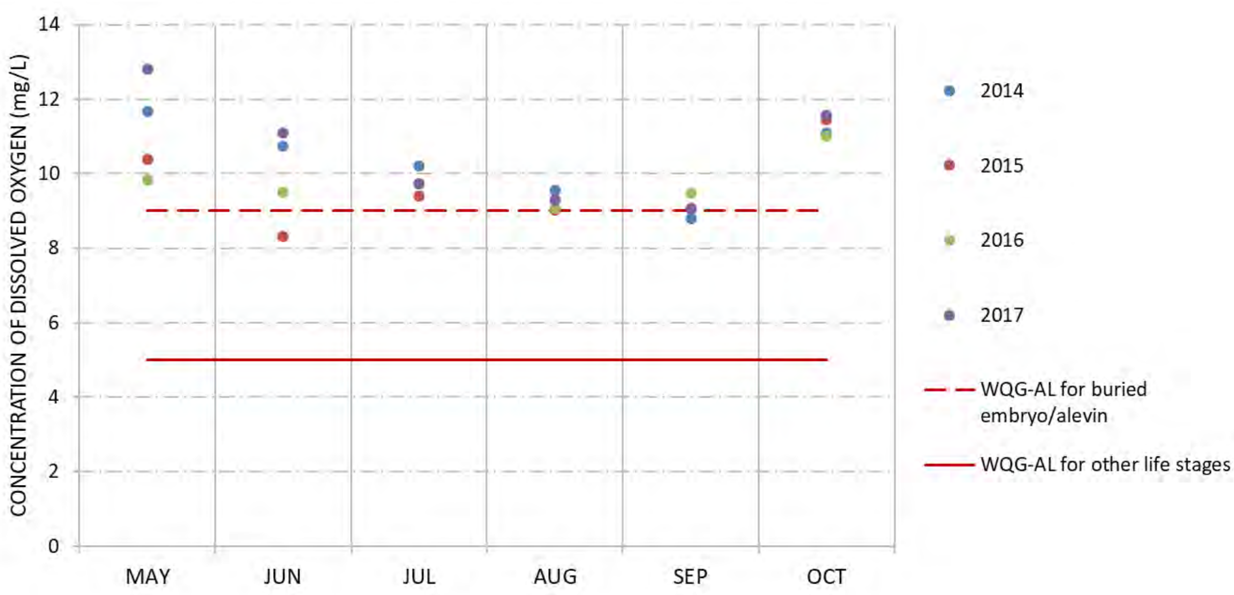
Figure 33. Turbidity measured in the Salmon River.



Dissolved Oxygen

Dissolved oxygen (DO) concentrations in the Salmon River were generally moderate to high over all four years of monitoring. In BC, surface waters generally exhibit DO concentrations greater than 10 mg/L, and are close to equilibrium with the atmosphere (i.e., ~100% saturated; RISC 1997b). DO concentrations in the Salmon River ranged from 8.31 mg/L to 12.81 mg/L, with a mean of 10.1 mg/L and a standard deviation of 1.1 mg/L. Concentrations of DO declined below the 9.0 mg/L minimum guideline for the protection of buried embryos and alevins at the end of the Rainbow Trout/steelhead incubation period in June 2015, based on periodicity shown in Table 1. The only other time that DO concentrations declined below 9.0 mg/L was in September 2014; this overlapped with the estimated start of the incubation periods of Chinook Salmon and Pink Salmon (Table 1), although the water quality site was upstream of the assumed upstream limits to the distributions of these species (Burt 2010; Marriner et al. 2016). Seasonally, DO decreased by late summer when water temperatures were highest, with the lowest DO concentrations measured in August and September (Figure 34). DO concentrations then increased in October as water temperatures cooled. There was no clear longer-term trend evident in dissolved oxygen concentrations over the four years.

Figure 34. Dissolved oxygen concentrations in the water column, Salmon River.



Total Gas Pressure

Monitoring of TGP was discontinued in Year 2 following evaluation of results in Year 1, and the limited potential of the Salmon River diversion to have caused elevated TGP concentrations. Results from TGP monitoring in Year 1 are presented in Appendix A.

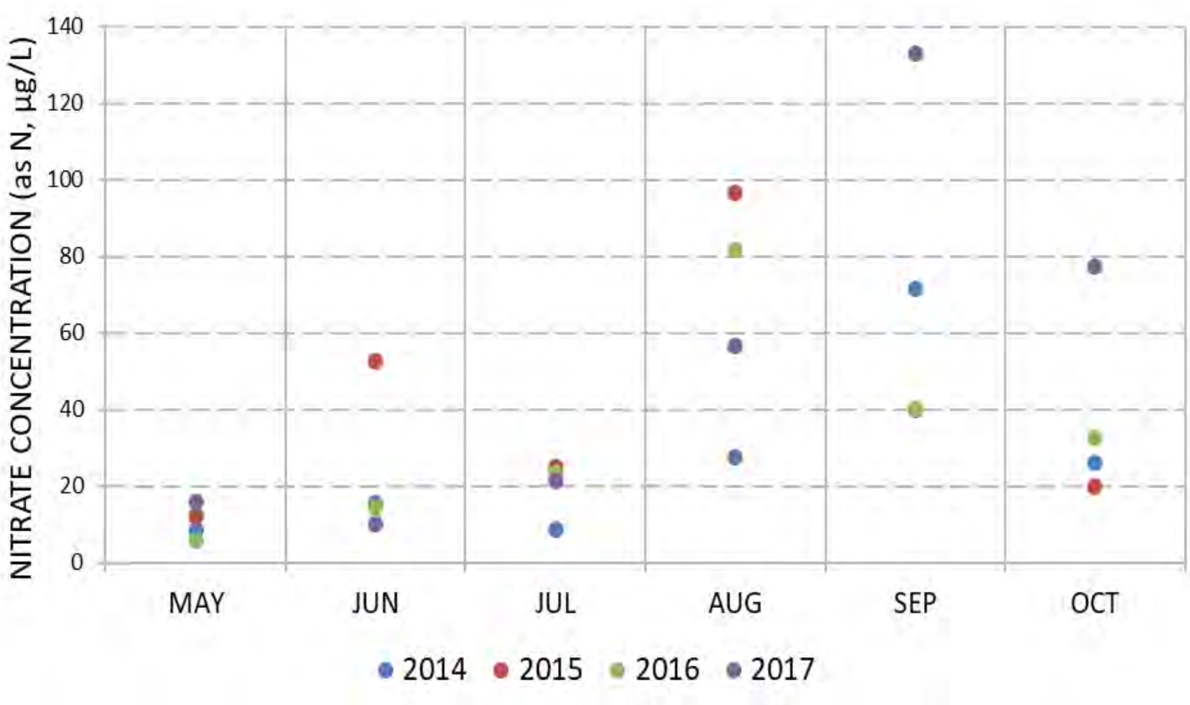
Nitrogen

Total ammonia (including the ammonium ion) concentrations in the Salmon River at SAM-WQ (not plotted) were less than the MDL of 5.0 μg N/L, except for one duplicate sample collected on August 8, 2017 for which the ammonia (as N) concentration was 12.9 μg/L. The cause of this outlier is uncertain but it is suspected to be due to sample contamination. Ammonia is usually present at low concentrations (<100 μg N/L) in waters not affected by wastewater discharges (Nordin and Pommen 1986).

Nitrite concentrations (not plotted) were below the MDL of 1.0 μg N/L for all the monthly sampling dates with the exception of one replicate sample collected in May 2016 that had a concentration of 1.5 μg N/L. Nitrite is an unstable intermediate ion that serves as an indicator of recent contamination from sewage and/or agricultural runoff; concentrations are typically <1.0 μg N/L (RISC 1997b).

Nitrate concentrations ranged from <5 μg N/L to 133.0 μg N/L, with a mean of 38.2 μg N/L and a standard deviation of 32.5 μg/L during the four years of monitoring (Figure 35), with the highest concentrations measured in August and September. These concentrations are typical of oligotrophic streams, which generally have nitrate concentrations lower than 100 μg N/L (Nordin and Pommen 1986). The maximum concentration coincided with a small increase in flow during the summer low-flow period and likely reflects mobilization of nitrogen from riparian sources that had accumulated over a prolonged dry period.

Figure 35. Nitrate concentrations measured in the Salmon River.



Phosphorus

Orthophosphate concentrations (not plotted) were below the detection limit of 1.0 µg P/L for all monthly sampling events with the exception of a measurement of 1.1 µg P/L for one replicate sample collected in August 2014. Very low orthophosphate concentrations are typical of coastal BC streams, which commonly have orthophosphate concentrations <1.0 µg P/L (Slaney and Ward 1993; Ashley and Slaney 1997).

Total phosphorus concentrations were low with 34 of 48 samples having concentrations below the MDL of 2.0 µg/L. Maximum concentrations occurred in 2014 and 2016 with values up to 5.6 µg/L in 2014 and up to 5.0 µg/L in 2016. These results are consistent with past observations that low phosphorus concentrations limit productivity in the Salmon River watershed (Pellett 2011).

3.3.2.1. Quinsam River

Overview

The Year 5 *in situ* and lab water chemistry results for the Quinsam River at QUN-WQ are summarized in Table 28 (general variables measured *in situ*), Table 29 (DO measured *in situ*), Table 30 (general variables measured at ALS labs), and Table 31 (low level nutrients measured at ALS labs).

Table 28. Quinsam River (QUN-WQ) general water quality variables measured *in situ* during Year 5 (2018).

Year	Date	Site	Air Temperature °C				Conductivity (In Situ) µS/cm				Specific Conductivity (In Situ) µS/cm				Temperature (In Situ) °C				pH (In Situ) pH units			
			Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2018	10-May	QUN-WQ	9.0	9.0	9.0	0.0	66.7	66.6	66.8	0.1	95.9	95.8	96.0	0.1	9.7	9.7	9.7	0.0	6.02	5.92	6.11	0.10
	05-Jun	QUN-WQ	8.0	8.0	8.0	0.0	118.5	118.5	118.5	0.0	153.4	153.3	153.4	0.1	13.6	13.6	13.6	0.0	6.58	6.57	6.58	0.01
	04-Jul	QUN-WQ	11.5	11.5	11.5	0.0	116.1	116.1	116.1	0.0	139.0	139.0	139.0	0.0	16.8	16.8	16.8	0.0	7.59	7.59	7.59	0.00
	09-Aug	QUN-WQ	14.0	14.0	14.0	0.0	129.9	129.8	129.9	0.1	137.4	137.3	137.4	0.1	22.1	22.1	22.1	0.0	7.05	7.04	7.06	0.01
	12-Sep	QUN-WQ	10.0	10.0	10.0	0.0	91.0	91.0	91.0	0.0	112.8	112.8	112.8	0.0	15.3	15.3	15.3	0.0	7.69	7.69	7.70	0.01
	05-Oct	QUN-WQ	5.0	5.0	5.0	0.0	79.3	79.3	79.4	0.1	112.5	112.4	112.6	0.1	9.5	9.5	9.5	0.0	-	-	-	-

[1] Average of three replicates (n=3) on each date unless otherwise indicated.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 29. Quinsam River (QUN-WQ) dissolved gases measured *in situ* during Year 5 (2018).

Year	Date	Site	Oxygen Dissolved (In Situ) %				Oxygen Dissolved (In Situ) mg/L			
			Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2018	10-May	QUN-WQ	97	96	97	1	10.99	10.97	11.02	0.03
	05-Jun	QUN-WQ	85	85	85	0	8.86	8.85	8.87	0.01
	04-Jul	QUN-WQ	82	82	83	0	7.99	7.97	8.02	0.03
	09-Aug	QUN-WQ	91	90	92	1	8.25	7.85	8.87	0.55
	12-Sep	QUN-WQ	94	92	96	2	9.41	9.24	9.62	0.19
	05-Oct	QUN-WQ	85	84	86	1	9.75	9.65	9.80	0.08

[1] Average of three replicates (n=3) on each date unless otherwise indicated.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Blue shading indicates that the more conservative provincial guideline (DO instantaneous minimum of 9.0 mg/L) for the protection of aquatic life was not met.

Table 30. Quinsam River (QUN-WQ) general water quality variables measured at ALS labs during Year 5 (2018).

Year	Date	Alkalinity, Total (as CaCO3) mg/L				Conductivity (lab) µS/cm				Total Dissolved Solids mg/L				Total Suspended Solids mg/L				Turbidity (lab) NTU				pH (lab) pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2018	10-May	27.8	27.8	27.8	0.0	93.2	92.7	93.6	0.6	69.5	69.0	70.0	0.7	<1	<1	<1	0.0	0.5	0.4	0.5	0.0	7.6	7.6	7.6	0.0
	05-Jun	41.3	40.9	41.7	0.6	149.5	149.0	150.0	0.7	97.0	96.0	98.0	1.4	1.4	1.1	1.6	0.4	0.5	0.5	0.5	0.0	7.8	7.8	7.9	0.0
	04-Jul	38.7	38.4	39.0	0.4	132.5	132.0	133.0	0.7	92.5	87.0	98.0	7.8	1.4	1.3	1.5	0.1	0.6	0.5	0.6	0.1	7.8	7.8	7.8	0.0
	09-Aug	41.2	41.1	41.2	0.1	132.0	132.0	132.0	0.0	88.0	88.0	88.0	0.0	<1	<1	1.1	0.1	0.6	0.5	0.8	0.2	7.8	7.8	7.8	0.0
	12-Sep	37.0	36.8	37.1	0.2	110.0	110.0	110.0	0.0	77.5	73.0	82.0	6.4	<3	<3	<3	0.0	0.4	0.3	0.4	0.1	7.8	7.8	7.8	0.0
	05-Oct	31.0	30.9	31.0	0.1	105.5	104.0	107.0	2.1	77.5	77.0	78.0	0.7	<1	<1	1.3	0.2	0.4	0.4	0.4	0.0	7.6	7.6	7.7	0.0

[1] Average of three replicates (n=3) on each date unless otherwise indicated.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 31. Quinsam River (QUN-WQ) nutrient concentrations measured at ALS labs during Year 5 (2018).

Year	Date	Ammonia, Total (as N) µg/L				Dissolved Orthophosphate (as P) µg/L				Nitrate (as N) µg/L				Nitrite (as N) µg/L				Total Phosphorus (P) µg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2018	10-May	<5	<5	<5	0.0	<1	<1	<1	0.0	9.6	8.5	10.6	1.5	<1	<1	<1	0	2.7	2.6	2.7	0.1
	05-Jun	<5	<5	5.4	0.3	<1	<1	<1	0.0	16.6	16.2	16.9	0.5	<1	<1	<1	0	3.1	2.9	3.3	0.3
	04-Jul	<5	<5	<5	0.0	<1	<1	<1	0.0	13.5	13.1	13.9	0.6	<1	<1	<1	0	5.5	4.9	6.0	0.8
	09-Aug	<5	<5	<5	0.0	<1	<1	<1	0.0	21.6	21.5	21.6	0.1	<1	<1	<1	0	3.9	3.7	4.0	0.2
	12-Sep	<5	<5	<5	0.0	<1	<1	<1	0.0	30.4	30.2	30.5	0.2	<1	<1	<1	0	3.3	3.1	3.5	0.3
	05-Oct	16.8	16.7	16.9	0.1	<1	<1	1.5	0.4	21.6	21.3	21.8	0.4	<1	<1	<1	0	4.7	4.2	5.2	0.7

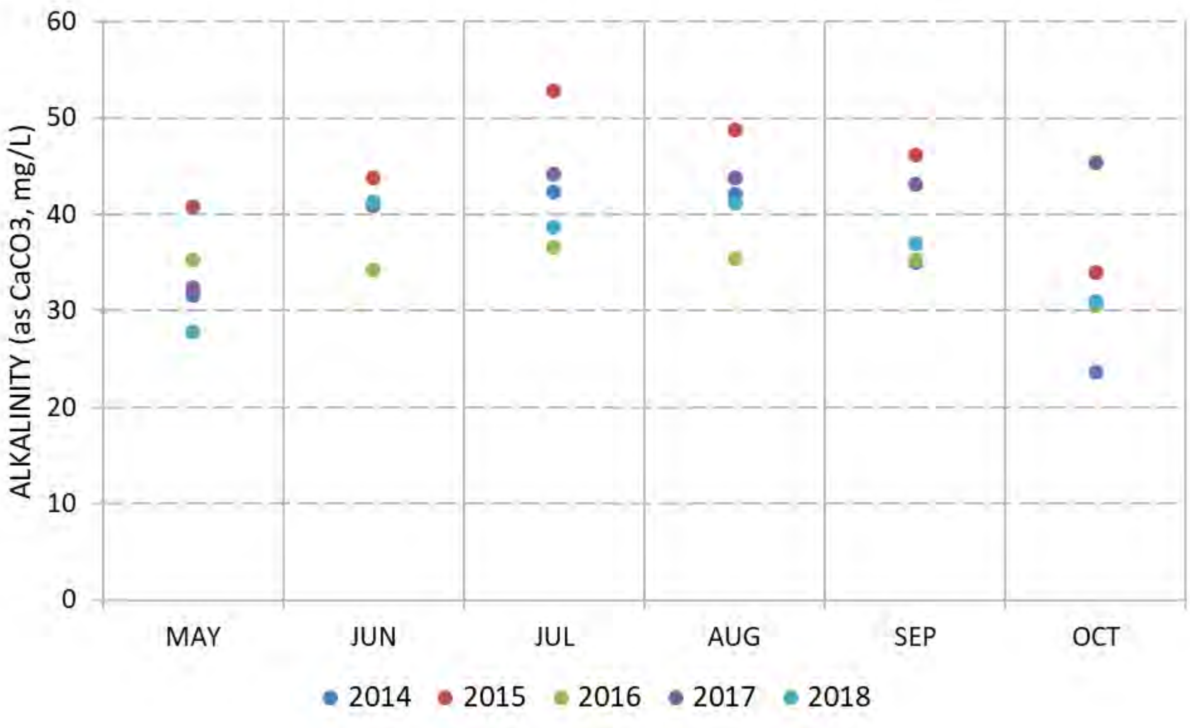
[1] Average of three replicates (n=3) on each date unless otherwise indicated.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Alkalinity

Alkalinity (as $CaCO_3$) measured at ALS labs ranged from 27.8 mg/L (May) to 41.3 mg/L (June; Figure 36) in Year 5. Results were generally in the middle of the range measured in previous years (Figure 36). Alkalinity concentrations were consistently greater than 20 mg/L, indicating that the Quinsam River has low sensitivity to acidic inputs (RISC 1997b).

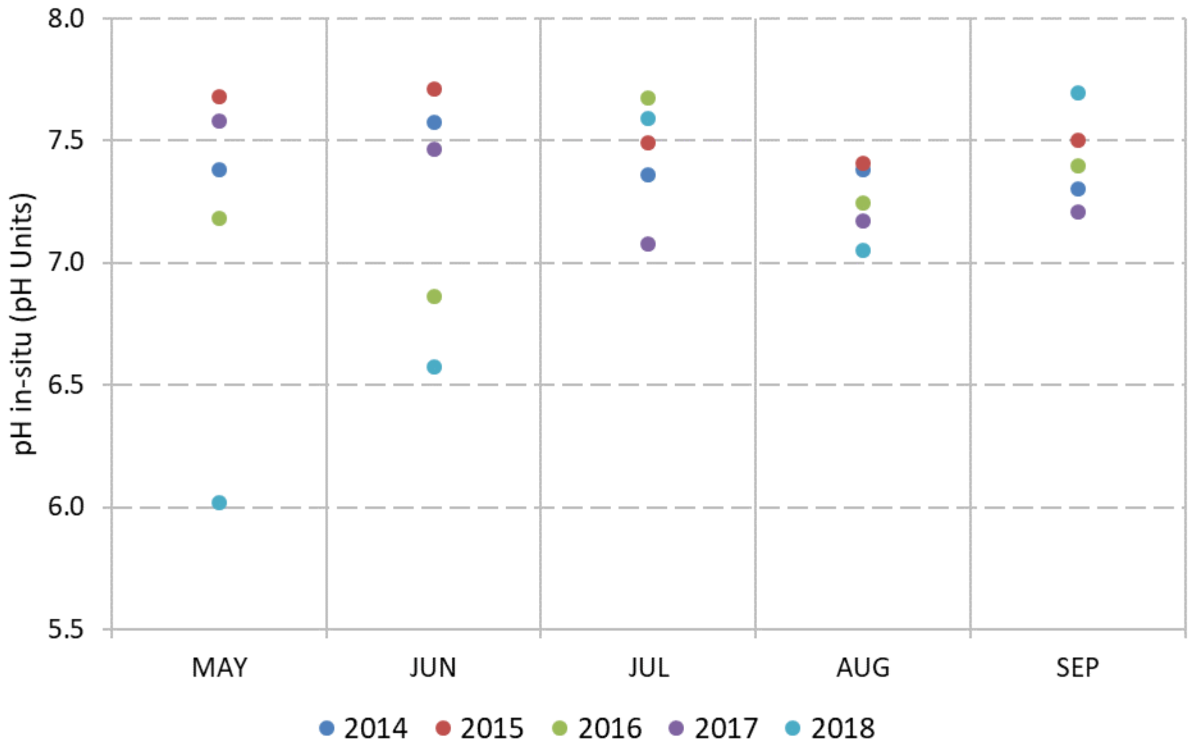
Figure 36. Alkalinity (as $CaCO_3$ mg/L) in the Quinsam River.



pH

pH values measured in the laboratory in Year 5 ranged from 7.59 to 7.85, while *in situ* pH ranged from 6.02 to 7.69 (Table 28 and Figure 37, respectively). The laboratory values are consistent with those measured in previous years, however the *in situ* (Figure 37) measurements from May and June 2018 are markedly lower than those previously observed and those measured by the laboratory on corresponding dates. Natural fresh waters have a pH range from 4 to 10, BC lakes tend to have a pH ≥ 7.0, and coastal streams commonly have pH values of 5.5 to 6.5 (RISC 1997b). Given that the pH measured in the laboratory samples exceeded the recommended hold time, the *in situ* measurements are generally considered to be more accurate; however, there is uncertainty regarding the two lowest *in situ* values measured in 2018, as described above.

Figure 37. pH measured *in situ* in the Quinsam River.



Specific Conductivity and Total Dissolved Solids

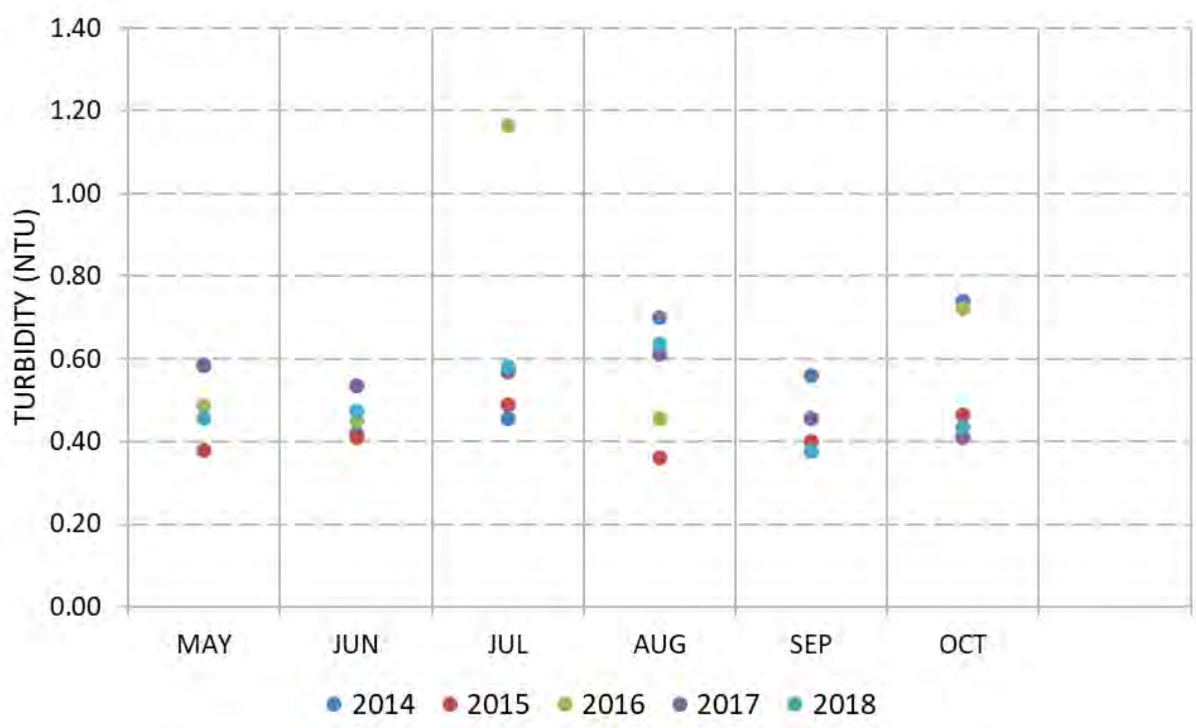
In situ specific conductivity (conductivity normalized to 25°C) measured in Year 5 ranged from 95.9 µS/cm (May) to 153.4 µS/cm (October; Table 28). Values were similar to previous years. Coastal BC streams generally have specific conductivity of ~100 µS/cm (RISC 1997b). Most specific conductivity values in the Quinsam River were higher than typical levels in coastal streams. This may reflect the influence of primary productivity in the two lakes upstream of the monitoring site. Alternatively, high values of specific conductivity measured in the past have previously been linked with coal mining activities in the watershed (Redenbach 1990, cited in Burt 2003).

Total dissolved solids measured in the lab for the Quinsam River ranged from 70 mg/L (May) to 97 mg/L (June; Table 30) in Year 5. These are within the range of values previously observed (69 mg/L to 145 mg/L), which have a mean of 92 mg/L.

Turbidity and Total Suspended Solids (TSS)

Turbidity in the Quinsam River at QUN-WQ was low in all five monitoring years, indicating high water clarity (values in 2018 ranged from 0.38 NTU to 0.64 NTU; Figure 38). Similarly, TSS concentrations in 2018 (not plotted) were low and consistent with previous years, with values generally ranging from below the MDL of 1.0 mg/L to slightly above this MDL (1.4 mg/L). An exception was analysis of the September 12 sample, for which the laboratory was only able to provide low precision analysis (MDL = 3 mg/L), with the measurement below this MDL (Table 30).

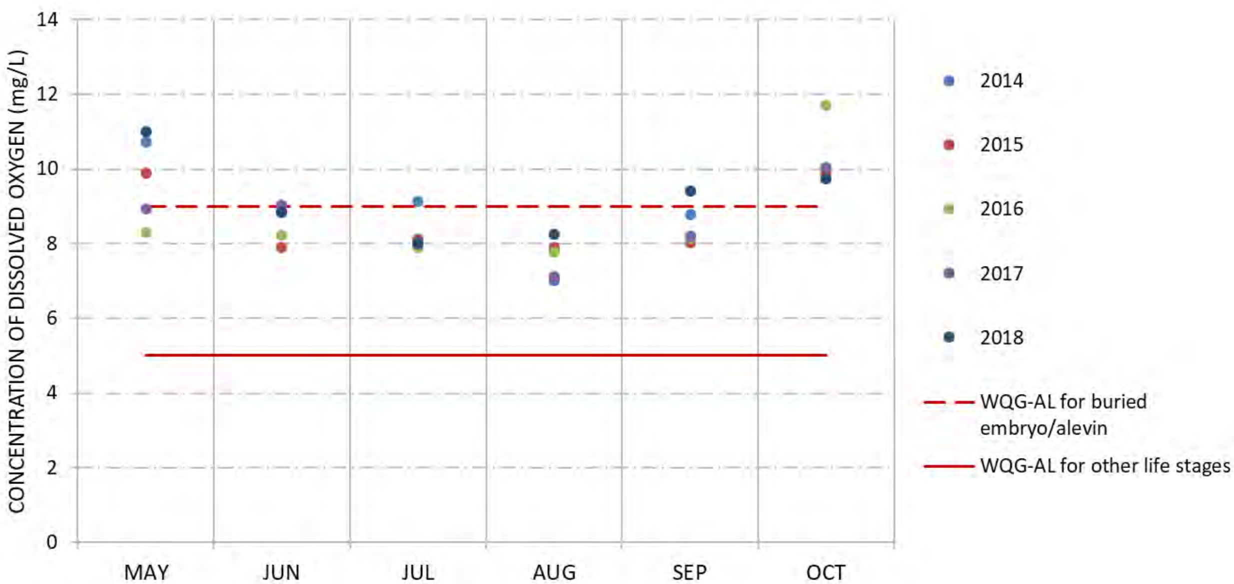
Figure 38. Turbidity in the Quinsam River.



Dissolved Oxygen

In Year 5, dissolved oxygen concentrations and % saturation in the Quinsam River were highest in May 2018 (when flows were elevated). However, during June to August 2018, the average DO concentration did not meet the more conservative provincial WQG-AL (DO instantaneous minimum of 9 mg/L) for the protection of buried embryos/alevins (Table 29; BC MOE 1997). There was some overlap (June) between the low DO period (<9.0 mg/L) and Rainbow Trout and steelhead incubation periods which extend into mid-June (see Table 37). This is consistent with previous years, when the guideline has not been met on occasion in May and is typically not met in June (Figure 39). Otherwise, all samples from the five years of monitoring met the WQG-AL for life stages other than buried embryo/alevin (DO instantaneous minimum of 5 mg/L; Figure 39).

Figure 39. Dissolved oxygen concentrations measured in the water column, Quinsam River.



Total Gas Pressure

Monitoring TGP was discontinued in Year 2 following evaluation of results in Year 1, and the limited potential of the Quinsam River diversion to cause elevated TGP concentrations. Results from TGP monitoring in Year 1 are presented in Appendix A.

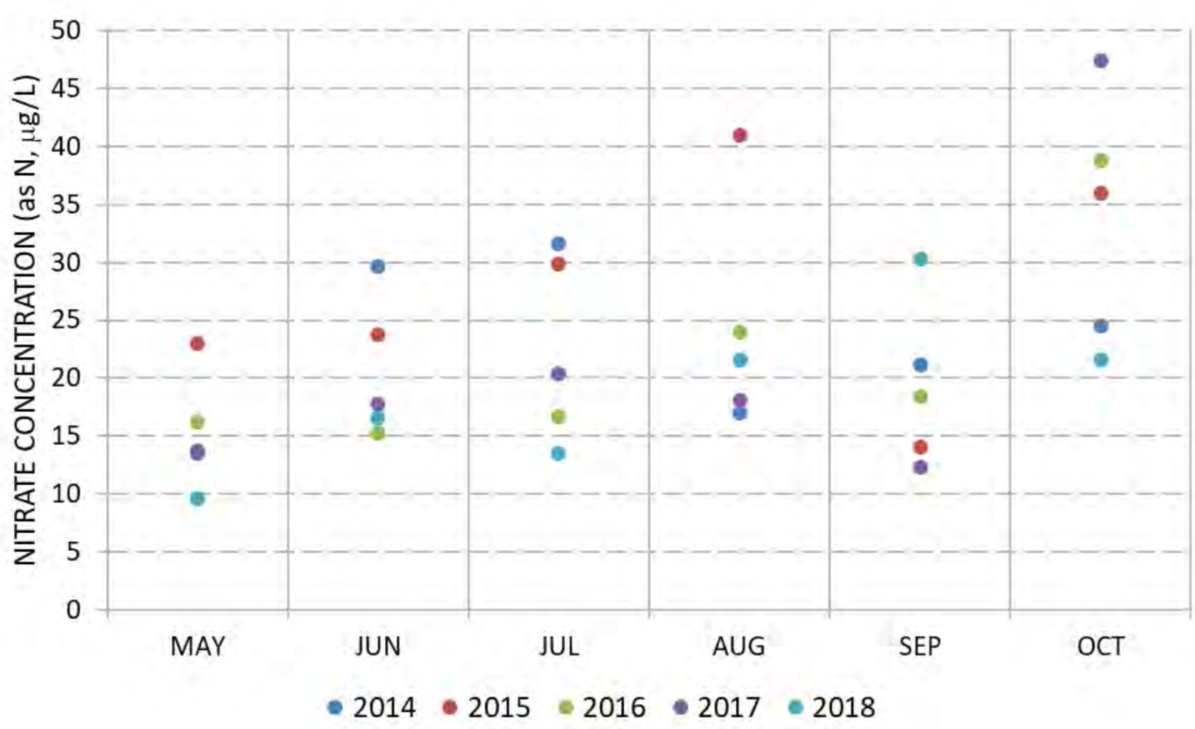
Nitrogen

Total ammonia concentrations in the Quinsam River at QUN-WQ were less than the detection limit of 5.0 µg N/L in five of the six sampling events in 2018 (Table 31), similar to previous years. During the October sampling event, total ammonia concentrations were detectable (average of 16.8 µg/L as N), but well below the WQG-AL. Ammonia is usually present at low concentrations (<100 µg N/L) in waters not affected by waste discharges (Nordin and Pommen 1986).

Nitrite concentrations were below the detection limit of 1.0 µg N/L for all the monthly sampling dates in 2018, consistent with previous years (Table 31). Nitrite is an unstable intermediate ion serving as an indicator of recent contamination from sewage and/or agricultural runoff; levels are typically <1.0 µg N/L (RISC 1997b).

Nitrate concentrations were low and ranged from 9.6 µg N/L (May) to 30.4 µg N/L (September) during 2018, similar to previous years (Figure 40; Table 31). The lowest concentration measured in May was the lowest mean concentration measured to date (Figure 40) and it corresponded to a sample with a hold time exceedance (Section 3.3.2.1). It is possible that this measurement was biased low due to the hold time exceedance (e.g., due to nitrate uptake by primary producers following sampling), although the magnitude of any error is expected to be low as the measurement was only slightly outside of the range of the other values (12.3–47.4 µg N/L). In oligotrophic lakes and streams, nitrate concentrations are usually lower than 100 µg N/L (Nordin and Pommen 1986).

Figure 40. Nitrate concentrations in the Quinsam River.



Phosphorus

Orthophosphate concentrations were below the detection limit of 1.0 µg P/L for all but one duplicate (1.5 µg P/L) during sampling in Year 5, similar to previous years (Table 31). Low orthophosphate concentrations are typical of coastal BC streams, which generally have orthophosphate concentrations <1.0 µg P/L (Slaney and Ward 1993; Ashley and Slaney 1997).

Total phosphorus concentrations over the Year 5 sampling period were low, similar to previous years, ranging from 2.7 µg P/L to 5.5 µg P/L (Table 31).

3.3.3. Water and Air Temperature Monitoring

3.3.3.1. Salmon River

The full records of water and air temperature measurements from Year 1 to Year 4 at SAM-WQ are shown in Figure 41 and Figure 42 respectively. Mean weekly maximum temperature statistics are shown in Table 32. These figures and table are reproduced from the Year 4 Annual Report (Sharron *et al.* 2018) to provide a summary of all data collected on the Salmon River during the JHTMON-8 program; readers should consult that report for discussion of the results.

Figure 41. Water temperature in the Salmon River (SAM-WQ) between May 2014 and October 2017. The gap in the records is due to missing TidbiTs.

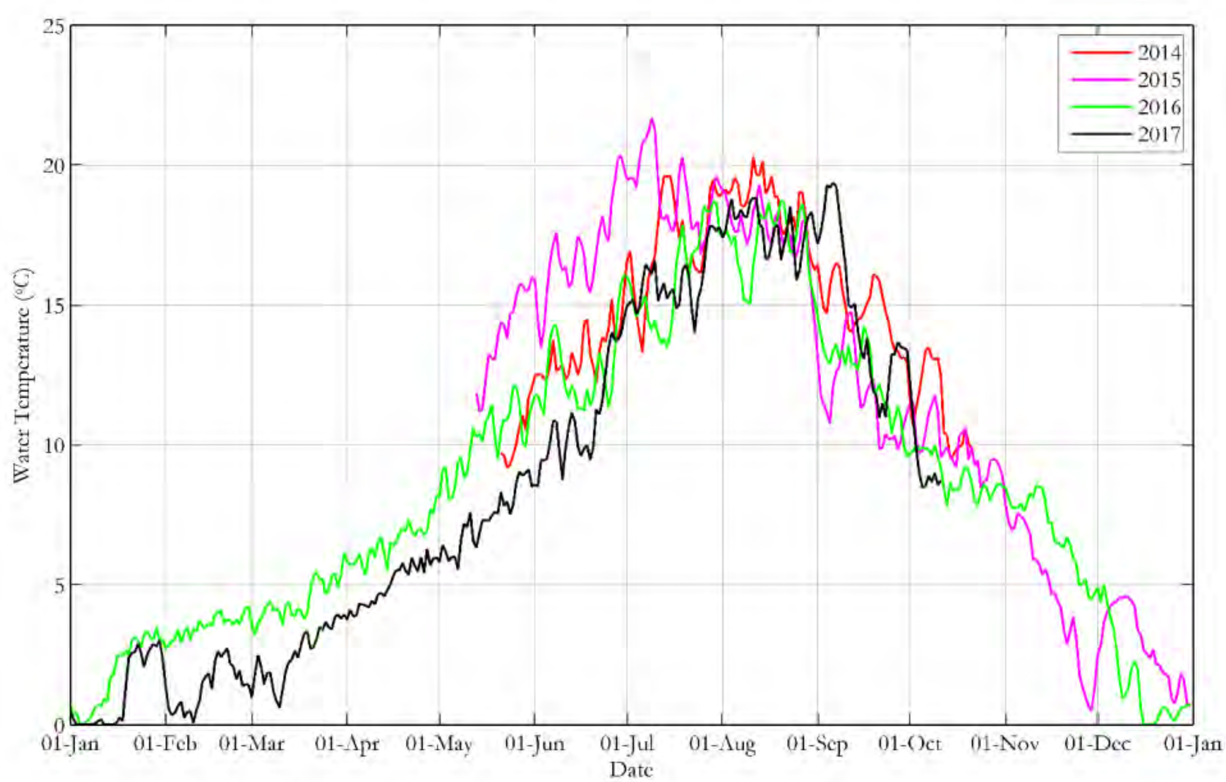
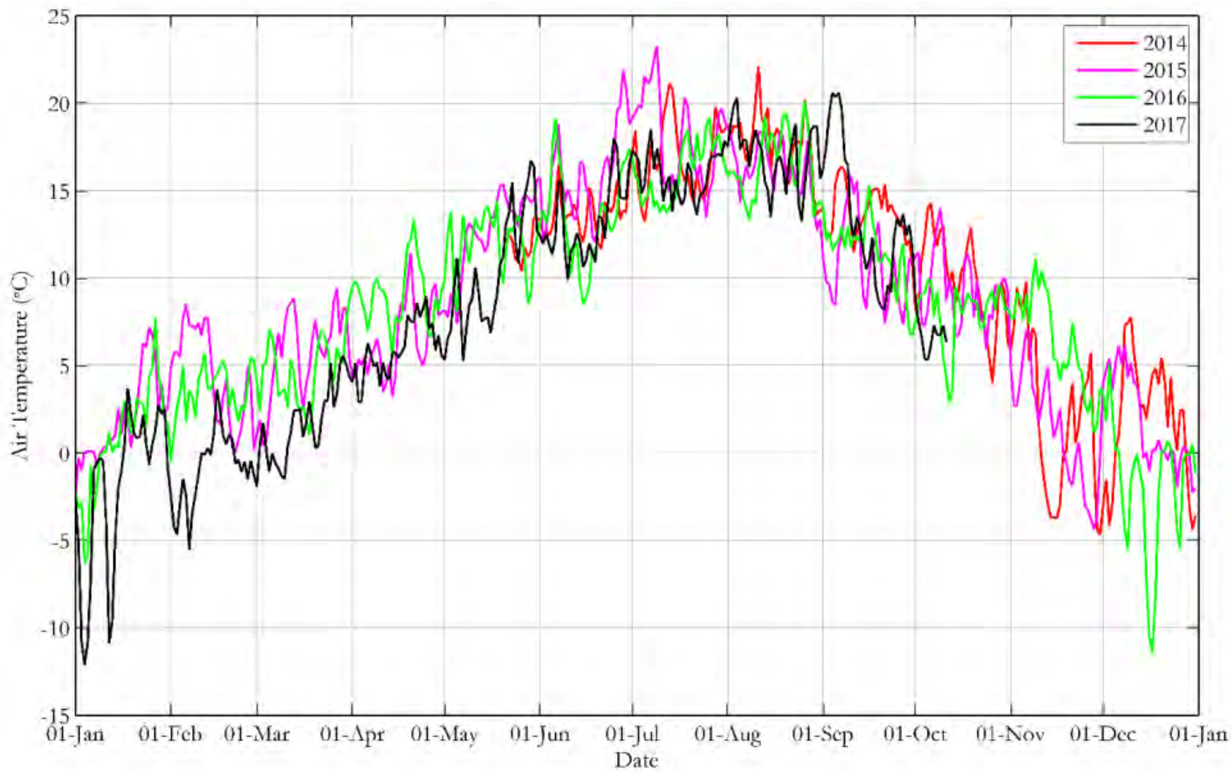


Table 32. Mean weekly maximum temperatures (MWMxT) in the Salmon River from 2014 to 2017 compared to optimum temperature ranges for fish species present. Periodicity information is from Burt (2010).

Species	Life Stage: Periodicity	Life Stage: Optimum Temperature Range (°C)	Life Stage: Duration (days)	Year	Percent Complete	MWMxT (°C): Min.	MWMxT (°C): Max.	% of MWMxT: Below Lower Bound by >1°C	% of MWMxT: Below Lower Bound	% of MWMxT: Between Bounds	% of MWMxT: Above Upper Bound	% of MWMxT: Above Upper Bound by >1°C
Chinook Salmon	Migration (Jul. 16 to Sep. 30)	3.3-19.0	77	2014	100	13.1	22.2	0.0	0.0	51.9	48.1	36.4
				2015	100	10.6	21.0	0.0	0.0	50.6	49.4	23.4
				2016	98.7	10.8	21.1	0.0	0.0	63.2	36.8	26.3
				2017	100	13.1	21.1	0.0	0.0	42.9	57.1	32.5
	Spawning (Sep. 01 to Oct. 31)	5.6-13.9	61	2014	80.3	10.2	17.7	0.0	0.0	42.9	57.1	46.9
				2015	98.4	8.4	15.4	0.0	0.0	88.3	11.7	8.3
				2016	98.4	8.5	15.3	0.0	0.0	71.7	28.3	5.0
				2017	63.9	9.7	20.7	0.0	0.0	43.6	56.4	38.5
	Incubation (Sep. 01 to Apr. 22)	5.0-14.0	234	2014	21.4	-	-	-	-	-	-	-
				2015	99.6	0.4	15.4	33.0	52.4	44.6	3.0	1.7
				2016	100	0.0	15.3	46.6	54.7	38.0	7.3	1.3
				2017	16.7	-	-	-	-	-	-	-
	Rearing (Mar. 08 to Jul. 22)	10.0-15.5	137	2014	45.3	-	-	-	-	-	-	-
				2015	51.8	12.9	23.3	0.0	0.0	9.9	90.1	85.9
				2016	99.3	4.6	18.9	38.2	41.2	42.6	16.2	9.6
				2017	100	1.9	18.1	52.6	55.5	24.8	19.7	15.3
Coho Salmon	Migration (Sep. 01 to Nov. 30)	7.2-15.6	91	2014	53.8	10.2	17.7	0.0	0.0	55.1	44.9	24.5
				2015	98.9	1.7	15.4	22.2	26.7	73.3	0.0	0.0
				2016	98.9	5.1	15.3	8.9	15.6	84.4	0.0	0.0
				2017	42.9	-	-	-	-	-	-	-
	Spawning (Oct. 01 to Dec. 15)	4.4-12.8	76	2014	26.3	-	-	-	-	-	-	-
				2015	98.7	1.7	11.9	14.7	29.3	70.7	0.0	0.0
				2016	100	1.2	10.8	11.8	14.5	85.5	0.0	0.0
				2017	11.8	-	-	-	-	-	-	-
	Incubation (Oct. 01 to Apr. 15)	4.0-13.0	197	2014	10.2	-	-	-	-	-	-	-
				2015	99.5	0.4	11.9	21.4	39.3	60.7	0.0	0.0
				2016	100	0.0	10.8	49.5	55.1	44.9	0.0	0.0
				2017	4.6	-	-	-	-	-	-	-
	Rearing (Jan. 01 to Dec. 31)	9.0-16.0	365	2014	41.6	-	-	-	-	-	-	-
				2015	63.4	1.0	23.3	25.9	27.2	29.3	43.5	41.4
				2016	99.5	0.2	21.1	44.9	53.7	30.3	16.0	12.9
				2017	77.3	0.0	21.1	46.8	48.9	23.8	27.3	24.8
Rainbow Trout/ Steelhead	Spawning (Mar. 01 to May. 31)	10.0-10.5	92	2014	10.9	-	-	-	-	-	-	-
				2015	19.6	-	-	-	-	-	-	-
				2016	98.9	4.2	12.8	64.8	69.2	4.4	26.4	20.9
				2017	100	1.9	10.6	85.9	90.2	6.5	3.3	0.0
	Incubation (Mar. 01 to Jun. 30)	10.0-12.0	122	2014	32.8	-	-	-	-	-	-	-
				2015	39.3	-	-	-	-	-	-	-
				2016	99.2	4.2	17.0	48.8	52.1	14.0	33.9	19.8
				2017	100	1.9	16.3	64.8	68.0	23.0	9.0	7.4
	Rearing (Jan. 01 to Dec. 31)	16.0-18.0	365	2014	41.6	-	-	-	-	-	-	-
				2015	63.4	1.0	23.3	53.0	56.5	6.9	36.6	31.0
				2016	99.5	0.2	21.1	81.3	84.0	5.5	10.5	7.7
				2017	77.3	0.0	21.1	70.6	72.7	10.3	17.0	15.6

Blue shading indicates provincial guideline exceedance of the lower bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).
Red shading indicates provincial guideline exceedance of the upper bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).

Figure 42. Air temperature at the Salmon River (SAM-AT) between May 2014 and October 2017.



3.3.3.2. Quinsam River

Summary of Water Temperature Records

Figure 43 shows the daily average water temperatures at QUN-WQ from May 2014 to October 2018. In 2018, monthly average water temperatures ranged between 2.9°C (January and February) and 20.1°C (August; Table 33). The August 2018 mean value was the highest in the five-year record, slightly higher than the mean temperature in August 2017 of 20.0ºC (Table 33).

The water temperature records for the Quinsam River show occurrences of warm water temperatures from a fisheries biology perspective. In 2018, there were 55 days (15%) with daily mean temperatures above 18°C, and 30 days (8%) with daily mean temperature above 20°C. Over the period of record between 2014 and 2017, there were 52 to 77 days per year (14% to 21%) with daily mean temperatures above 18°C, and 14 to 25 days (4% to 7%) with daily mean temperatures above 20°C (Table 34). The frequency of days with the mean daily temperature >20ºC (30 days) was therefore greater in Year 5 than in any of the preceding four years of monitoring. There were no days in Year 5 with mean water temperature <1ºC and this only occurred in 2017 (7 days).

Figure 43. Daily mean water temperatures in the Quinsam River (QUN-WQ) between May 2014 and October 2018.

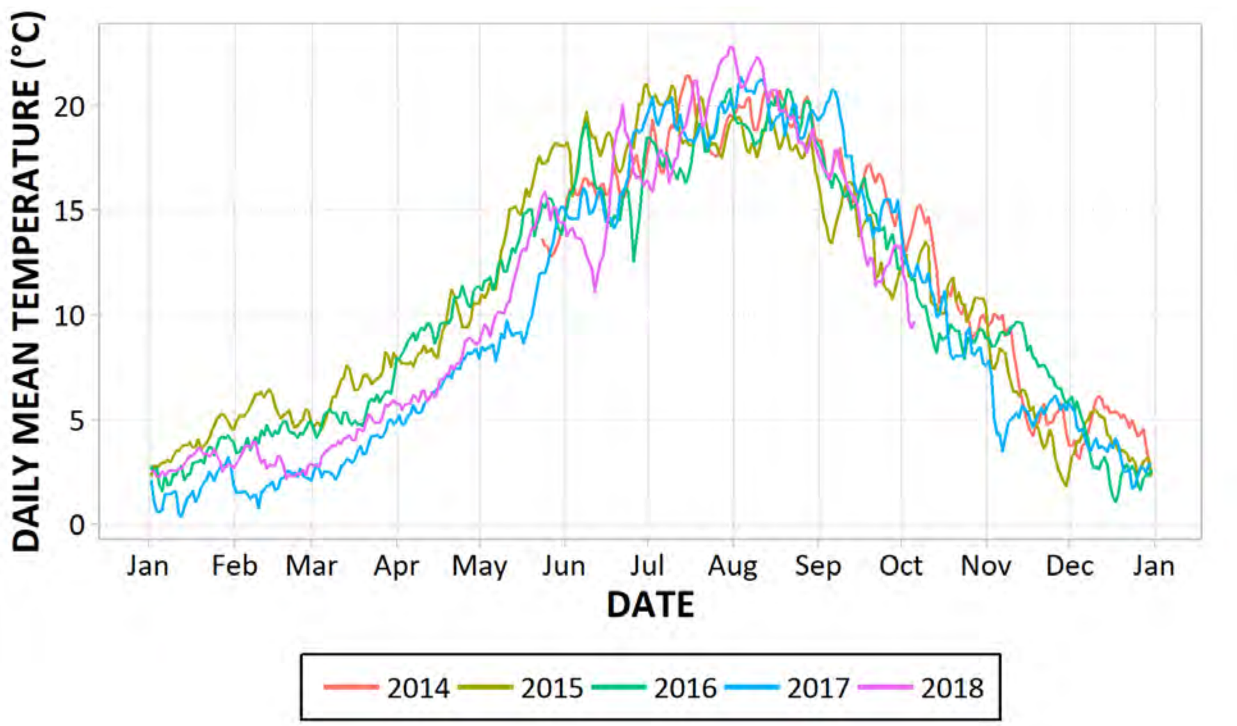


Table 33. Monthly water temperature in the Quinsam River (QUN-WQ) from 2014 to 2018. Statistics were not calculated for months with less than 3 weeks of observations.

Month	2014[1,2,3]				2015[1,3]				2016[1,3]				2017[1,3]				2018[1,2,3]			
	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
Jan	n/a	n/a	n/a	n/a	3.8	2.0	5.6	0.8	2.9	1.2	4.6	0.8	1.7	0.0	3.5	0.9	2.9	2.0	3.8	0.4
Feb	n/a	n/a	n/a	n/a	5.5	4.1	6.5	0.6	4.3	3.1	5.2	0.5	1.9	0.1	3.1	0.6	2.9	1.9	4.1	0.5
Mar	n/a	n/a	n/a	n/a	6.6	4.0	8.9	1.1	5.5	3.3	9.2	1.0	3.5	1.6	5.9	1.0	4.4	2.5	6.4	0.9
Apr	n/a	n/a	n/a	n/a	9.0	6.6	12.7	1.3	9.8	6.8	12.4	1.2	6.7	3.9	9.9	1.3	7.0	5.0	9.9	1.2
May	n/a	n/a	n/a	n/a	15.1	9.6	18.5	2.5	13.7	10.1	16.2	1.5	10.6	6.7	16.6	2.4	12.6	8.3	16.9	2.4
Jun	16.3	14.4	18.8	0.7	18.3	15.0	23.0	1.4	16.1	11.9	19.8	1.7	16.1	13.6	20.2	1.8	15.3	10.1	20.6	2.5
Jul	18.9	16.5	22.7	1.4	19.2	16.0	23.0	1.6	18.2	15.5	21.2	1.3	19.3	17.6	20.9	0.8	19.4	14.9	23.6	2.2
Aug	19.8	17.5	22.2	1.0	18.3	15.9	21.2	1.1	19.3	17.7	21.3	0.9	20.0	18.0	21.8	0.9	20.1	17.3	23.1	1.5
Sep	16.3	13.9	18.6	1.1	13.7	10.2	17.0	1.8	15.1	11.8	18.1	1.4	16.8	13.4	21.1	2.3	14.6	10.8	18.6	2.1
Oct	11.8	8.3	15.5	2.1	11.2	9.3	13.7	1.1	9.6	7.4	13.1	1.2	10.0	7.1	13.9	1.8	n/a	n/a	n/a	n/a
Nov	6.6	3.6	10.3	2.2	5.3	1.5	10.0	2.1	8.0	5.5	9.8	1.3	5.4	3.1	8.1	0.8	n/a	n/a	n/a	n/a
Dec	4.5	2.1	6.2	1.0	3.8	2.0	5.6	1.0	2.8	0.6	6.2	1.2	3.4	1.5	5.7	0.9	n/a	n/a	n/a	n/a

[1]"Avg", "Min", "Max" and "SD" denote the monthly average, minimum, maximum, and standard deviation of water temperatures
[2]"n/a" indicates that TidbiTs were not installed.
[3]Blue and orange shadings highlight minimum and maximum temperatures, respectively.

Table 34. Summary of the frequency of exceedances of mean daily water temperature extremes (T_{water}>18°C, T_{water}>20°C, and T_{water}<1°C) in the Quinsam River at QUN-WQ from 2014 to 2018.

Year	Record Length (days)	Days T_{water}> 20°C	Days T_{water}> 18°C	Days T_{water} < 1°C
2014	222	20	54	0
2015	365	16	69	0
2016	366	14	52	0
2017	365	25	77	7
2018	277	30	55	0

Rates of Change

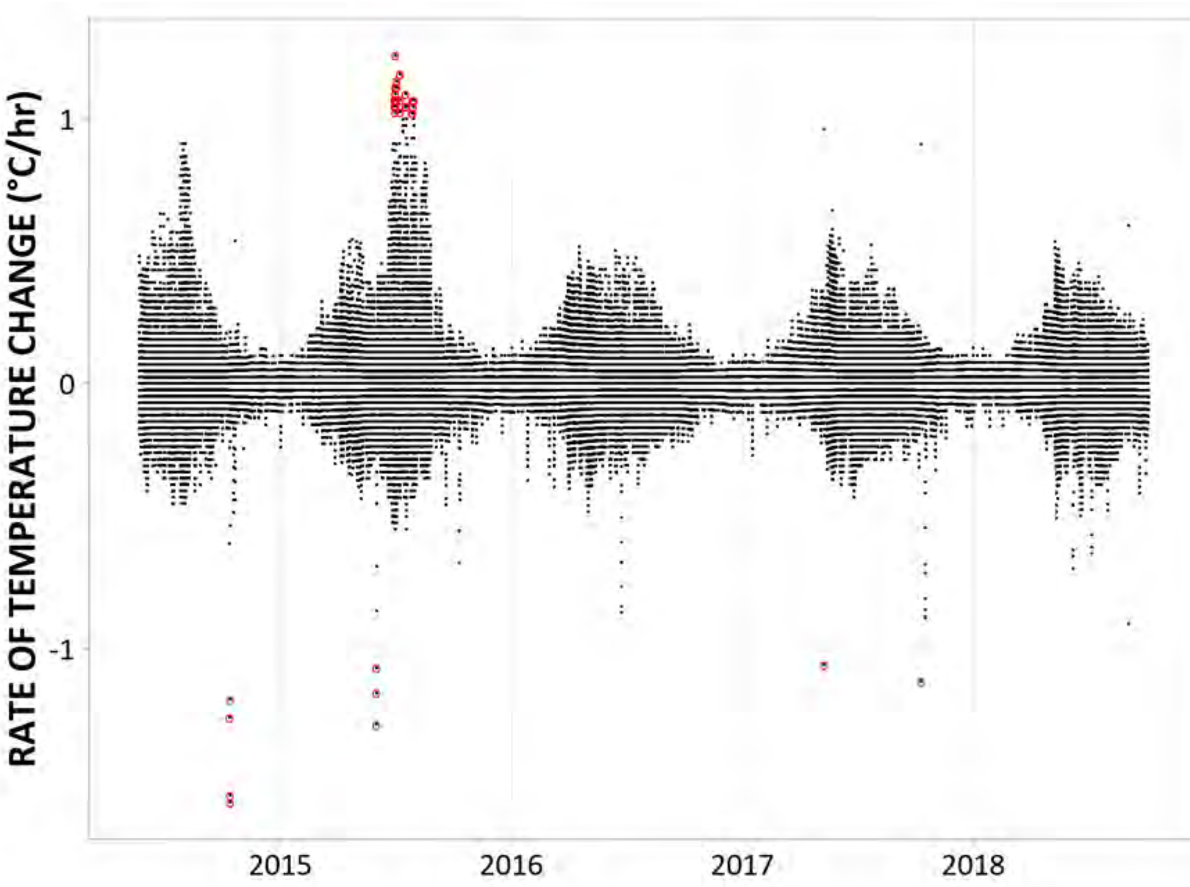
Rates of change of water temperature at QUN-WQ are summarized in Table 35 and presented in Figure 44. For the period of record, the hourly rates of temperature change at QUN-WQ were between -0.2°C/hr and +0.2°C/hr for at least 90% of the time (based on the 5th and 95th percentiles) and were between -0.3°C/hr and +0.4°C/hr for at least 98% of the time (based on the 1st and 99th percentiles).

The maximum rate of temperature increase was +1.2°C/hr, and the maximum rate of temperature decrease was -1.6°C/hr (Table 35). Rates of temperature change with magnitudes >1°C/hr occurred for 0.02% of the records. Based on our experience on other streams in BC, it is normal for a small percentage of data points to have hourly rates of water temperature change that exceed ±1°C.

Table 35. Statistics for the hourly rates of change in water temperature at QUN-WQ in the Quinsam River, 2014–2018.

Station	Start of record	End of record	Number of Datapoints	Occurrence of rates >1°C/hr		Maximum Negative Rate	Percentile				Maximum Positive Rate
				Number	% of record		1th	5th	95th	99th	
QUN-WQ	23-May-2014	5-Oct-2018	153,216	27	0.02	-1.6	-0.3	-0.2	0.2	0.4	1.2

Figure 44. Hourly rate of change in 15-minute water temperature in the Quinsam River (QUN-WQ) from 2014 to 2018. Large red dots indicate rates with magnitudes exceeding ±1°C/hr.



Growing Season and Accumulated Thermal Units

The length of the growing season and accumulated thermal units (or degree days) are important indicators of the productivity of aquatic systems. As explained in Table 20, the growing season was taken to begin when the weekly average water temperature exceeded and remained above 5°C, and to end when the weekly average temperature dropped below 4°C (as per Coleman and Fausch 2007).

The growing season at QUN-WQ was determined for 2015 – 2017 (Years 2 – 4) for which complete annual records exist (Table 36). The most recent growing season for which data is available was 2017 (Year 4) for which the growing season commenced on March 28th, ended on December 9th, covering a period of 252 days, and accumulating 3,147 degree days. This was shorter than the growing season length calculated for Year 2 (259 days) and Year 3 (266 days). Growing season statistics for the 2018 growing season will be reported in the Year 6 report when all 2018 data are available.

Table 36. The growing season and growing degree days at QUN-WQ in the Quinsam River (2014 to 2018).

Station	Year	Number of days with valid data	Growing Season				
			Start Date	End Date	Length (day)	Gap (day)	Degree Days
QUN-WQ	2014†	223	-	23-Dec-2014	-	-	-
	2015	365	2-Mar-2015	18-Nov-2015	259	0	3,511
	2016	366	15-Mar-2016	8-Dec-2016	266	0	3,454
	2017	365	28-Mar-2017	9-Dec-2017	252	0	3,147
	2018‡	278	26-Mar-2018	-	-	-	-

†Growing season could not be estimated because a complete data set over the course of the growing season is not available.
‡Growing season will be reported once the data set covers a complete growing season.

Mean Weekly Maximum Water Temperatures

Fish species of primary interest for JHTMON-8 in the Quinsam River are steelhead, Coho Salmon and Chinook Salmon, although Pink Salmon are also particularly important to fishery managers. Steelhead and Coho Salmon are present both upstream and downstream of QUN-WQ, although falls and cascades downstream of Lower Quinsam Lake are complete barriers to Chinook Salmon and Pink Salmon (Burt 2003). Thus, results for the latter two species should be interpreted with caution.

The MWMxT data for 2014 through 2018 are compared to optimum temperature ranges for fish species in Table 37. For each life stage, Table 37 also shows the percentage of MWMxT data that are above, within, and below the optimum ranges for fish life stages during baseline monitoring. The percentages of MWMxT data above and below the optimum ranges by more than 1°C are also shown. Comparisons to the provincial WQG-AL are not made when records are ≤50% complete for the period of interest (Table 37). In addition, if the water temperature records are only slightly >50% complete for a particular species/life stage, comparisons to the provincial WQG-AL should be interpreted with caution.

Considering all years and all species/life stages, MWMxT in the Quinsam River exceeded optimum ranges by more than 1°C for an average 16.4% of the time and were below optimum ranges by more than 1°C an average 28.7% of the time.

For Chinook Salmon, all MWMxT values for all years (2014 – 2017) were with the optimum range for migration. Temperatures for spawning were mostly within the optimum range (57.4 – 100% of the time) with instances where ranges were exceeded by more than 1°C only occurring in 2014 and 2015. Temperatures during incubation were cooler than the optimum range at times during all years, particularly in 2016, when 52.3% of values exceeded the lower bound by more than 1°C. Water temperatures were outside the optimum range during most of the Chinook Salmon rearing period (temperatures were within the optimum range for 13.1–36.5 of the time). Year 5 (2018) was slightly cooler than average with 40.9% of values below the optimum range and 32.1% of values above the optimum range.

For Coho Salmon, temperatures were typically below the upper bound of the optimum ranges for migration, spawning, and incubation stages (except migration in 2014, where 6.5% of the temperatures were > 1°C higher than the upper bound). Water temperatures during the rearing period were highly variable, with the majority of values outside the optimum range (both above and below) for all years. Like other years, Year 5 (2018), water temperatures during the Coho Salmon rearing period were below the lower bound (41.1%) more often than above the upper bound (33.1%) of the optimum temperature range.

For Pink Salmon, the analysis indicates that for all years except Year 2 (2015), the majority of MWMxT values were above the upper bound for migration and spawning, with some years exceeding the upper bound by more than 1ºC for the majority of the time (up to 83% of the spawning period in 2014). Conditions in 2018 were within the ranges observed in 2014 - 2017. During the Pink Salmon incubation period, water temperatures were within optimum ranges for the majority of time, except 2016 when 42.6% of values were within the optimum range.

For steelhead, MWMxT were rarely (0% to 21.8% of the records) within the optimum ranges for any life stage. Most notably, water temperatures during the spawning stage between 2015 and 2018 were below the optimum range by more than 1°C for 75.0% to 100% of the time. In 2018, water temperatures were within the optimum bounds for 0% of the spawning stage, 6.7% of the incubation stage, and 10.9% of the rearing stage. Note that the WQG-AL temperature ranges for steelhead life stages are based on those for 'Rainbow Trout' (Oliver and Fidler 2001) and are not specific to fish with an anadromous life history (i.e., steelhead). Data specific to steelhead (Carter 2005 and references therein) indicate that steelhead are adapted to tolerate MWMxT considerably lower than the optimum ranges presented in Table 37 during spawning and incubation, although survival is likely to be affected by temperatures that exceed these ranges. For example, Carter (2005) cites WDOE (2002), which reports that the low end of the range of preferred spawning temperatures for steelhead is 4.4°C, rather than the value of 10.0°C reported in Table 37 for Rainbow Trout. Thus, although the alternative values cited above may not be fully representative of steelhead populations on Vancouver Island, the occurrence of MWMxT in the Quinsam River that are below 10.0°C do not necessarily indicate poor conditions for spawning and incubation steelhead life stages.

Table 37. Mean weekly maximum temperatures (MWMxT) in the Quinsam River from 2014 to 2018 compared to optimum temperature ranges for fish species present. Periodicity information is from Burt (2003).

Species	Life Stage: Periodicity	Life Stage: Optimum Temperature Range (°C)	Life Stage: Duration (days)	Year	Percent Complete	MWMxT (°C): Min.	MWMxT (°C): Max.	% of MWMxT: Below Lower Bound by >1°C	% of MWMxT: Below Lower Bound	% of MWMxT: Between Bounds	% of MWMxT: Above Upper Bound	% of MWMxT: Above Upper Bound by >1°C
Chinook Salmon	Migration (Sep. 23 to Nov. 22)	3.3-19.0	61	2014	100	5.2	16.5	0.0	0.0	100.0	0.0	0.0
				2015	100	4.4	12.9	0.0	0.0	100.0	0.0	0.0
				2016	100	7.3	14.4	0.0	0.0	100.0	0.0	0.0
				2017	100	4.7	15.6	0.0	0.0	100.0	0.0	0.0
				2018	16.4	-	-	-	-	-	-	-
	Spawning (Oct. 01 to Nov. 30)	5.6-13.9	61	2014	100	4.6	15.0	0.0	26.2	57.4	16.4	3.3
				2015	100	2.8	12.9	16.4	23.0	77.0	0.0	0.0
				2016	100	6.0	12.6	0.0	0.0	100.0	0.0	0.0
				2017	100	4.7	14.0	0.0	26.2	72.1	1.6	0.0
				2018	3.3	-	-	-	-	-	-	-
	Incubation (Oct. 16 to Apr. 30)	5.0-14.0	197	2014	100	2.8	11.6	9.6	21.3	78.7	0.0	0.0
				2015	100	2.4	12.5	25.8	49.0	51.0	0.0	0.0
				2016	100	1.3	9.6	52.3	57.4	42.6	0.0	0.0
				2017	100	2.6	10.1	42.1	54.3	45.7	0.0	0.0
				2018	0	-	-	-	-	-	-	-
	Rearing (Mar. 08 to Jul. 22)	10.0-15.5	137	2014	42.3	-	-	-	-	-	-	-
				2015	100	6.6	22.5	22.6	29.2	19.0	51.8	48.2
				2016	100	5.4	19.3	17.5	22.6	36.5	40.9	26.3
				2017	100	2.8	20.3	42.3	50.4	13.1	36.5	23.4
				2018	100	4.0	21.0	34.3	40.9	27.0	32.1	26.3
Coho Salmon	Migration (Sep. 16 to Dec. 31)	7.2-15.6	107	2014	100	3.1	17.1	44.9	45.8	44.9	9.3	6.5
				2015	100	2.8	14.9	43.9	48.6	51.4	0.0	0.0
				2016	100	2.2	16.2	30.8	36.4	60.7	2.8	0.0
				2017	100	2.6	16.0	55.1	56.1	41.1	2.8	0.0
				2018	15.9	-	-	-	-	-	-	-
	Spawning (Oct. 16 to Jan. 15)	4.4-12.8	92	2014	100	2.8	11.6	10.9	28.3	71.7	0.0	0.0
				2015	100	2.4	11.4	33.7	47.8	52.2	0.0	0.0
				2016	100	1.3	9.6	41.3	44.6	55.4	0.0	0.0
				2017	100	2.6	10.1	29.3	44.6	55.4	0.0	0.0
				2018	0	-	-	-	-	-	-	-
	Incubation (Oct. 16 to Dec. 31)	4.0-13.0	77	2014	100	3.1	11.6	0.0	6.5	93.5	0.0	0.0
				2015	100	2.8	11.4	5.2	31.2	68.8	0.0	0.0
				2016	100	2.2	9.6	27.3	32.5	67.5	0.0	0.0
				2017	100	2.6	10.1	14.3	22.1	77.9	0.0	0.0
				2018	0	-	-	-	-	-	-	-
	Rearing (Jan. 01 to Dec. 31)	9.0-16.0	365	2014	60.3	3.1	21.9	23.2	24.1	23.6	52.3	38.2
				2015	100	2.8	22.5	38.4	42.7	26.6	30.7	28.5
				2016	100	2.2	20.8	36.1	38.5	35.2	26.2	21.0
				2017	100	1.3	21.3	47.1	53.7	19.7	26.6	23.0
				2018	75.3	2.6	23.1	40.0	41.1	25.8	33.1	29.8

Blue shading indicates provincial guideline exceedance of the lower bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).
Red shading indicates provincial guideline exceedance of the upper bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).

Table 37. Continued.

Species	Life Stage			Year	Percent Complete	MWMxT (°C)		% of MWMxT				
	Periodicity	Optimum Temperature Range (°C)	Duration (days)			Min.	Max.	Below Lower Bound by >1°C	Below Lower Bound	Between Bounds	Above Upper Bound	Above Upper Bound by >1°C
Pink Salmon	Migration (Aug. 01 to Oct. 15)	7.2-15.6	76	2014	100	11.8	21.9	0.0	0.0	26.3	73.7	67.1
				2015	100	11.0	20.9	0.0	0.0	50.0	50.0	40.8
				2016	100	9.3	20.8	0.0	0.0	35.5	64.5	48.7
				2017	100	10.5	21.3	0.0	0.0	35.5	64.5	59.2
				2018	82.9	12.1	22.6	0.0	0.0	30.2	69.8	65.1
	Spawning (Sep. 16 to Oct. 15)	7.2-12.8	30	2014	100	11.8	17.1	0.0	0.0	10.0	90.0	83.3
				2015	100	11.0	14.9	0.0	0.0	70.0	30.0	16.7
				2016	100	9.3	16.2	0.0	0.0	50.0	50.0	33.3
				2017	100	10.5	16.0	0.0	0.0	40.0	60.0	53.3
				2018	56.7	12.1	14.4	0.0	0.0	35.3	64.7	11.8
	Incubation (Sep. 16 to Apr. 07)	4.0-13.0	204	2014	100	2.8	17.1	2.0	9.3	77.5	13.2	12.3
				2015	100	2.4	14.9	9.8	24.9	72.2	2.9	2.0
				2016	100	1.3	16.2	44.1	50.5	42.6	6.9	4.4
				2017	100	2.6	16.0	16.7	40.7	50.5	8.8	7.4
				2018	8.3	-	-	-	-	-	-	-
Rainbow Trout/ Steelhead	Spawning (Feb. 16 to Apr. 15)	10.0-15.5	60	2014	0	-	-	-	-	-	-	-
				2015	100	5.3	9.4	86.4	100.0	0.0	0.0	0.0
				2016	100	4.7	10.2	75.0	86.7	13.3	0.0	0.0
				2017	100	2.4	6.9	100.0	100.0	0.0	0.0	0.0
				2018	100	2.6	7.0	100.0	100.0	0.0	0.0	0.0
	Incubation (Feb. 16 to Jun.	10.0-12.0	121	2014	13.8	-	-	-	-	-	-	-
				2015	100	5.3	19.3	42.5	50.0	14.2	35.8	34.2
				2016	100	4.7	18.6	37.2	43.0	16.5	40.5	33.9
				2017	100	2.4	16.4	65.0	74.2	4.2	21.7	20.0
				2018	100	2.6	16.1	55.8	63.3	6.7	30.0	26.7
	Rearing (Jan. 01 to Dec. 31)	16.0-18.0	365	2014	60.3	3.1	21.9	45.0	47.7	21.8	30.5	22.7
				2015	100	2.8	22.5	65.8	69.3	4.4	26.3	18.1
				2016	100	2.2	20.8	64.8	73.8	10.4	15.8	10.9
				2017	100	1.3	21.3	66.3	73.4	4.7	21.9	19.5
				2018	75.3	2.6	23.1	62.2	66.9	10.9	22.2	17.5

Blue shading indicates provincial guideline exceedance of the lower bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).
Red shading indicates provincial guideline exceedance of the upper bound of the optimum temperature range by more than 1°C (Oliver and Fidler 2001).

Air Temperature

Figure 45 shows the daily average air temperature for the period of record from May 2014 to October 2018. The monthly average, minimum, and maximum air temperatures are shown in Table 38. The mean monthly air temperature ranged from -1.5°C to 18.5°C during the period of record. The lowest air temperature measured during the monitoring period was -12.8ºC measured in January 2017, while the highest air temperature was 33.3°C in July 2018. The maximum monthly mean air temperature (18.7°C) was in July 2015.

Air and water temperatures were highly correlated (Figure 46). Daily mean water temperatures typically exceeded daily mean air temperatures, which likely partly reflected the influence of warming in lakes upstream.

Figure 45. Air temperature at the Quinsam River (QUN-AT) between May 2014 and October 2018.

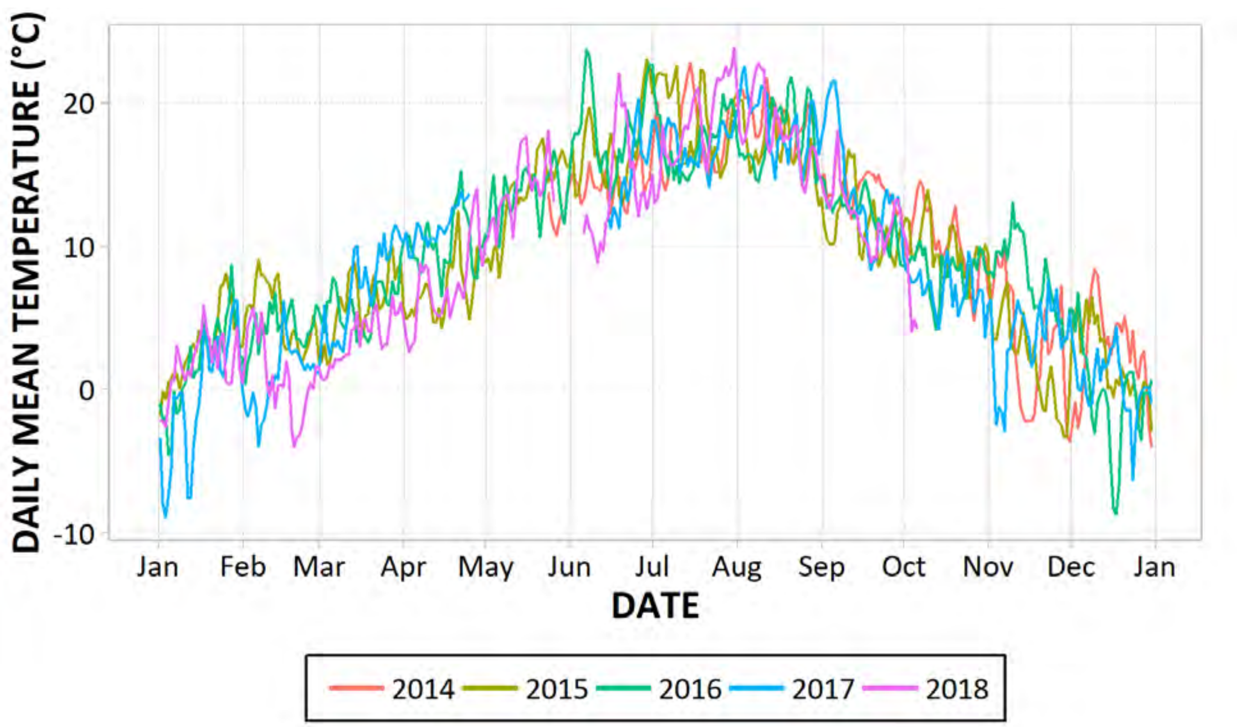
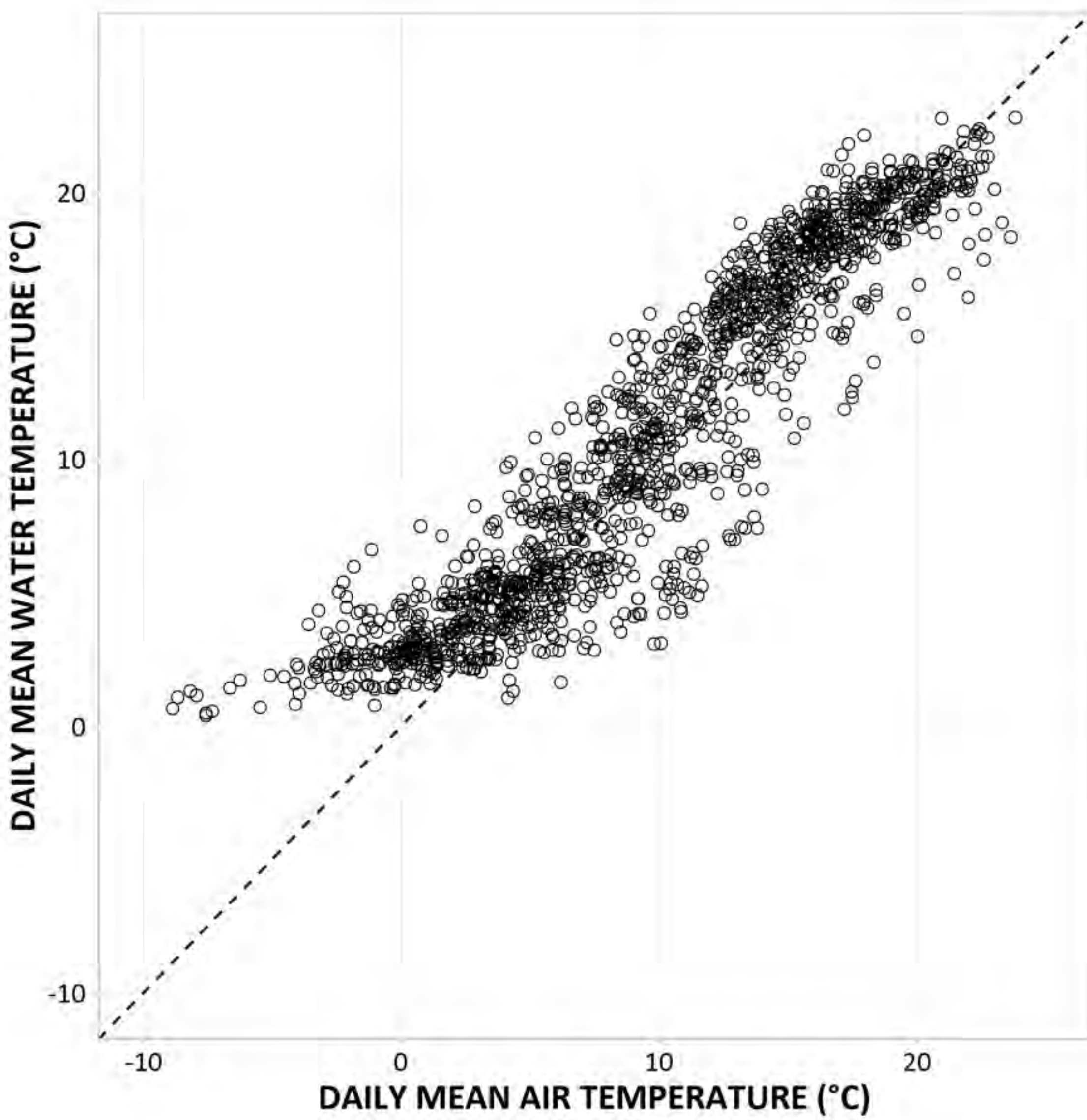


Table 38. Monthly air temperature statistics at the Quinsam River (QUN-AT) from 2014 to 2018. Statistics were not calculated for months with less than 3 weeks of observations.

Month	2014[1,2,3]				2015[1,3]				2016[1,3]				2017[1,2,3]				2018[1,2,3]			
	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD	Avg	Min	Max	SD
Jan	n/a	n/a	n/a	n/a	3.1	-4.6	9.5	2.7	1.7	-8.2	9.2	3.4	-0.7	-12.8	7.6	4.7	1.7	-5.4	7.3	2.3
Feb	n/a	n/a	n/a	n/a	5.2	-1.9	10.9	3.1	3.9	-2.0	10.2	2.2	-0.3	-8.9	9.8	3.0	0.9	-9.1	8.4	3.3
Mar	n/a	n/a	n/a	n/a	6.1	-2.4	14.6	3.5	5.5	-2.1	19.3	3.6	2.9	-5.1	11.6	3.3	3.6	-2.4	12.8	3.3
Apr	n/a	n/a	n/a	n/a	7.0	-1.0	20.7	4.1	9.8	0.6	25.3	4.2	6.2	-1.6	14.4	2.7	7.3	-2.3	24.2	4.7
May	n/a	n/a	n/a	n/a	13.7	0.6	26.5	5.1	12.9	2.8	25.2	4.8	-	-	-	-	14.0	4.0	26.7	5.1
Jun	14.3	4.6	23.9	3.8	16.9	5.4	32.9	5.2	14.5	4.1	29.8	4.7	-	-	-	-	14.1	2.2	32.6	5.0
Jul	17.8	8.4	32.1	4.9	18.7	8.6	31.5	5.3	16.7	8.9	27.8	3.8	17.0	7.2	27.4	4.1	18.5	6.0	33.3	5.6
Aug	18.5	8.8	30.5	4.7	16.8	7.9	29.0	4.4	17.5	9.0	31.3	4.8	18.4	7.8	32.0	5.0	17.9	7.3	31.2	5.2
Sep	14.1	4.4	27.3	4.4	11.5	2.7	24.6	3.8	11.8	2.6	22.8	3.5	14.0	2.4	30.9	5.4	12.1	3.0	24.6	3.7
Oct	10.1	1.2	18.4	2.9	9.9	1.8	19.8	3.0	8.2	-0.8	13.0	2.3	6.9	-0.3	16.6	3.3	n/a	n/a	n/a	n/a
Nov	3.1	-7.6	12.4	4.7	1.7	-7.8	9.7	3.6	6.5	-0.7	14.3	3.1	3.57	-7.1	11.6	3.14	n/a	n/a	n/a	n/a
Dec	2.4	-7.1	10.4	3.7	1.8	-5.8	8.9	3.0	-1.5	-12.1	7.7	3.7	0.34	-8.5	6.61	2.41	n/a	n/a	n/a	n/a

[1]"Avg", "Min", "Max" and "SD" denote the monthly average, minimum, maximum, and standard deviation of air temperatures (°C).
[2]"n/a" indicates that TidbiTs weren't installed. "-" indicates that data gap is due to missing Tidbits.
[3]Blue and orange shadings highlight minimum and maximum temperatures, respectively.

Figure 46. Relationship between daily average water and air temperature in the Quinsam River (QUN-AT) between May 2014 and October 2018. Dashed line denotes 1:1 line.



3.4. Hydrology

Quality assured data collected by the Water Survey of Canada were available until the end of 2017 (Year 4). Hydrographs for 2014–2017 at sites on the Salmon River and Quinsam River are presented in Figure 47 to Figure 48; hydrological metrics (Indicators of Hydrologic Alteration) for these years are presented in Table 39.

For all years, discharge was low during the summer period, with minimum mean daily discharge of <0.5 m^3/s measured in the mainstem of both rivers, downstream of the diversion facilities (when they were not operating). It is also notable that maximum discharge was particularly high during the incubation periods for Pacific salmon species that emerged in 2015 and 2017, reflecting floods during December 2014 and November 2016.

Figure 47. Discharge measured on the Salmon River upstream of Memekay River (Map 2) during 2014–2017.

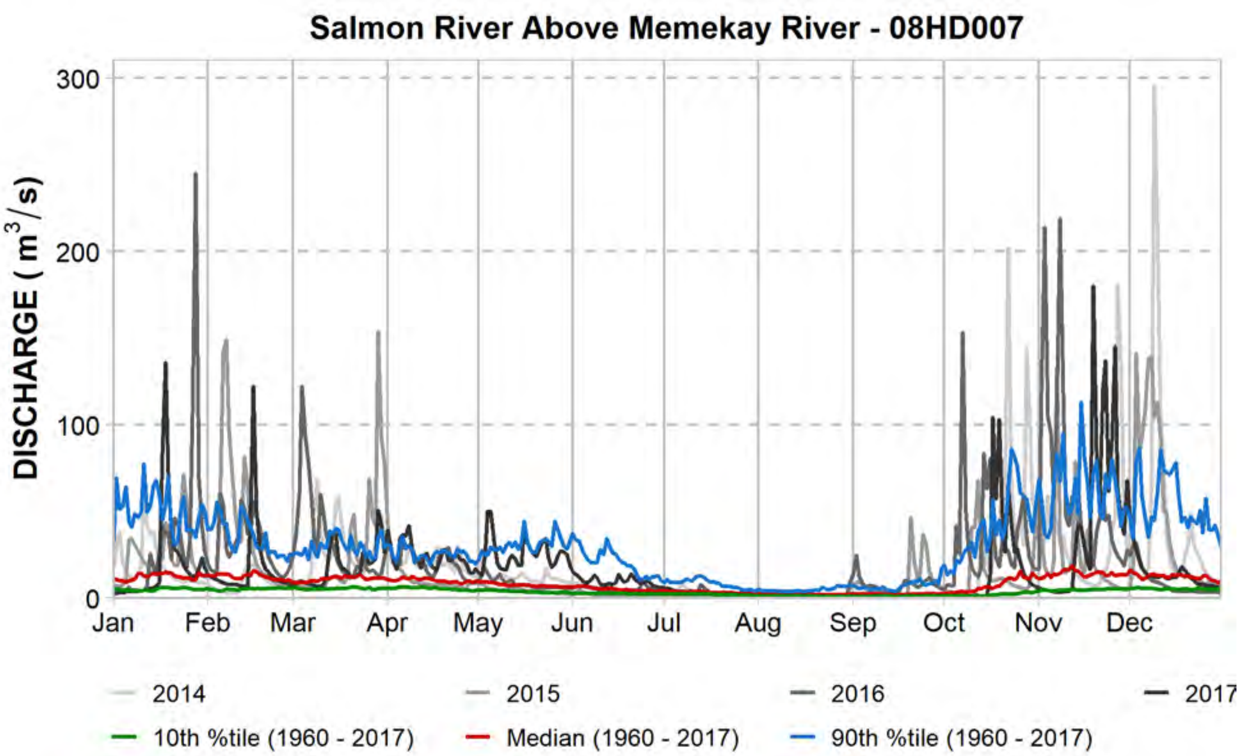


Figure 48. Discharge measured on the Quinsam River upstream of Campbell River (Map 3) during 2014–2017.

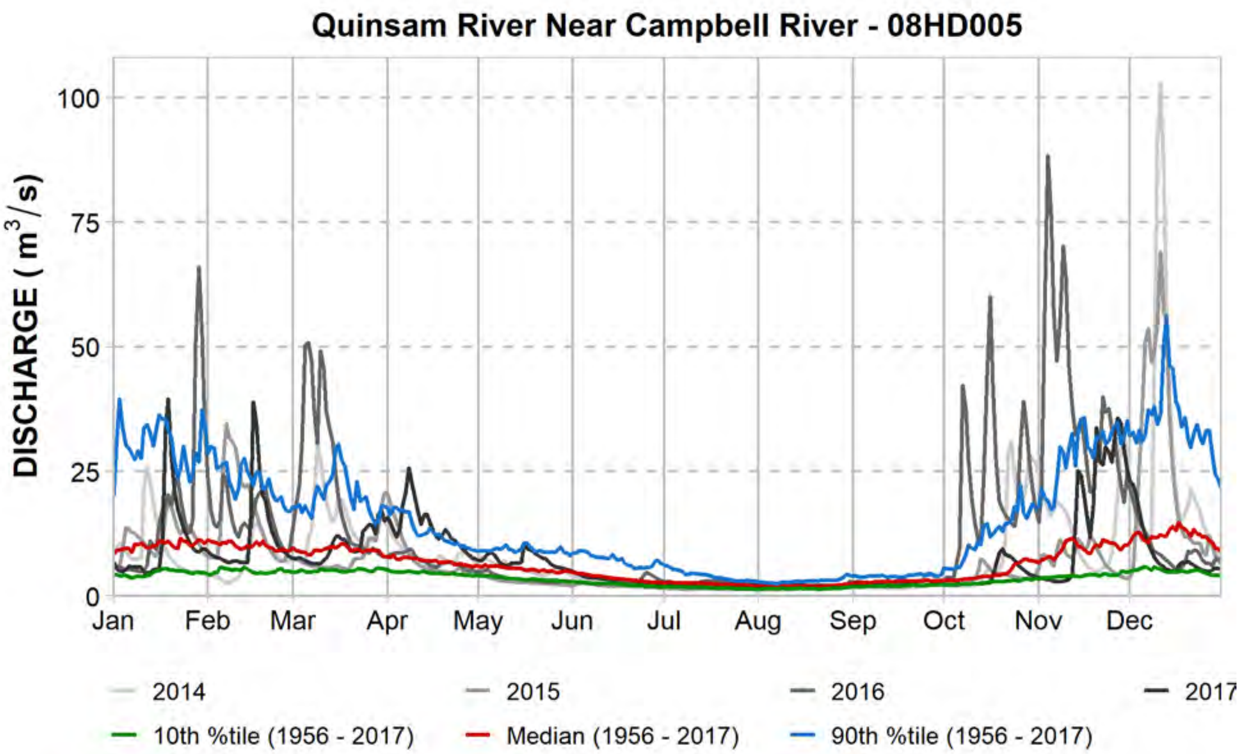


Figure 49. Discharge measured on the Quinsam River at Argonaut Bridge (Map 3) during 2014–2017.

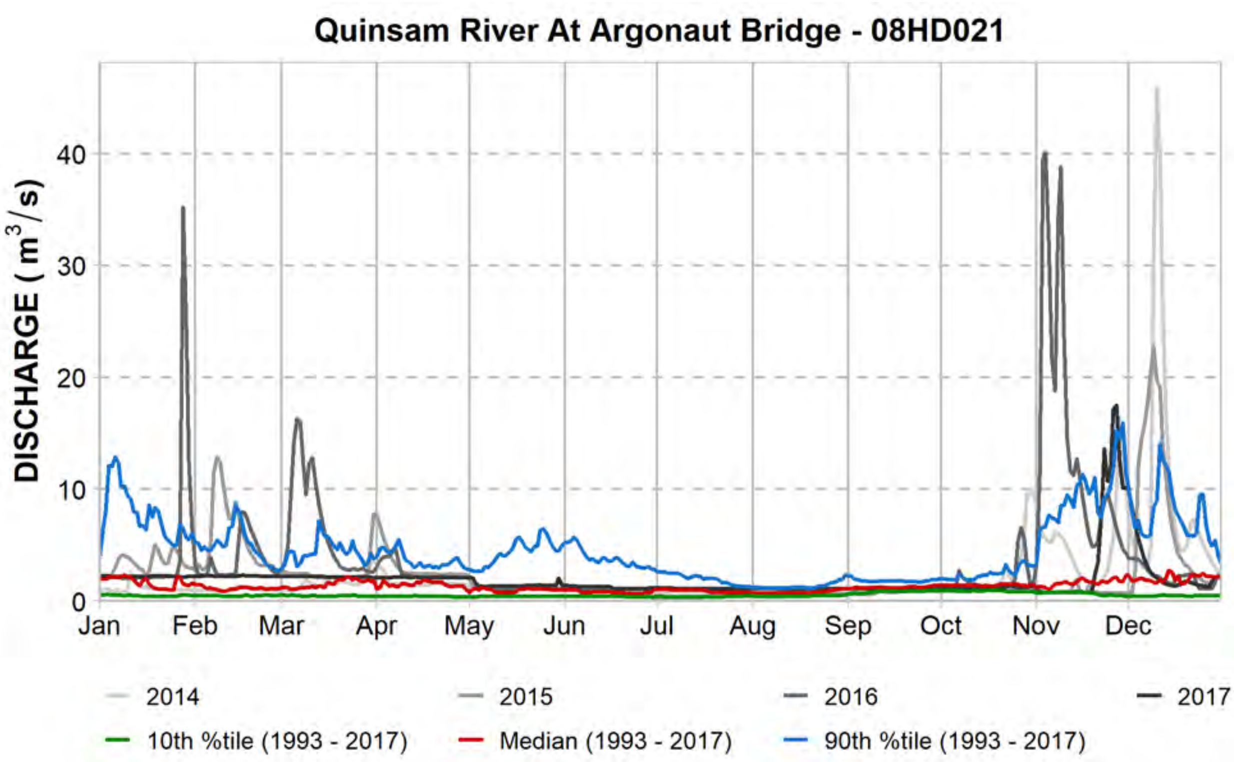


Table 39. Hydrological metrics calculated for 2014–2017. See Map 2 and Map 3 for hydrometric gauge locations.

Stream	Gauge	Year	Hydrological Metric (m^3/s)						
			Minimum Mean Discharge (m^3/s)			Maximum Discharge During Spawning and Incubation Periods[1]			
			1-Day Min.	3-Day Min.	30-Day Min.	Coho Salmon	Steelhead	Chinook Salmon	Pink Salmon
Salmon River	08HD007	2014	0.474	0.477	0.571	68.7	68.7	-	-
		2015	0.477	0.488	0.696	296	154	-	-
		2016	0.696	0.706	1.24	245	122	-	-
		2017	0.731	0.738	0.85	219	51	-	-
Quinsam River	08HD021	2014	0.442	0.448	0.565	3.63	3.63	3.63	3.63
		2015	0.265	0.270	0.328	45.9	7.91	45.9	45.9
		2016	0.987	0.994	1.03	35.2	16.3	35.2	35.2
		2017	0.717	0.718	0.95	40.1	2.3	40.1	40.1
	08HD005	2014	1.15	1.16	1.30	30.4	30.4	30.4	30.4
		2015	1.23	1.24	1.32	103	20.9	103	103
		2016	1.99	2.00	2.16	69.1	50.8	69.1	69.1
		2017	1.97	1.98	2.01	88.4	38.9	88.4	88.4

[1]'-' denotes that the value was not calculated as juvenile abundance of this species is not monitored. For fall spawners, this metric was calculated based on the discharge between the start of spawning the previous year and fry emergence during the current year.

Value is partially or fully based on data graded as "estimated" by Water Survey of Canada.

3.5. Invertebrate Drift

3.5.1. Overview

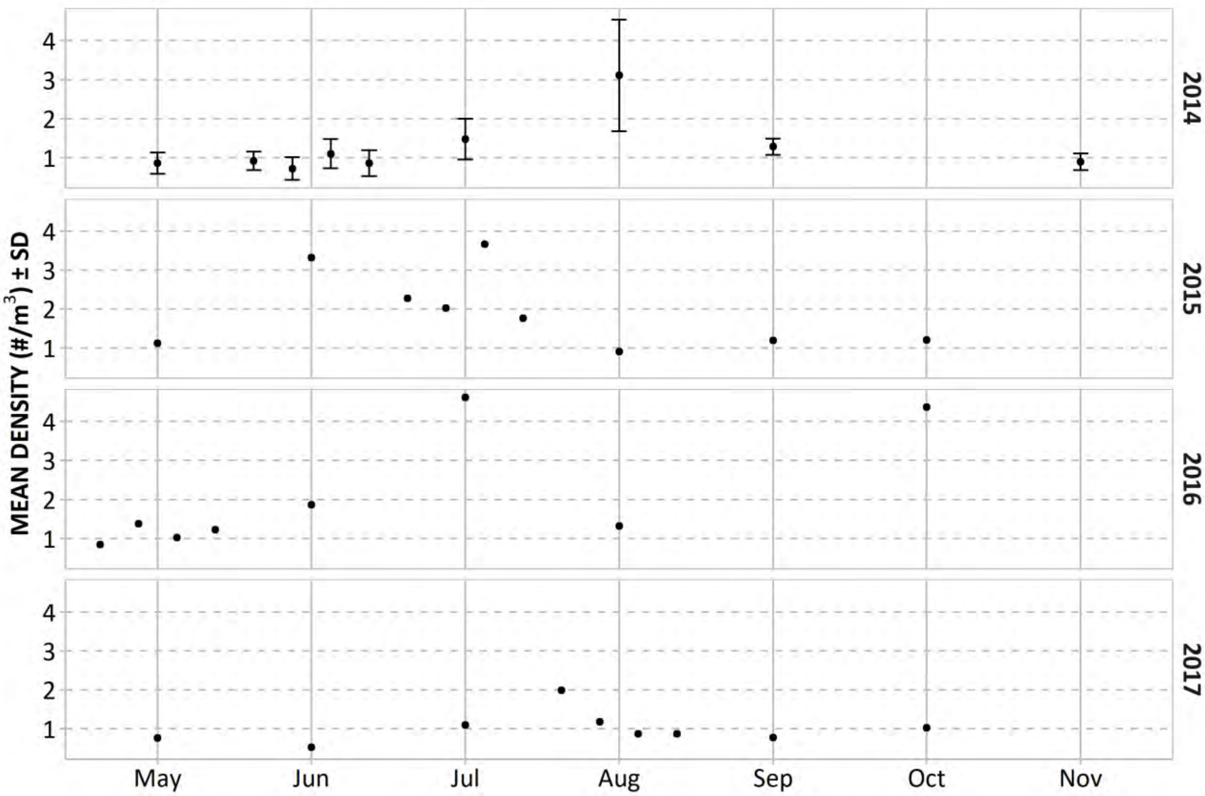
Results relating to invertebrate drift density (individuals/m^3) and biomass (mg/m^3) are provided in subsequent sections for the Salmon and Quinsam rivers as potential indicators of changes in fish abundance. Supplementary invertebrate drift results relating to Simpson's family-level diversity index (1-λ), richness (# families), CEFI, and cluster analysis are provided in Appendix B. Standard deviation values are provided for Year 1 (2014) data only, which is the only year when samples from all five drift nets were analyzed separately. All values except for the CEFI (for which only aquatic taxa are considered) were calculated based on results for all taxa (aquatic, semi-aquatic, and terrestrial).

3.5.2. Salmon River Invertebrate Drift

3.5.2.1. Density

Invertebrate drift density ranged from a minimum in June 2017 of 0.53 individuals/m^3 to a maximum of 4.63 individuals/m^3 in July 2016, with a mean value of 1.57 individuals/m^3 and a standard deviation of 1.04 individuals/m^3. Density was generally lowest at the beginning (May and June) and end (September and October) of each growing season, with a mid-season peak typically occurring in July. There was no clear among-year trend in invertebrate density over the course of the monitoring (Figure 50).

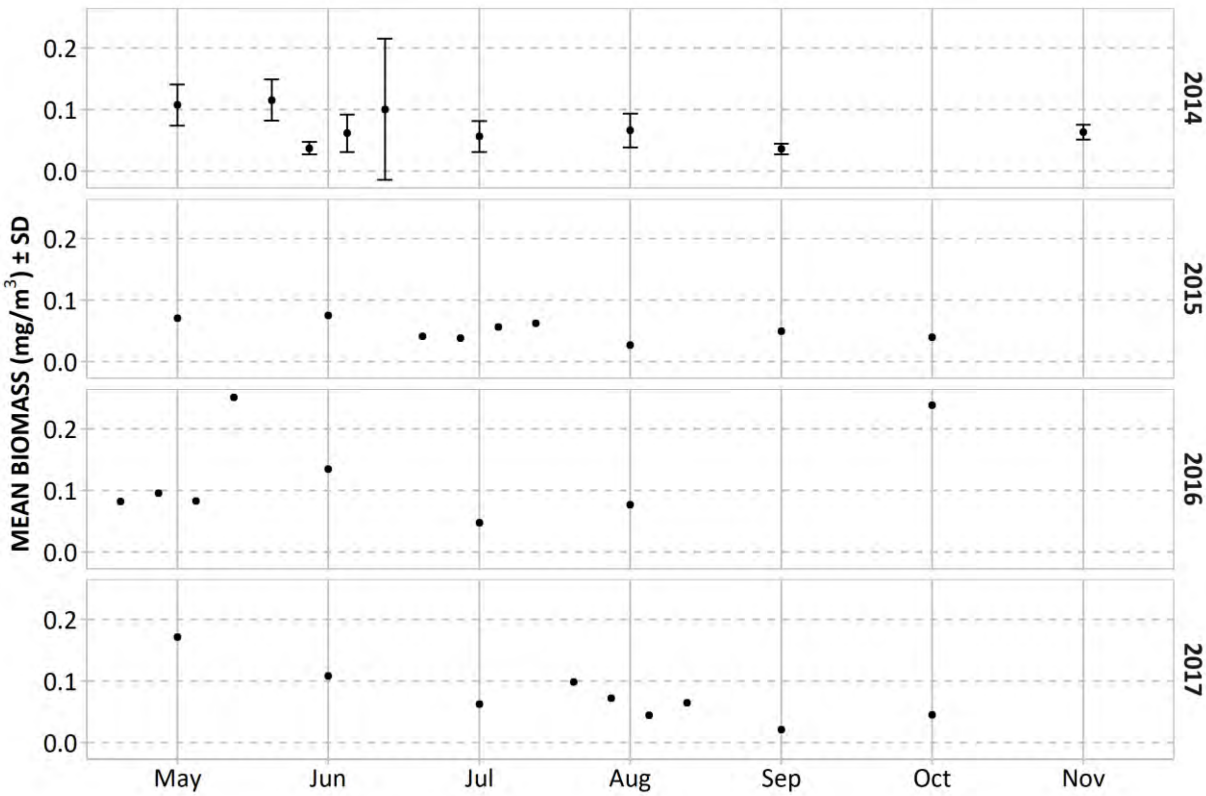
Figure 50. Drift invertebrate density (all taxa) in the Salmon River. Standard Deviation (SD) was only calculated for 2014, when five drift nets were analyzed separately per sampling event.



3.5.2.2. Biomass

Invertebrate drift biomass in the Salmon River varied between 0.02 mg/m^3 (September 2017) and 0.25 mg/m^3 (May 2016) (Figure 51). The maximum value was a clear outlier, as was a similarly high value of 0.24 mg/m^3 collected in October 2016 (Figure 51). These values were scrutinized during analysis in Year 3 to investigate whether the measurements were skewed by a small number of very large individuals, which may not be representative of the communities present in the stream and might warrant a need to correct the data. This analysis showed that this was not the case; instead, the samples contained a large number of relatively large individuals and were therefore considered to be representative of the invertebrate drift community present at the time of sampling (see discussion in Abell *et al.* 2017). Overall, biomass was generally higher early in the growing season and declined as the season progressed, although a notable exception to this was the observation of 0.24 mg/m^3 in October 2016 (Figure 51).

Figure 51. Salmon River mean invertebrate (all taxa) drift biomass (mg/m^3) ± 1 standard deviation (SD). SD was only calculated for 2014, when five drift nets were analyzed separately per site.



3.5.2.3. Top Five Families Contributing to Biomass

A summary of the top five families contributing to biomass across all four years sampled is provided in Table 40. Note that in some instances, a taxonomic level higher than family is listed (e.g., Nematomorpha), as this was the lowest taxonomic level enumerated.

These results show some consistencies in the top five families in the Salmon River over the four monitoring years, with mayfly (Ephemeroptera), caddisfly (Trichoptera), and true fly (Diptera) families consistently included. Two families (Baetidae and Limnephilidae) were present in the top five list in all four years, and a further three families (Chironomidae, Heptageniidae, and Simuliidae) present in three of four years. Ephemeroptera, Trichoptera, and Diptera have been shown to be important invertebrate taxa for juvenile salmonids (Johnson and Ringler 1980, Rader 1997), and for the most part, dominated the top five families each year. An outlier is the dominance of aquatic worms (phylum Nematomorpha) in Year 4 which formed 29.4% of the biomass, and it is notable that the abundance of Heptageniidae varied from not being included in the top five families in 2015, to dominating the biomass in 2016 with 44.2% of the total.

Table 40. Annual top five families contributing to invertebrate drift biomass (all taxa) in the Salmon River throughout Years 1 to 4. Names in parentheses represent taxonomic levels that are higher than families, denoting instances when family level classifications were unavailable.

SAM-IV	2014	SAM-IV	2015	SAM-IV	2016	SAM-IV	2017	Key
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	True Flies
								Mayflies
Baetidae	12.3	Chironomidae	21.5	Heptageniidae	44.2	(Nematomorpha)	29.4	Caddisflies
Heptageniidae	8.5	Baetidae	11.0	Limnephilidae	11.8	Limnephilidae	9.9	Mites
Chironomidae	7.8	Simuliidae	8.0	Baetidae	8.4	Heptageniidae	9.6	Aquatic Worms
Limnephilidae	7.0	Torrenticolidae	6.7	Chironomidae	3.5	Baetidae	9.4	
Lepidostomatidae	6.5	Limnephilidae	5.0	Simuliidae	3.2	Simuliidae	4.8	
Sum	42.2	Sum	52.3	Sum	71.0	Sum	63.1	

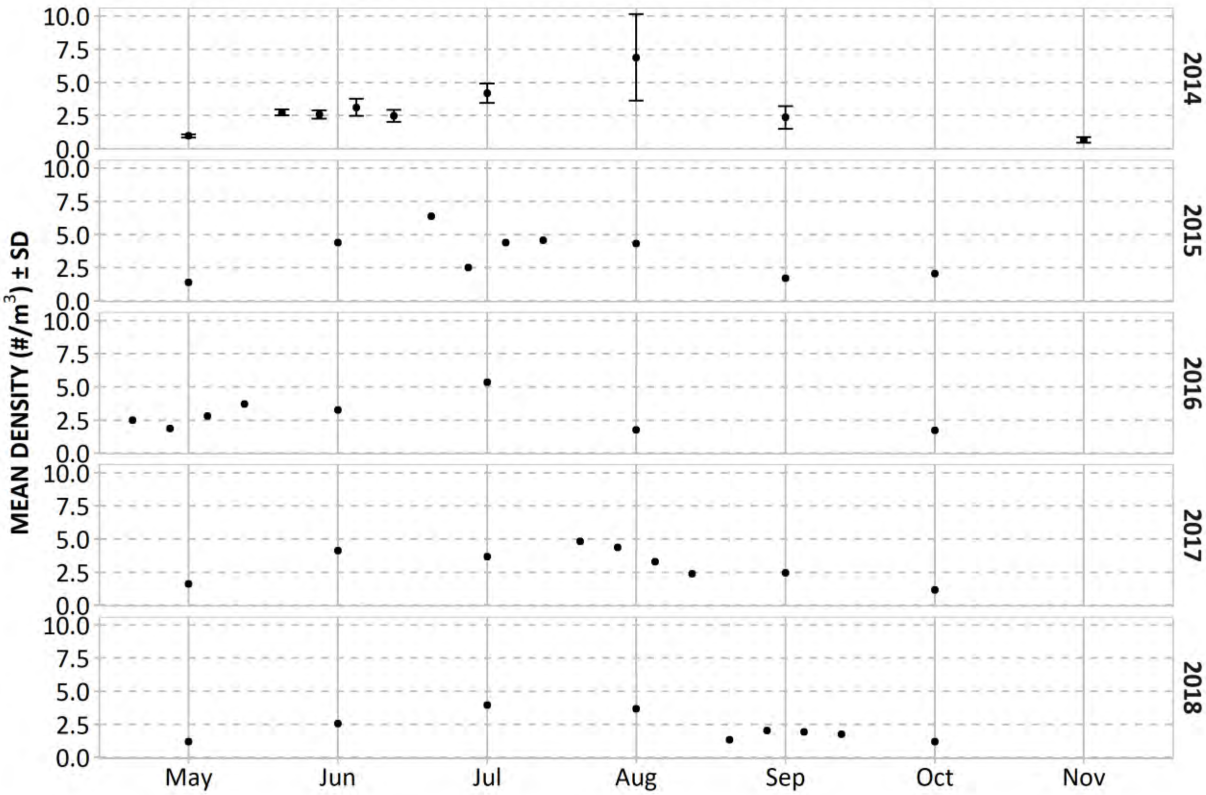
3.5.3. Quinsam River Invertebrate Drift

3.5.3.1. Density

Invertebrate drift density in the Quinsam River was variable across sampling dates in Year 5 (Figure 52). Density reached a peak of 3.97 individuals/m^3 in July 2018, with lower values observed earlier and later in the season (e.g., 1.21 individuals/m^3 in May; 1.19 individuals/m^3 in October; Figure 52). Density measured at weekly intervals during September ranged from 1.35 – 2.04 individuals/m^3. Density in 2018 was within the range of values observed in previous years (0.65 – 6.88 individuals/m^3).

During the five-year monitoring program to date, the density data show similar seasonal patterns with lower invertebrate drift density early (May) and late (October) in the growing season, and annual maximum density occurring sometime in July or August. Annual maximum invertebrate density declines through the monitoring period (Figure 52), with the highest annual maximum values occurring in Year 1 (6.88 individuals/m^3). This annual maximum was lower in each subsequent year, with a decline to a maximum of 3.97 individuals/m^3 by Year 5.

Figure 52. Drift invertebrate density (all taxa) in the Quinsam River throughout 2014 – 2018.

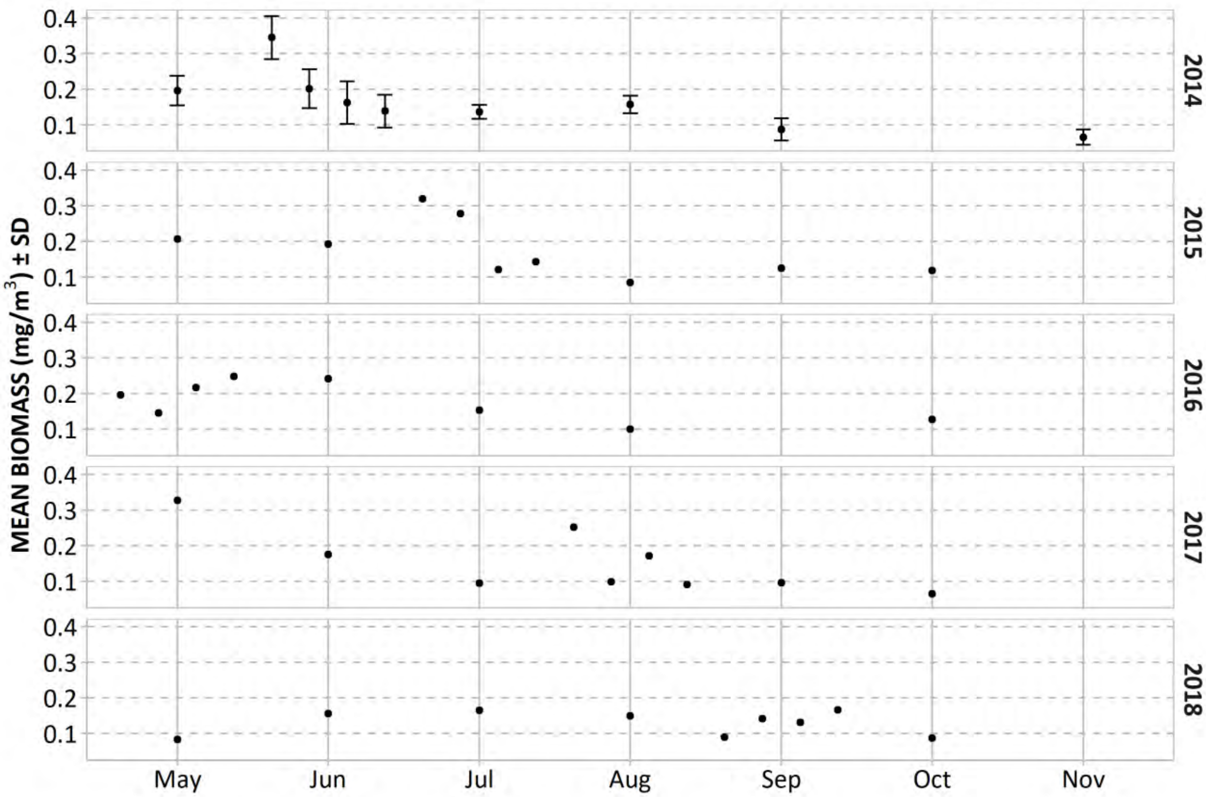


3.5.3.2. Biomass

Invertebrate drift biomass in the Quinsam River ranged from 0.08–0.17 mg/m^3 in Year 5, which is within the range observed in previous years (0.06 – 0.34 mg/m^3). Biomass was variable throughout Year 5, with the annual maximum value of 0.17 mg/m^3 observed in both July and September 2018. There were no relatively high values (e.g., >0.20 mg/m^3) in Year 5, although this may partly reflect that the weekly sampling occurred in September in Year 5; therefore, sampling effort at the start of the season (when the highest biomass values are typically measured) was lower in Year 5 than in some other years.

For the five-year study period, invertebrate drift biomass was highly variable both within and across sampling years (Figure 53). Annual minimum observations were 0.06–0.10 mg/m^3 in all years, while annual maxima were more variable across years with observations in the range 0.17–0.34 mg/m^3, with the highest annual maximum value measured in Year 1 and the lowest in Year 5.

Figure 53. Drift invertebrate biomass (all taxa) in the Quinsam River throughout 2014 – 2018.



3.5.3.3. Top Five Families Contributing to Biomass

A summary of the top five families contributing to biomass in Year 5 for the invertebrate drift community is provided in Table 41. Note that in some instances, a taxonomic level higher than family is listed (e.g., Ephemeroptera), as this was the highest taxonomic resolution enumerated.

The invertebrate community was dominated (in terms of biomass) by mayflies (notably Baetidae) and true flies (most notably Chironomidae and Simuliidae). Baetidae was the most dominant family throughout Year 5, as it was the top-ranked family on seven of nine sampling dates and ranked second on the remaining two dates. True flies were also consistently present in the top five, with two or more true fly families present on eight of nine sampling dates. The contribution to biomass of mayflies ranged from 13.8% to 34.1% while true flies ranged from 18.0% to 50.4%.

Other taxa sometimes present in the top five included Caddisflies (Limnephilidae, Hydropsychidae, Philopotamidae, and unspecified Trichoptera families), true bugs (Gerridae and Aphididae), stoneflies (Capniidae and unspecified Plecoptera families) and spiders (Araneae).

A summary of the top five families contributing to biomass across all sample years in the Quinsam River is provided in Table 42. These results show consistencies in the top five families across years, with Baetidae comprising the top family in four of five years and present in all five years along with two other families (Chironomidae and Simuliidae). In all years, these three families formed 37.2 – 46.0% of the biomass. Ephemeroptera, Trichoptera, and Diptera have been shown to be important invertebrate taxa for juvenile salmonids (Johnson and Ringler 1980, Rader 1997), and for the most part, dominated the top five families each year during each sampling date in 2018 as well as across years.

Table 41. Top five families contributing to invertebrate drift biomass (all taxa) in the Quinsam River in Year 5. Names in parentheses represent taxa higher than families from instances where family level classifications were unavailable.

QUN-IV	10-May-18	QUN-IV	5-Jun-18	QUN-IV	4-Jul-18	QUN-IV	9-Aug-18	Key
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	True Flies
								Mayflies
Simuliidae	31.3	Baetidae	15.1	Baetidae	16.4	Baetidae	24.6	Caddisflies
Baetidae	23.6	Chironomidae	13.8	Hydropsychidae	16.2	Simuliidae	13.0	True Bugs
Chironomidae	19.1	Simuliidae	13.1	Chironomidae	14.9	Chironomidae	11.0	Stoneflies
(Araneae)	4.5	Limnephilidae	10.2	Simuliidae	14.3	Gerridae	8.9	Spiders
Aphididae	2.3	Philopotamidae	9.9	(Trichoptera)	7.0	Hydropsychidae	8.3	
Sum	80.8	Sum	62.1	Sum	68.9	Sum	65.7	

QUN-IV	4-Sep-18	QUN-IV	12-Sep-18	QUN-IV	21-Sep-18	QUN-IV	26-Sep-18	QUN-IV	5-Oct-18
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass
Baetidae	26.4	Baetidae	21.1	Baetidae	23.5	Baetidae	27.6	(Trichoptera)	24.5
Gerridae	23.3	Psychodidae	20.7	Chironomidae	21.7	Tachinidae	15.7	Baetidae	13.8
Simuliidae	10.1	Simuliidae	17.9	(Araneae)	14.8	Simuliidae	9.1	Chironomidae	10.5
Chironomidae	7.9	Chironomidae	7.9	Capniidae	4.7	Hydropsychidae	8.2	(Plecoptera)	8.7
Heptageniidae	4.2	(Plecoptera)	7.5	Hydropsychidae	4.4	(Ephemeroptera)	6.5	Simuliidae	7.9
Sum	72.0	Sum	75.2	Sum	69.1	Sum	67.0	Sum	65.4

Table 42. Annual top five families contributing to invertebrate drift biomass (all taxa) in the Quinsam River throughout Years 1 to 5. Names in parenthesis represent taxa higher than families from instances where family level classifications were unavailable.

QUN-IV	2014	QUN-IV	2015	QUN-IV	2016
Family	% of Total Biomass	Family	% of Total Biomass	Family	% of Total Biomass
Baetidae	20.2	Chironomidae	14.4	Baetidae	15.9
Limnephilidae	15.8	Simuliidae	13.2	Chironomidae	15.3
Chironomidae	9.5	Baetidae	11.5	Simuliidae	12.0
Simuliidae	7.5	Chrysomeloidea	6.7	Limnephilidae	5.8
(Ephemeroptera)	5.8	(Plecoptera)	4.2	Cicadellidae	3.5
Sum	58.8	Sum	50.0	Sum	52.5

QUN-IV	2017	QUN-IV	2018	Key
Family	% of Total Biomass	Family	% of Total Biomass	True Flies
				Mayflies
Baetidae	18.0	Baetidae	21.3	Caddisflies
Chironomidae	12.0	Simuliidae	12.6	True Bugs
Simuliidae	9.4	Chironomidae	12.1	Stoneflies
Empididae	8.6	Hydropsychidae	6.0	Spiders
Bibionidae	5.7	(Araneae)	3.8	Beetles
Sum	53.8	Sum	55.9	

3.5.4. Comparison of kick net and drift net sampling methods

Invertebrates collected using kick net sampling were exclusively aquatic taxa (100%) in the Quinsam River whereas drift sampling captured 64.2–75.0% aquatic invertebrates (based on biomass; Table 43). The kick net method involves holding the collection net completely under the stream surface for three minutes, so the greater dominance of aquatic taxa is expected. Drift nets are installed with the top of the net above the stream surface, so that any invertebrates suspended on the surface are collected, in addition to submerged invertebrates. These invertebrates are more likely to have entered the stream from terrestrial or semi-aquatic (riparian) habitats.

The contribution of individual families to invertebrate biomass differed between the two sampling methods (Table 44). In the Quinsam River, two groups (true flies and mayflies) accounted for the majority of the biomass in drift net samples and most of the top five families comprised these taxa on all dates, whereas a wider range of families were present during kick sampling including Hydropsychidae (caddisflies), Gomphidae (dragonflies) and Astacidae (crayfish). Overall, the taxa present in the kick net samples were more diverse within and among sampling dates than taxa present in drift net samples.

Table 43. Contribution of invertebrate taxa to total biomass by habitat type. Kick net data were not collected in 2014 and 2016.

Stream	Sample Date	Collection Method	Relative Contribution to Biomass (%)		
			Aquatic Taxa	Semi-Aquatic Taxa	Terrestrial Taxa
Quinsam River	16-Sep-2015	Driftnet	75.0	19.2	5.8
		Kicknet	100.0	0.0	0.0
	13-Sep-2017	Driftnet	64.5	15.7	19.8
		Kicknet	100.0	0.0	0.0
	12-Sep-2018	Driftnet	64.2	24.9	10.9
		Kicknet	100.0	0.0	0.0

Table 44. Top five families contributing to invertebrate biomass collected using drift nets and a kick net in the Quinsam River.

Date	Driftnet		Kicknet		Key
	Family	% of Biomass	Family	% of Biomass	
9/16/2015	Simuliidae	39.0	Hydropsychidae	16.5	True Bugs
	Chironomidae	15.5	Tipulidae	14.5	Aquatic Worm
	Ephemeroptera	13.7	Trichoptera	13.7	Mites
	Ameletidae	6.3	Chironomidae	7.3	True Flies
	Sperchontidae	4.7	Lumbriculidae	5.9	Mayflies
9/13/2017	Chironomidae	25.4	Astacidae	26.5	Caddisflies
	Simuliidae	17.5	Naididae	11.8	Crustacean
	Baetidae	11.3	Gomphidae	10.8	Dragonflies
	Curculionidae	8.6	Elmidae	9.0	Stoneflies
	Aphididae	6.2	Chironomidae	6.0	Beetles
9/12/2018	Baetidae	21.1	Heptageniidae	33.6	
	Psychodidae	20.7	Perlidae	17.9	
	Simuliidae	17.9	Hydropsychidae	13.0	
	Chironomidae	7.9	Tipulidae	8.8	
	(Plecoptera)	7.5	Baetidae	7.9	

4. DISCUSSION

4.1. Overview

A summary of the current status of each of the six hypotheses is provided below, including brief details of analyses that are planned to test each hypothesis during the final analysis in Year 10. The discussion focuses on the Quinsam River as this stream is now the sole focus of JHTMON-8 and the hypotheses are not scheduled to be tested for the Salmon River. Readers should consult the Year 4 Annual Report (Sharron *et al*. 2018) for discussion of results for the Salmon River.

As described below in relation to $H_0$6, we plan to construct species-specific spawner-recruitment curves using juvenile and adult fish data. The potential influence of environmental factors on these relationships will then be examined to test $H_0$2–$H_0$5 by quantifying whether environmental factors affect juvenile fish abundance after the potential influence of variability in adult escapement has been accounted for. Further details of the proposed data analysis methods are also provided in Section 1.5.

4.2. <u>$H_0$1: Annual population abundance does not vary with time (i.e., years) over the course of the Monitor</u>

This hypothesis focuses on juvenile fish (BC Hydro 2018a). The JHTMON-8 results, and historical data compiled so far show considerable inter-annual variability in juvenile fish abundance, suggesting that this hypothesis will be rejected in Year 10. Work undertaken in Year 5 to compile and analyze juvenile fish outmigration data collected at the Quinsam River during 1974–2018 shows substantial interannual variability among years in the abundance of JHTMON-8 priority species; e.g., juvenile abundance varies among years by at least a factor of four for juvenile Chinook Salmon, Coho Salmon and steelhead (Figure 23). Compiling this multi-decadal time series during Year 5 will substantially increase the statistical power of analysis to quantify variability in juvenile fish abundance in the Quinsam River.

When testing this hypothesis, it is relevant to consider both wild and hatchery-raised (colonized) fish (Figure 24). During the JHTMON-8 study period, there was marked variability in the outmigration of juvenile wild Chinook Salmon, with abundance particularly low in 2015 and 2016 (~500–1500 fish) and highest in 2017 (~114,000 fish; Figure 21). There was less variability in juvenile Coho Salmon outmigration, with the annual total outmigration of both wild and colonized Coho Salmon estimated to have varied by up to a factor of approximately two during the five JHTMON-8 study years approximately (Figure 21). Variability in annual estimated outmigration during JHTMON-8 was slightly higher for steelhead smolts (~3000–9000 smolts[7]), although the estimated abundance of outmigrating juvenile steelhead was lower than that of Chinook Salmon and Coho Salmon (Figure 21). When considering all data compiled to date, there seemed to be some synchrony in trends among species; e.g., see peaks in Chinook Salmon and Coho Salmon in 1999, 2009, 2013 in Figure 23. To date, no statistical analysis has been undertaken of this dataset and, therefore, observations at this stage are speculative. However, this apparent synchrony suggests that one or more common environmental factors influence outmigration of priority species in the Quinsam River.

[7] Note that these estimates are expected to less accurate than the estimates for the other two priority species and may also be biased high, reflecting that mark-recapture experiments are not undertaken with steelhead smolts to estimate species-specific capture efficiency. See Murphy and Duncan (2017) for discussion of this issue and suggestions of how it could be examined. This issue does not invalidate the proposed JHTMON-8 analysis as the focus is on relative trends among years.

Variability in juvenile fish abundance will be analyzed by reviewing time series graphs and calculating summary statistics (e.g., standard deviation and percentile values). Where feasible, spawner-recruitment relationships will be constructed and analyzed to isolate variability in juvenile fish abundance that is due to variability in freshwater survival, from variability due to fluctuations in the abundance of adult fish (discussed further below in Section 4.7 in relation to H_06). These spawner-recruitment relationships will be used to test the other hypotheses discussed below; specifically, analysis will be undertaken to quantify whether variability in factors corresponding to each hypothesis (e.g., WUA for H_02) explains variability in the spawner recruitment relationships.

4.3. H_02: Annual population abundance is not correlated with annual habitat availability as measured by Weighted Usable Area (WUA)

WUA (in m^2) provides an index of habitat availability calculated using relationships developed between flow and the area of different habitats, accounting of differences in habitat suitability across different flows (Lewis *et al.* 2004). In Year 5, we quantified WUA for different life stages of JHTMON-8 priority species (Figure 27 and Figure 29). This analysis will be updated in Year 10 and used to test H_02. We propose to test this hypothesis separately for each of the JHTMON-8 priority species. For Chinook Salmon and Coho Salmon, we propose to construct spawner-recruitment relationships (discussed above) and then test whether variability in WUA explains variability in the spawner-recruitment relationships, which would indicate that variability in WUA affects juvenile fish recruitment (indicating that H_02 can be rejected). For these two species, the flow-habitat relationships that have been previously developed relate to spawning (not rearing) habitat. For Chinook Salmon, this is reasonable because this species only spends up to a few months rearing in the Quinsam River (Burt 2003). Coho Salmon typically rear in freshwater for 1–2 years in the Quinsam River (Burt 2003) and therefore we will consider whether it is feasible to also analyze whether variability in rearing habitat WUA affects juvenile Coho abundance. At this time, we expect it will be appropriate to use steelhead fry rearing habitat WUA estimates as a proxy for juvenile Coho Salmon rearing habitat; however, we plan to examine this assumption further in Year 10 (e.g., by comparing the HSI curve used to calculate steelhead fry habitat with curves developed elsewhere for juvenile Coho Salmon). In addition to these two priority salmon species, we also propose to test H_02 using the same approach for Pink Salmon, which is a species of interest in the Quinsam River watershed. For steelhead, H_02 will be tested in relation to spawning habitat, as well as rearing habitat for two life stages (fry and parr; Figure 27). We do not expect to construct spawner-recruitment relationships for steelhead because adult steelhead abundance is not monitored in the Quinsam River; instead, we plan to complete the analysis using total steelhead smolt outmigration as the dependent variable.

4.4. H_03: Annual population abundance is not correlated with water quality

H_03 focuses on juvenile fish. Results from JHTMON-8 to date show that the Quinsam River is fairly typical of streams in coastal BC watersheds with low nutrient concentrations (oligotrophic), near-neutral pH, and low turbidity during baseflow. Results show that measurements of some water quality variables were, at times, outside of the biologically optimum ranges for fish species present in the watershed. Specifically, water temperatures were recorded in the Quinsam River that exceeded WQG-AL temperature ranges for suitable salmonid rearing conditions and maximum summer water temperatures have exceeded 21ºC during each year of JHTMON-8, with a maximum temperature of 23.6 ºC in July 2018. Concentrations of DO less than the provincial WQG-AL for the protection of buried embryos/alevins have been recorded at times during reported incubation periods (Burt 2003) for resident Rainbow Trout and steelhead. Measurements also indicated that DO concentrations were below the WQG-AL range during the start of the Pink Salmon incubation period.

Analysis to test this hypothesis will be undertaken separately for individual species and water quality variables. Analysis will initially focus on the ten-year period of the monitor, although there are opportunities to use water temperature data collected by other parties to extend the time period over which the potential effects of water temperature are considered (Dinn *et al*. 2016). Analysis will initially involve evaluating scatterplots, time series graphs, and correlation metrics to examine whether there is a link between variability in water quality variables and juvenile fish abundance. In Year 4, an initial screening analysis of the water quality variables was completed. This showed that alkalinity or specific conductivity, DO, and water temperature are expected to be the most suitable predictor variables to include in statistical models to quantify the effect of water quality on juvenile fish abundance (Sharron *et al*. 2018), although all variables that are monitored as part of JHTMON-8 will nonetheless be considered. The Year 4 screening analysis generally showed that interannual variability in many of the water quality variables was low, which may limit the power of the final analysis to quantify effects of water quality (if present) on fish abundance. As an alternate line of evidence, it will therefore also be important to continue to evaluate water quality results in the context of WQG-AL to make qualitative conclusions about the potential for water quality to limit juvenile fish abundance in the Quinsam River.

4.5. $H_0$4: Annual population abundance is not correlated with the occurrence of flood events

As part of JHTMON-8, data collected by the Water Survey of Canada have been collated and analyzed to quantify hydrologic variability in the Quinsam River. Analysis of data collected for the first four years of JHTMON-8 shows that the largest flood event occurred in December 2014, when flow at the mouth of the Quinsam River briefly peaked at just over 100 m^3/s (Figure 48). Particularly high flows also occurred in November 2016, when flow at the mouth of the Quinsam River reached approximately 85 m^3/s (Figure 48). For all years, discharge was low during the summer low-flow period, with minimum mean daily discharge of <1.0 m^3/s measured in the Quinsam River during each year in the summer (when the diversion facility was not operating).

This hypothesis will be tested by quantifying high flow metrics separately for each watershed based on discharge measured at gauges maintained by the Water Survey of Canada. Relationships between the occurrence of floods and juvenile fish abundance will then be analyzed. Further, we propose to extend the analysis to consider hydrologic variability more widely (discussed in Section 1.5.5). Analysis will be completed using a subset of Indicators of Hydrologic Alteration (Richter *et al*. 1996), which were identified following a review conducted in Year 3. Candidate metrics include measures of both high and low flows to provide an opportunity to extend the analysis to consider hydrologic variability more widely, reflecting that the occurrence of low summer flows can be a significant limiting factor for juvenile salmonid productivity (e.g., Grantham *et al.* 2012), in addition to the occurrence of floods. We plan to consider additional metrics in future years; e.g., that quantify the duration of high flows. Following the collation of a historical dataset collected at the Quinsam Hatchery fence, we also plan to extend the analysis of H_04 to consider years prior to JHTMON-8.

4.6. $H_0$5: Annual population abundance is not correlated with food availability as measured by aquatic invertebrate sampling

Invertebrate drift data have now been collected for five growing seasons for the Quinsam River. There are no clear differences in invertebrate drift biomass among years, although data indicate that invertebrate drift biomass was slightly lower in 2018 (Year 5) than previous years (Figure 52). Otherwise, results show that invertebrate drift biomass generally tends to decline during the growing season (Figure 52), while analysis of similarity in the invertebrate assemblages shows consistent trends among years, with distinct communities present early in the growing season (May and June) relative to later in the growing season (Appendix B). The potential effect of diversion operations on changes in community structure has not been analyzed but the seasonal patterns in invertebrate community that were observed are consistent with those that we would expect in unregulated streams. Therefore, we expect that the broad seasonal trends are at least largely driven by natural changes (phenology) in invertebrate community composition. These seasonal trends have potential implications for juvenile salmonid productivity, because invertebrates typically form the bulk of the diet of salmonids in rivers (Quinn 2005) and a change in invertebrate community structure can affect food quality (i.e., a decrease in the biomass of taxa preferred by salmonids), which could theoretically affect juvenile growth and abundance.

Relationships between invertebrate drift and fish abundance will be examined in Year 10. To test $H_0$5, we plan to examine whether variability in invertebrate drift biomass explains variability in species-specific spawner recruitment curves for JHTMON-8 priority species. If robust spawner recruitment curves cannot be established (due to weak or no relationships between adult and juvenile fish), then we plan to use juvenile fish abundance as the dependent variable in the analysis. $H_0$5 would be rejected if invertebrate biomass is shown to be a statistically significant predictor of juvenile fish abundance, although it will be necessary to then evaluate the effect size to infer biological significance. Further we plan to trial invertebrate density as a secondary measure of food abundance; however, consistent with the TOR (BC Hydro 2018a), we expect to use invertebrate biomass as the main measure of food availability because it is a direct measure of the energy available for fish to consume.

If strong relationships are detected between fish abundance and invertebrate biomass/density, then we may conduct inferential statistical analysis (modelling) of invertebrate diversity metrics (family richness and Simpson's diversity index) to provide greater insight. As discussed in Section 1.5.6, salmonids can preferentially forage on certain taxa and therefore it is plausible that changes to invertebrate community composition could affect food quality by changing foraging opportunities. However, a clear link between invertebrate diversity and fish productivity is not well-established in the literature and therefore, at this stage, the main purpose of evaluating invertebrate community composition and diversity is to provide a more general understanding of the invertebrate food available to rearing fish.

Results so far show marked within-year (seasonal) variability in invertebrate drift biomass but variability in invertebrate drift biomass among years is generally low (Figure 52). Therefore, as for some water quality metrics (discussed above in Section 4.4), this may limit the statistical power of the analysis conducted in Year 10; i.e., without a clear gradient in invertebrate drift biomass among years, it will be challenging to quantify how variability in this metric affects annual estimates of juvenile fish abundance. Therefore, as an alternate line of evidence, it will be useful to also compare invertebrate drift biomass in the Quinsam River with benchmarks such as measurements collected at other streams to inform conclusions about whether a lack of invertebrate drift biomass is expected to limit juvenile fish abundance in the Quinsam River. As with water quality, the study is currently premised on the assumption that invertebrate drift measured at a single index site is representative of conditions experienced by fish in the wider watershed.

4.7. $H_0$6: Annual smolt abundance is not correlated with the number of adult returns (Quinsam River)

We propose to test this hypothesis by constructing spawner-recruitment relationships to quantify the relationship between the abundance of adult fish and the subsequent recruitment of juvenile fish each year. This hypothesis will therefore be tested using juvenile and adult fish abundance data. This analysis will use the juvenile abundance data collected at the Quinsam Hatchery salmon counting fence and the adult escapement data collected by DFO. The work undertaken in Year 5 to compile the historical juvenile abundance dataset for the Quinsam River (Section 4.2) now provides the potential to substantially increase the duration of the dataset that can be analyzed to test this analysis, thereby increasing statistical power.

Preliminary analysis was undertaken in Year 5 to construct spawner-recruitment relationships for priority species (results not presented). In Year 6, we plan to further refine this analysis, before final analysis is completed in Year 10. Spawner-recruitment relationships will then be reviewed to test $H_0$6; i.e., to confirm whether the ratio of smolts to spawners varies as a function of adult returns. Spawner-recruitment relationships can then be analyzed as part of analysis to test the remaining hypotheses; i.e., to quantify whether variability in the environmental factors that have been identified can explain variability in the spawner-recruitment relationships (assuming such relationships are present; Lawson *et al*. 2004). Such consideration of the potential influence of adult returns on juvenile fish abundance is important to avoid misleading inferences about the role of environmental factors in driving population fluctuations (Walters and Ludwig 1981).

At a minimum, we propose to test $H_0$6 separately for Chinook Salmon, Coho Salmon and Pink Salmon. Quantitative analysis is not proposed to test $H_0$6 for steelhead because adult abundance is not monitored on the Quinsam River. Instead, we propose to adopt a qualitative approach to assess steelhead by evaluating historical data and information relevant to BC watersheds more widely (e.g., Lill 2002) to consider whether estimated steelhead smolt production indicates that the Quinsam River is "fully seeded" for this species, which would indicate that additional adult returns would not affect smolt production.

5. ADDITIONAL TASKS FOR YEAR 6

A background review conducted at the start of the study identified individual analysis tasks to be undertaken during each year of JHTMON-8 to streamline final hypothesis testing in Year 10 (Abell *et al*. 2015a). This review was specific to the Salmon River watershed, but the tasks are also relevant to the Quinsam River. In Year 5, we proposed to identify and apply flow-habitat relationships to calculate WUA; this task was successfully completed (Section 3.2). In Year 6, we propose to build on work started in Year 5 to confirm methods that will be used to derive spawner-recruitment relationships.

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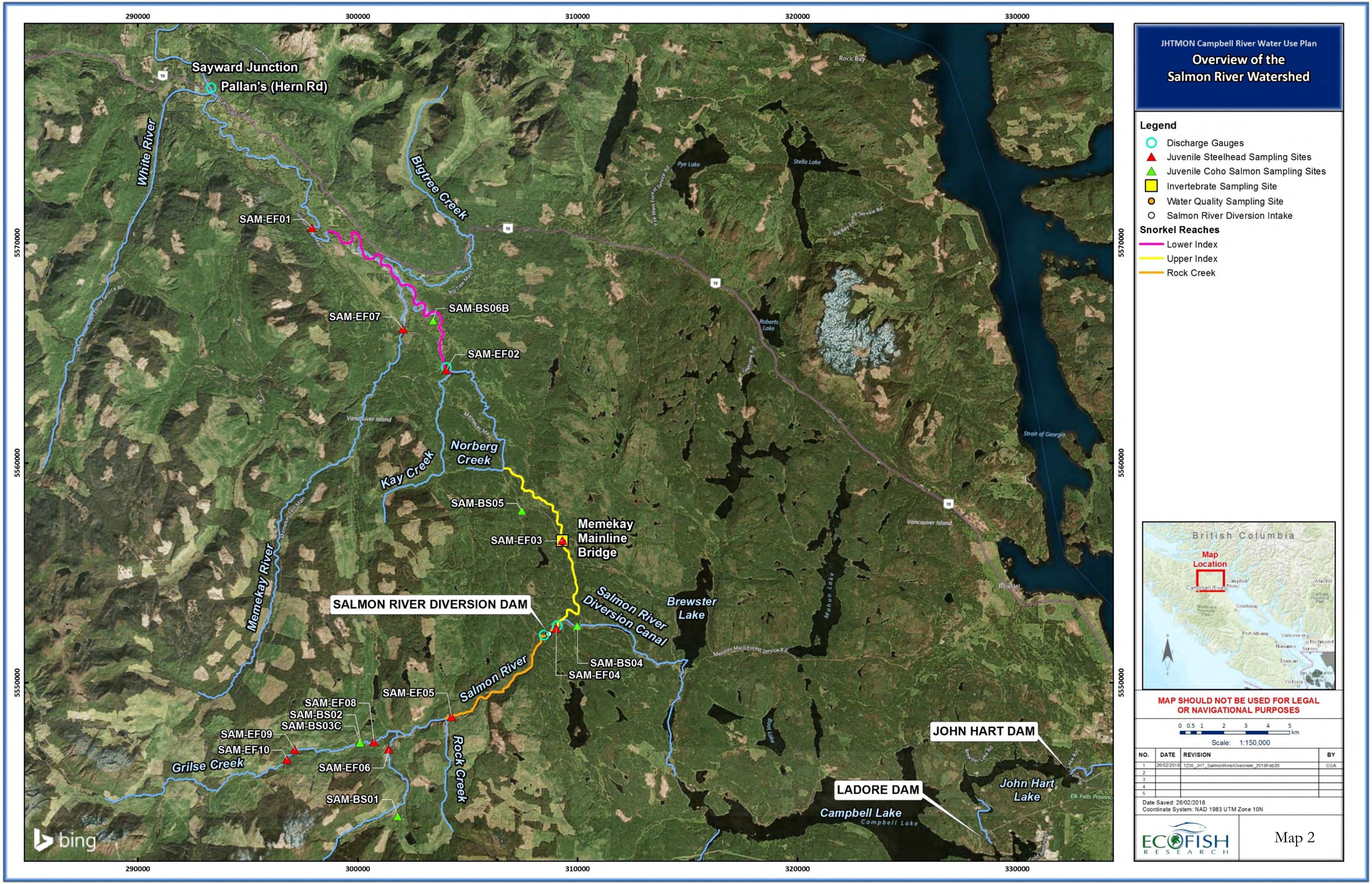
PROJECT MAPS



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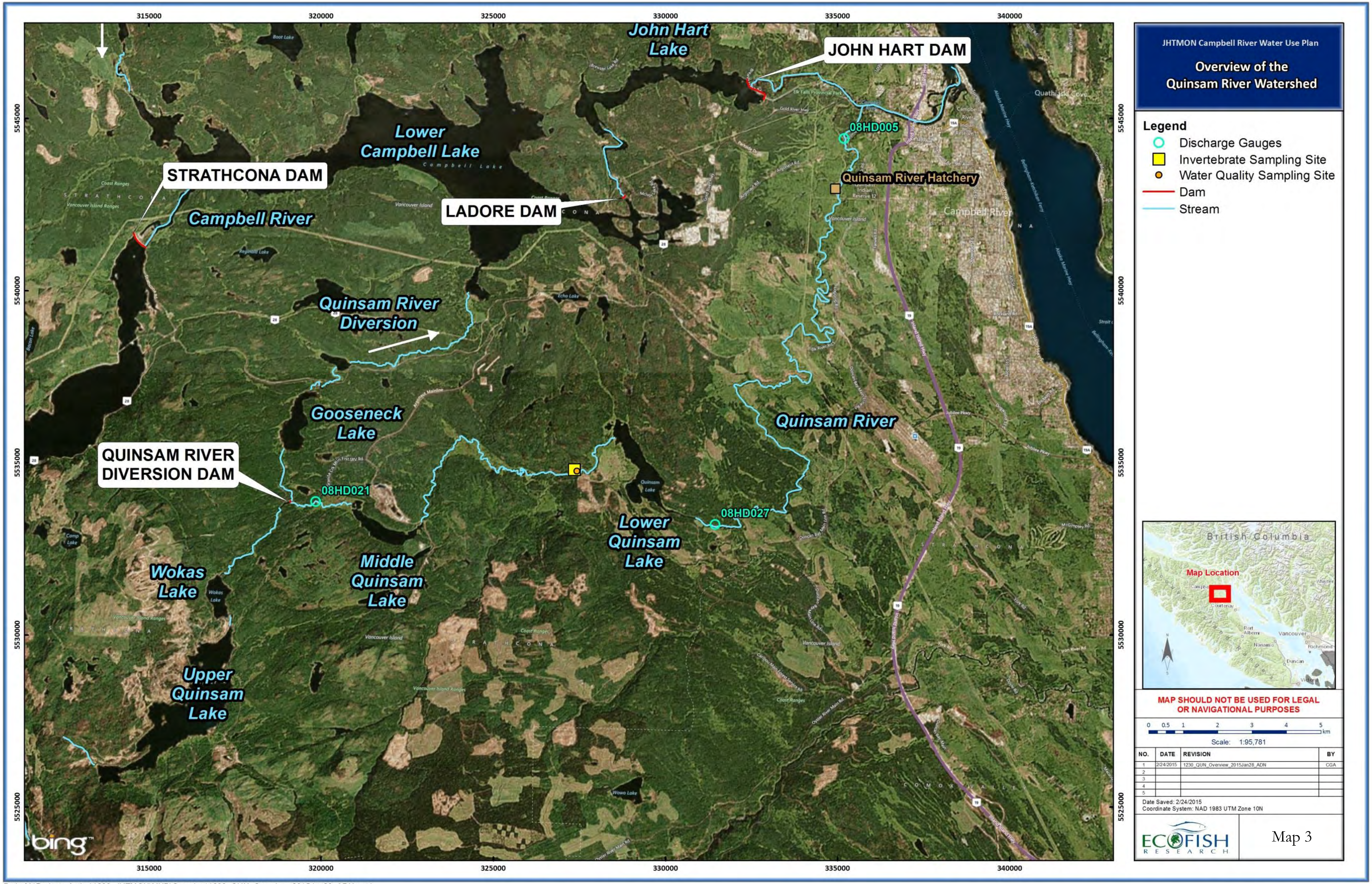

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APPENDICES

Appendix A. Water Quality Guidelines, Typical Parameter Values, Previous Results, and Quality Control Results Summary

TABLE OF CONTENTS

LIST OF TABLES

1. WATER QUALITY GUIDELINES AND TYPICAL PARAMETER VALUES

Table 1. Water quality guidelines for the protection of aquatic life in British Columbia for parameters with less complex guidelines.

Parameter	Unit	BC Guideline for the Protection of Aquatic Life[1]	Guideline Reference
Specific Conductivity	µS/cm	No provincial or federal guidelines	n/a
pH	pH units	When baseline values are between 6.5 and 9 there is no restriction on changes within this range (lethal effects observed below 4.5 and above 9.5)	McKean and Nagpal (1991)
Alkalinity	mg/L	No provincial or federal guidelines. However, waterbodies with <10 mg/L are highly sensitive to acidic inputs, 10 to 20 mg/L are moderatly sensitive to acidic inputs, > 20 mg/L have a low sensitivity to acidic inputs	n/a
Total Ammonia (N)	µg/L	Dependent on pH and temperature, too numerous to present, lowest maximum allowable concentration of 680 µg/L occurs at a pH of 9 and water temperature of 8ºC, lowest maximum average 30 day concentration of 102 µg/L occurs at a pH of 9 and water temperature of 20ºC	Nordin and Pommen (1986)
Nitrite (N)	µg/L	The lowest maximum allowable concentration occurs when chloride is ≤ 2 mg/L; instantaneous maximum allowable concentration is 60 µg/L and a maximum 30 day average of 20 µg/L is allowed when chloride is ≤ 2 mg/L	Nordin and Pommen (1986)
Nitrate (N)	µg/L	The 30 day average concentration to protect freshwater aquatic life is 3,000 µg/L[2] and the maximum concentration is 32,800 µg/L.	Meays (2009)
Orthophosphate	µg/L	No provincial or federal guidelines	n/a
Total Phosphate (P)	µg/L	Trigger ranges that would signify a change in the trophic classification: <4: ultra-oligotrophic, 4-10 oligotrophic, 10 -20 mesotrophic, 20-35 meso-eutrophic, 35-100 eutrophic, > 100 hyper-eutrophic	CCME (2004)

[1] Guideline for total phosphate is a federal guideline; provincial guidelines do not exist

[2] The 30-d average (chronic) concentration is based on 5 weekly samples collected within a 30-day period.

Table 2. Total suspended solids and turbidity guidelines for the protection of aquatic life in British Columbia.

Period	British Columbia[1] Suspended Sediment and Turbidity Guidelines for the Protection of Aquatic Life	
	Total Suspended Sediments (mg/L)	**Turbidity (NTU)**
Clear Flow Period (less than 25 mg/L or less than 8 NTU)	"Induced suspended sediment concentrations should not exceed background levels by more than 25 mg/L during any 24-hour period (hourly sampling preferred). For sediment inputs that last between 24 hours and 30 days (daily sampling preferred), the average suspended sediment concentration should not exceed background by more than 5 mg/L."	"Induced turbidity should not exceed background levels by more than 8 NTU during any 24-hour period (hourly sampling preferred). For sediment inputs that last between 24 hours and 30 days (daily sampling preferred) the mean turbidity should not exceed background by more than 2 NTU."
Turbid Flow Period (greater than or equal to 25 mg/L or greater than or equal to 8 NTU)	"Induced suspended sediment concentrations should not exceed background levels by more than 10 mg/L at any time when background levels are between 25 and 100 mg/L. When background exceeds 100 mg/L, suspended sediments should not be increased by more than 10% of the measured background level at any one time."	"Induced turbidity should not exceed background levels by more than 5 NTU at any time when background turbidity is between 8 and 50 NTU. When background exceeds 50 NTU, turbidity should not be increased by more than 10% of the measured background level at any one time."

[1] reproduced from Singleton (2001)

Table 3. Dissolved oxygen guidelines for the protection of aquatic life in British Columbia.

	BC Guidelines for the Protection of Aquatic Life[1]		
	Life Stages Other Than Buried Embryo/Alevin	**Buried Embryo/Alevin[2]**	**Buried Embryo/Alevin[2]**
Dissolved Oxygen Concentration	Water column mg/L O_2	Water column mg/L O_2	Interstitial Water mg/L O_2
Instantaneous minimum[3]	5	9	6
30-day mean[4]	8	11	8

[1] MOE (1997a) and MOE (1997b)

[2] For the buried embryo / alevin life stages these are in-stream concentrations from spawning to the point of yolk sac absorption or 30 days post-hatch for fish; the water column concentrations recommended to achieve interstitial dissolved oxygen values when the latter are unavailable. Interstitial oxygen measurements would supersede water column measurements in comparing to criteria.

[3] The instantaneous minimum level is to be maintained at all times.

[4] The mean is based on at least five approximately evenly spaced samples. If a diurnal cycle exists in the water body, measurements should be taken when oxygen levels are lowest (usually early morning).

Table 4. Total gas pressure guidelines for the protection of aquatic life in British Columbia.

Water Depth	Maximum Allowable ΔP (Total Gas Pressure - Barometric Pressure) for the Protection of Aquatic Life in BC[1]
> 1 m	76 mm Hg regardless of pO_2 levels
< 1 m	$\Delta P_{\text{initiation of swim bladder overinflation}} = 73.89 * \text{water depth (m)} + 0.15 * pO_2$ where pO_2 = 157 mm Hg (i.e., sea level normoxic condition) In its most conservative form (assuming water column depth = 0 m), the BC guideline for waters less than 1 m deep is that the maximum allowable ΔP should not exceed 24 mm Hg

[1] Fidler and Miller (1994)

Table 5. Typical values for water quality parameters in British Columbia waters.

Parameter	Unit	Typical range in British Columbia streams and rivers	Reference
Specific Conductivity	µS/cm	The typical value in coastal BC streams is 100 µS/cm	RISC (1998)
pH	pH units	Natural fresh waters have a pH range from 4 to 10, lakes tend to have a pH ≥ 7.0 and coastal streams commonly have pH values of 5.5 to 6.5	RISC (1998)
Alkalinity	mg/L	Natural waters almost always have concentrations less than 500 mg/L, with waters in coastal BC typically ranging from 0 to 10 mg/L; waters in interior BC can have values greater than 100 mg/L	RISC (1998)
Total Suspended Solids	mg/L	In BC natural concentrations of suspended solids vary extensively from waterbody to waterbody and can have large variation within a day and among seasons	Singleton (1985) in Caux *et al.* (1997)
Turbidity	NTU	In BC natural concentrations of suspended solids vary extensively from waterbody to waterbody and can have large variation within a day and among seasons	Singleton (1985) in Caux *et al.* (1997)
Dissolved Oxygen	mg/L	In BC surface waters are generally well aerated and have DO concentrations > 10 mg/L	MOE (1997a)
Dissolved Oxygen	% saturation	In BC surface waters are generally well aerated and have DO concentrations close to equilibrium with the atmosphere (i.e., close to 100% saturation)	MOE (1997a)
ΔP (Total Gas Pressure - Barometric Pressure)	mm Hg	In BC, dissolved gas supersaturation is a natural feature of many waters with ΔP commonly being between 50 – 80 mm Hg. (We often see values between -10 and 60)	Fidler and Miller (1994)
Total Ammonia (N)	µg/L	<100 µg/L for waters not affected by waste discharges	Nordin and Pommen (1986)
Nitrite (N)	µg/L	Due to its unstable nature, nitrite concentrations are very low, typically present in surface waters at concentrations of <1 µg/L	RISC (1998)
Nitrate (N)	µg/L	In oligotrophic lakes and streams, nitrate concentrations are expected to be <100 µg/L; in most streams and lakes not impacted by anthropogenic activities, nitrate is typically <900 µg/L.	Nordin and Pommen (1986); CCME (2012)
Orthophosphate (P)	µg/L	Coastal BC streams typically have concentrations <1 µg/L	Slaney and Ward (1993); Ashley and Slaney (1997)
Total Phosphorus (P)	µg/L	Oligotrophic water bodies have total phosphorus concentrations that are between 4 to 10 µg/L while concentrations are typically between 10 to 20 µg/L in mesotrophic water bodies.	CCME (2004)

2. 2014 TO 2018 WATER QUALITY IN THE QUINSAM RIVER AND SALMON RIVER

Table 6. Salmon River (SAM-WQ) general water quality variables measured *in situ* during Years 1 to 4 (2014 to 2017).

Year	Date	Air Temperature °C				Oxygen Dissolved (In Situ) mg/L				Specific Conductivity (In Situ) µS/cm				Temperature (In Situ) °C				pH (In Situ) pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	21-May	-	-	-	-	11.7	11.7	11.7	0.0	28	28	28	0	9.1	9.1	9.1	0.0	6.91	6.91	6.91	0.00
	17-Jun	12.0	12.0	12.0	0.0	10.7	10.7	10.8	0.0	37	37	37	0	12.2	12.1	12.2	0.1	7.21	7.17	7.23	0.03
	23-Jul	14.0	14.0	14.0	0.0	10.2	10.2	10.2	0.0	47	47	47	0	15.5	15.5	15.5	0.0	7.03	7.03	7.03	0.00
	18-Aug	16.0	16.0	16.0	0.0	9.6	9.4	9.7	0.2	54	54	54	0	17.2	17.2	17.2	0.0	7.14	7.12	7.16	0.02
	23-Sep	16.5	16.5	16.5	0.0	8.8	8.7	8.9	0.1	55	55	55	0	14.6	14.6	14.6	0.0	7.22	7.21	7.23	0.01
	03-Nov	8.0	-	-	-	11.1	11.0	11.2	0.1	36	36	36	0	8.2	8.2	8.2	0.0	6.85	6.83	6.87	0.02
2015	13-May	10.5	10.5	10.5	0.0	10.4	10.4	10.4	0.0	42	42	42	0	10.8	10.8	10.8	0.0	7.36	7.34	7.39	0.03
	16-Jun	16.5	16.5	16.5	0.0	8.3	8.3	8.3	0.0	41	41	41	0	14.5	14.5	14.6	0.1	7.87	7.86	7.88	0.01
	22-Jul	16.0	16.0	16.0	0.0	9.4	9.4	9.4	0.0	53	53	53	0	16.5	16.5	16.5	0.0	7.60	7.58	7.62	0.02
	12-Aug	15.0	15.0	15.0	0.0	9.0	9.0	9.1	0.0	48	48	48	0	16.3	16.3	16.3	0.0	7.32	7.32	7.32	0.00
	17-Sep	10.5	10.5	10.5	0.0	9.1	9.0	9.1	0.1	47	47	47	0	11.2	11.2	11.2	0.0	7.09	7.08	7.09	0.01
	15-Oct	8.9	8.9	8.9	0.0	11.5	11.4	11.5	0.0	42	42	42	0	9.0	9.0	9.0	0.0	7.38	7.37	7.40	0.02
2016	17-May	14.0	14.0	14.0	0.0	9.8	9.8	9.8	0.0	43	43	43	0	9.8	9.8	9.8	0.0	6.41	6.37	6.45	0.04
	14-Jun	9.0	9.0	9.0	0.0	9.5	9.5	9.5	0.0	65	65	65	0	10.5	10.5	10.5	0.0	6.40	6.40	6.41	0.01
	12-Jul	14.0	14.0	14.0	0.0	9.7	9.7	9.7	0.0	74	74	74	0	13.3	13.3	13.3	0.0	6.47	6.43	6.51	0.04
	16-Aug	18.0	18.0	18.0	0.0	9.1	9.1	9.1	0.0	78	78	78	0	16.5	16.5	16.5	0.0	6.56	6.53	6.60	0.04
	13-Sep	8.0	8.0	8.0	0.0	9.5	9.4	9.5	0.0	83	83	83	0	12.0	11.9	12.0	0.1	7.17	7.17	7.17	0.00
	11-Oct	-	-	-	-	11.0	11.0	11.1	0.0	45	45	45	0	7.7	7.7	7.7	0.0	6.66	6.66	6.66	0.00
2017	09-May	5.0	5.0	5.0	0.0	12.8	12.8	12.8	0.0	28	28	28	0	5.9	5.9	5.9	0.0	7.37	7.37	7.37	0.00
	13-Jun	11.0	11.0	11.0	0.0	11.1	11.1	11.2	0.0	24	24	24	0	10.1	10.1	10.1	0.0	7.26	7.26	7.26	0.00
	11-Jul	13.0	13.0	13.0	0.0	9.7	9.7	9.8	0.1	37	37	37	0	13.4	13.4	13.4	0.0	6.38	6.30	6.44	0.07
	08-Aug	11.5	11.5	11.5	0.0	9.3	9.3	9.3	0.0	48	48	48	0	15.8	15.8	15.8	0.0	6.43	6.42	6.45	0.02
	12-Sep	12.0	12.0	12.0	0.0	9.0	9.0	9.1	0.0	55	55	55	0	13.8	13.8	13.8	0.0	6.13	6.10	6.17	0.04
	10-Oct	7.0	7.0	7.0	0.0	11.6	11.5	11.6	0.1	53	53	54	0	8.3	8.3	8.3	0.0	6.23	6.23	6.24	0.01

[1] Average of three replicates (n=3) on each date unless otherwise indicated. A single data listed under Avg. indicates n=1.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 7. Salmon River (SAM-WQ) dissolved gases measured *in situ* during Years 1 to 4 (2014 to 2017).

Year	Quarter	Dissolved Oxygen %				Dissolved Oxygen mg/L				Barometric Pressure mm Hg				TGP %				TGP mm Hg				ΔP mm Hg			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	21-May	102.6	102.6	102.6	0.0	11.68	11.67	11.68	0.01	748	748	748	0	102	102	102	0	761	761	761	0	13	13	13	0
	17-Jun	99.3	99.1	99.7	0.3	10.73	10.68	10.76	0.04	749	749	749	0	101	101	102	1	758	755	761	3	9	6	12	3
	23-Jul	101.8	101.8	101.9	0.1	10.20	10.20	10.20	0.00	747	747	747	0	101	101	101	0	755	755	755	0	8	8	8	0
	18-Aug	98.9	98.0	100.6	1.4	9.56	9.43	9.73	0.15	750	750	750	0	101	101	102	1	761	757	764	4	11	7	14	4
	23-Sep	88.2	87.1	88.8	0.9	8.80	8.71	8.86	0.08	760	760	760	0	98	98	99	1	749	748	751	2	-11	-12	-9	2
	03-Nov	95.7	95.1	96.5	0.7	11.08	11.02	11.18	0.09	763	762	763	1	100	100	100	0	763	761	764	2	0	-2	1	2
2015	13-May	93.7	93.7	93.8	0.1	10.38	10.37	10.39	0.01	742	742	742	0	-	-	-	-	-	-	-	-	-	-	-	-
	16-Jun	81.5	81.3	81.8	0.3	8.31	8.27	8.34	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	22-Jul	96.1	96.1	96.2	0.1	9.40	9.38	9.42	0.02	744	744	744	0	-	-	-	-	-	-	-	-	-	-	-	-
	12-Aug	92.0	91.9	92.1	0.1	9.02	8.98	9.06	0.04	747	747	747	0	-	-	-	-	-	-	-	-	-	-	-	-
	17-Sep	82.8	82.4	83.3	0.5	9.08	9.04	9.14	0.05	746	746	746	0	-	-	-	-	-	-	-	-	-	-	-	-
	15-Oct	99.1	98.9	99.3	0.2	11.46	11.44	11.48	0.02	750	750	750	0	-	-	-	-	-	-	-	-	-	-	-	-
2016	17-May	86.6	86.4	86.7	0.2	9.82	9.81	9.84	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	14-Jun	85.1	84.9	85.3	0.2	9.49	9.47	9.51	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12-Jul	92.9	92.7	93.0	0.2	9.72	9.70	9.74	0.02	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	16-Aug	92.8	92.6	92.9	0.2	9.07	9.06	9.08	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13-Sep	87.8	87.4	88.2	0.4	9.47	9.43	9.52	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11-Oct	92.2	91.8	92.5	0.4	11.01	10.97	11.06	0.05	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2017	09-May	102.7	102.7	102.8	0.1	12.81	12.80	12.82	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	13-Jun	98.5	98.3	98.7	0.2	11.10	11.07	11.15	0.04	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	11-Jul	92.9	92.9	93.0	0.1	9.72	9.69	9.79	0.06	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	08-Aug	93.6	93.5	93.7	0.1	9.29	9.25	9.31	0.03	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	12-Sep	87.1	86.8	87.4	0.3	9.05	9.04	9.05	0.01	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
	10-Oct	98.1	97.9	98.5	0.3	11.56	11.52	11.64	0.07	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

[1] Average of three replicates (n=3) on each date unless otherwise indicated.

Blue shading indicates that the more conservative provincial guideline (DO instantaneous minimum of 9 mg/L) for the protection of buried embryo/alevin has not been achieved. Note that the guideline for life stages other than buried embryo/alevin is met (DO instantaneous minimum of 5 mg/L).

Dashes (-) mean that no data were collected.

Table 8. Salmon River (SAM-WQ) general water quality variables measured at ALS labs during Years 1 to 4 (2014 to 2017).

Year	Date	Alkalinity, Total (as CaCO3) mg/L				Specific Conductivity µS/cm				Total Dissolved Solids mg/L				Total Suspended Solids mg/L				Turbidity NTU				pH pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	21-May	12.3	12.2	12.3	0.1	27.2	27.0	27.3	0.2	32	31	32	1	<1.0	<1.0	<1.0	0.0	0.30	0.22	0.38	0.11	7.38	7.35	7.40	0.04
	17-Jun	17.6	17.3	17.8	0.4	40.5	37.5	43.5	4.2	33	31	34	2	<1.0	<1.0	<1.0	0.0	0.22	0.17	0.26	0.06	7.57	7.55	7.59	0.03
	23-Jul	21.0	20.7	21.2	0.4	46.5	46.4	46.6	0.1	38	38	38	0	<1.0	<1.0	<1.0	0.0	0.92	0.71	1.12	0.29	7.58	7.53	7.62	0.06
	18-Aug	23.8	23.6	23.9	0.2	56.3	55.3	57.3	1.4	49	43	55	8	<4.6	<1.0	8.1	5.0	0.22	0.20	0.23	0.02	7.79	7.76	7.82	0.04
	23-Sep	23.9	23.8	23.9	0.1	53.1	52.8	53.4	0.4	46	41	51	7	<1.0	<1.0	<1.0	0.0	0.26	0.23	0.28	0.04	7.65	7.48	7.82	0.24
	03-Nov	16.6	16.5	16.6	0.1	37.2	36.7	37.7	0.7	53	37	69	23	<1.0	<1.0	<1.0	0.0	0.33	0.32	0.34	0.01	7.61	7.56	7.65	0.06
2015	13-May	15.8	15.3	16.2	0.6	33.5	33.3	33.6	0.2	25	23	27	3	<1.0	<1.0	<1.0	0.0	0.16	0.14	0.17	0.02	7.38	7.33	7.42	0.06
	16-Jun	21.6	20.8	22.4	1.1	47.8	47.7	47.8	0.1	32	31	33	1	<1.0	<1.0	<1.0	0.0	0.11	0.11	0.11	0.00	7.66	7.65	7.66	0.01
	22-Jul	23.1	22.6	23.5	0.6	59.9	55.0	64.8	6.9	32	31	32	1	<1.0	<1.0	<1.0	0.0	0.13	0.12	0.13	0.01	7.69	7.68	7.70	0.01
	12-Aug	22.6	21.7	23.4	1.2	51.4	51.2	51.6	0.3	47	45	48	2	<1.0	<1.0	<1.0	0.0	0.16	0.14	0.18	0.03	7.85	7.81	7.88	0.05
	17-Sep	20.4	20.4	20.4	0.0	47.2	47.1	47.3	0.1	32	32	32	0	<1.0	<1.0	<1.0	0.0	0.18	0.16	0.19	0.02	7.72	7.70	7.74	0.03
	15-Oct	18.2	18.1	18.2	0.1	40.7	40.6	40.8	0.1	37	36	37	1	<1.0	<1.0	<1.0	0.0	0.36	0.24	0.48	0.17	7.43	7.43	7.43	0.00
2016	17-May	12.9	12.8	12.9	0.1	26.4	26.3	26.5	0.1	19	18	20	1	<1.0	<1.0	<1.0	0.0	0.18	0.16	0.20	0.03	7.43	7.40	7.46	0.04
	14-Jun	14.8	14.8	14.8	0.0	35.4	35.1	35.6	0.4	28	27	28	1	<1.0	<1.0	<1.0	0.0	0.16	0.14	0.17	0.02	7.48	7.46	7.49	0.02
	12-Jul	17.9	17.6	18.1	0.4	37.0	36.9	37.0	0.1	31	30	32	1	<1.0	<1.0	<1.0	0.0	0.14	0.14	0.14	0.00	7.48	7.46	7.49	0.02
	16-Aug	21.5	21.3	21.6	0.2	50.3	50.1	50.4	0.2	32	28	36	6	<1.2	<1.0	1.4	0.3	0.13	0.12	0.13	0.01	7.33	7.32	7.34	0.01
	13-Sep	20.4	20.3	20.5	0.1	48.1	47.8	48.4	0.4	34	34	34	0	<1.0	<1.0	<1.0	0.0	0.18	0.15	0.20	0.04	7.74	7.65	7.82	0.12
	11-Oct	20.2	20.1	20.3	0.1	47.2	46.4	48.0	1.1	37	34	39	4	<1.1	<1.0	1.2	0.1	0.42	0.40	0.44	0.03	7.67	7.63	7.70	0.05
2017	09-May	12.6	12.4	12.8	0.3	28.3	28.2	28.4	0.1	19	18	20	1	<2.1	<1.0	3.1	1.5	0.33	0.30	0.36	0.04	7.41	7.41	7.41	0.00
	13-Jun	12.6	12.6	12.6	0.0	28.2	27.9	28.4	0.4	28	27	28	1	<1.0	<1.0	<1.0	0.0	0.20	0.18	0.21	0.02	7.55	7.52	7.57	0.04
	11-Jul	17.0	16.9	17.0	0.1	35.1	35.0	35.2	0.1	31	29	32	2	<1.9	<1.0	2.7	1.2	0.18	0.17	0.19	0.01	7.59	7.57	7.60	0.02
	08-Aug	20.8	19.4	22.1	1.9	46.3	46.0	46.5	0.4	36	34	37	2	<1.0	<1.0	<1.0	0.0	0.21	0.18	0.23	0.04	7.58	7.57	7.59	0.01
	12-Sep	25.4	25.3	25.4	0.1	54.8	53.5	56.0	1.8	46	44	47	2	<1.0	<1.0	<1.0	0.0	0.31	0.29	0.33	0.03	7.67	7.65	7.68	0.02
	10-Oct	23.2	23.0	23.3	0.2	55.1	52.8	57.3	3.2	37	36	38	1	<1.0	<1.0	<1.0	0.0	0.19	0.18	0.19	0.01	7.32	7.31	7.32	0.01

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 9. Salmon River (SAM-WQ) low level nutrients measured at ALS labs during Years 1 to 4 (2014 to 2017).

Year	Date	Ammonia, Total (as N) µg/L				Dissolved Orthophosphate (as P) µg/L				Nitrate (as N) µg/L				Nitrite (as N) µg/L				Total Phosphorus (P) µg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	21-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	8.8	8.4	9.1	0.5	<1.0	<1.0	<1.0	0.0	3.2	3.1	3.2	0.1
	17-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	15.5	15.2	15.7	0.4	<1.0	<1.0	<1.0	0.0	<2.1	<2.0	2.1	0.1
	23-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	8.5	8.5	8.5	0.0	<1.0	<1.0	<1.0	0.0	2.4	2.2	2.5	0.2
	18-Aug	5.8	5.5	6.0	0.4	<1.1	<1.0	1.1	0.1	27.6	27.4	27.7	0.2	<1.0	<1.0	<1.0	0.0	<3.8	<2.0	5.6	2.5
	23-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	71.6	70.8	72.4	1.1	<1.0	<1.0	<1.0	0.0	<2.3	<2.0	2.5	0.4
	03-Nov	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	26.1	25.6	26.5	0.6	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
2015	13-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	12.2	12.1	12.3	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	16-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	52.8	52.8	52.8	0.0	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	22-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	25.0	24.6	25.4	0.6	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	12-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	96.6	95.9	97.3	1.0	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	17-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	40.0	39.9	40.0	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	15-Oct	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	20.1	20.0	20.1	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
2016	17-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	5.6	<5.0	6.1	0.8	<1.3	<1.0	1.5	0.4	<2.7	<2.0	3.4	1.0
	14-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	14.4	14.1	14.7	0.4	<1.0	<1.0	<1.0	0.0	<3.5	<2.0	5.0	2.1
	12-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	23.6	23.5	23.6	0.1	<1.0	<1.0	<1.0	0.0	<2.8	<2.0	3.5	1.1
	16-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	81.9	81.4	82.4	0.7	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	13-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	40.4	40.2	40.5	0.2	<1.0	<1.0	<1.0	0.0	<2.2	<2.0	2.3	0.2
	11-Oct	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	32.7	32.4	32.9	0.4	<1.0	<1.0	<1.0	0.0	3.0	3.0	3.0	0.0
2017	09-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	16.1	15.7	16.4	0.5	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	13-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	10.1	10.0	10.1	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	11-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	21.5	20.6	22.3	1.2	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	3.1	0.8
	08-Aug	<5.0	<5.0	12.9	5.6	<1.0	<1.0	<1.0	0.0	56.6	56.1	57.1	0.7	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	12-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	133.0	133.0	133.0	0.0	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	10-Oct	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	77.4	77.2	77.5	0.2	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 10. Quinsam River (QUN-WQ) general water quality variables measured *in situ* during Years 1 to 5 (2014 to 2018).

Year	Date	Air Temperature °C				Conductivity (In Situ) µS/cm				Specific Conductivity µS/cm				Water Temperature °C				pH (In Situ) pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	23-May	-	-	-	-	73.3	73.3	73.3	0.0	95.6	95.6	95.6	0.0	12.8	12.8	12.8	0.0	7.38	7.38	7.39	0.01
	18-Jun	14	14	14	0	121.5	121.5	121.6	0.1	143.1	143.1	143.1	0.0	17.1	17.1	17.1	0.0	7.58	7.57	7.58	0.01
	22-Jul	16	16	16	0	127.5	127.5	127.5	0.0	148.1	148.1	148.1	0.0	17.7	17.7	17.7	0.0	7.36	7.36	7.36	0.00
	19-Aug	19	19	19	0	138.2	138.1	138.3	0.1	152.3	152.2	152.4	0.1	20.2	20.2	20.2	0.0	7.38	7.36	7.43	0.04
	24-Sep	14	14	14	0	91.2	91.2	91.3	0.1	109.9	109.9	109.9	0.0	16.1	16.1	16.1	0.0	7.30	7.23	7.36	0.07
	04-Nov	7	7	7	0	48.9	48.9	48.9	0.0	69.4	69.4	69.4	0.0	9.6	9.6	9.6	0.0	7.01	7.01	7.02	0.01
2015	12-May	14	14	14	0	114.6	114.6	114.6	0.0	144.4	144.4	144.5	0.1	14.2	14.2	14.2	0.0	7.68	7.68	7.68	0.00
	17-Jun	15	15	15	0	121.9	121.9	121.9	0.0	98.1	14.0	140.2	72.8	18.2	18.2	18.2	0.0	7.71	7.71	7.71	0.00
	23-Jul	17	17	17	0	161.6	161.6	161.7	0.1	190.7	190.7	190.7	0.0	17.0	17.0	17.0	0.0	7.49	7.49	7.49	0.00
	13-Aug	17	17	17	0	173.2	173.1	173.2	0.1	197.7	197.6	197.7	0.1	18.5	18.5	18.5	0.0	7.41	7.40	7.41	0.01
	16-Sep	12	12	12	0	147.1	147.1	147.1	0.0	185.7	185.7	185.7	0.0	14.1	14.1	14.1	0.0	7.50	7.50	7.50	0.00
	14-Oct	11	11	11	0	92.9	92.9	92.9	0.0	131.9	131.8	131.9	0.1	9.5	9.5	9.6	0.1	7.52	7.50	7.54	0.02
2016	18-May	12	12	12	0	119.1	119.1	119.2	0.1	150.1	150.0	150.2	0.1	14.7	14.7	14.7	0.0	7.18	7.16	7.20	0.02
	15-Jun	9	9	9	0	112.1	112.0	112.1	0.1	143.5	143.4	143.6	0.1	14.0	14.0	14.0	0.0	6.86	6.86	6.87	0.01
	13-Jul	15	15	15	0	125.5	125.4	125.6	0.1	154.2	154.1	154.4	0.2	15.7	15.7	15.7	0.0	10.52	10.46	10.59	0.07
	17-Aug	19	19	19	0	139.4	139.4	139.4	0.0	157.4	157.4	157.4	0.0	19.3	19.3	19.3	0.0	7.25	7.24	7.25	0.01
	14-Sep	12	12	12	0	138.5	138.5	138.5	0.0	172.6	172.6	172.7	0.1	15.1	15.1	15.1	0.0	7.40	7.39	7.40	0.01
	12-Oct	5	5	5	0	115.2	114.9	115.5	0.3	175.9	175.5	176.1	0.3	7.7	7.7	7.7	0.0	15.86	15.86	15.86	0.00
2017	10-May	7	7	7	0	73.3	73.3	73.3	0.0	105.7	105.7	105.8	0.1	8.9	8.9	8.9	0.0	7.58	7.58	7.58	0.00
	14-Jun	9	9	9	0	99.3	99.3	99.3	0.0	124.1	124.1	124.1	0.0	15.0	15.0	15.0	0.0	7.47	7.46	7.47	0.01
	12-Jul	17	17	17	0	140.4	140.4	140.4	0.0	158.2	158.2	158.2	0.0	19.4	19.4	19.4	0.0	7.08	7.05	7.10	0.03
	09-Aug	13	13	13	0	149.8	149.8	149.8	0.0	162.7	162.6	162.7	0.1	21.1	21.1	21.1	0.0	7.17	7.17	7.17	0.00
	13-Sep	8	8	8	0	137.6	137.6	137.6	0.0	166.8	166.8	166.9	0.1	16.2	16.2	16.2	0.0	7.21	7.20	7.22	0.01
	11-Oct	2	2	2	0	128.9	128.8	128.9	0.1	178.0	178.0	178.1	0.1	11.2	11.2	11.2	0.0	7.21	7.17	7.24	0.04
2018	10-May	9	9	9	0	66.7	66.6	66.8	0.1	95.9	95.8	96.0	0.1	9.7	9.7	9.7	0.0	6.02	5.92	6.11	0.10
	05-Jun	8	8	8	0	118.5	118.5	118.5	0.0	153.4	153.3	153.4	0.1	13.6	13.6	13.6	0.0	6.58	6.57	6.58	0.01
	04-Jul	12	12	12	0	116.1	116.1	116.1	0.0	139.0	139.0	139.0	0.0	16.8	16.8	16.8	0.0	7.59	7.59	7.59	0.00
	09-Aug	14	14	14	0	129.9	129.8	129.9	0.1	137.4	137.3	137.4	0.1	22.1	22.1	22.1	0.0	7.05	7.04	7.06	0.01
	12-Sep	10	10	10	0	91.0	91.0	91.0	0.0	112.8	112.8	112.8	0.0	15.3	15.3	15.3	0.0	7.69	7.69	7.70	0.01
	05-Oct	5	5	5	0	79.3	79.3	79.4	0.1	112.5	112.4	112.6	0.1	9.5	9.5	9.5	0.0	-	-	-	-

[1] Average of three replicates (n=3) on each date unless otherwise indicated. A single data listed under Avg. indicates n=1.
Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 11. Quinsam River (QUN-WQ) dissolved gases measured *in situ* during Years 1 to 5 (2014 to 2018).

Year	Date	Barometric Pressure mm Hg				Oxygen Dissolved (In Situ) %				Oxygen Dissolved (In Situ) mg/L				TGP %				TGP mm Hg				ΔP mm Hg			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	23-May	744	743	745	1	101.8	101.4	102.6	0.7	10.74	10.69	10.82	0.07	100	100	100	0	744	744	745	1	0	0	1	1
	18-Jun	748	748	749	1	91.3	90.9	91.9	0.5	8.84	8.80	8.87	0.04	101	101	101	0	755	753	757	2	7	5	8	2
	22-Jul	747	747	748	1	95.8	95.8	95.9	0.1	9.13	9.12	9.13	0.01	101	101	101	0	753	753	753	0	6	5	6	1
	19-Aug	745	744	745	1	77.9	77.7	78.3	0.3	7.01	6.99	7.03	0.02	99	99	99	0	735	735	735	0	-10	-10	-9	1
	24-Sep	753	752	753	1	91.7	90.1	92.7	1.4	8.78	8.53	8.91	0.21	98	98	98	0	739	739	740	1	-13	-14	-13	1
	04-Nov	761	761	762	1	88.5	88.4	88.5	0.1	9.95	9.94	9.96	0.01	99	99	99	0	755	755	755	0	-6	-7	-6	1
2015	12-May	741	741	741	0	96.2	96.2	96.3	0.1	9.89	9.88	9.89	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	17-Jun	-	-	-	-	83.7	83.6	83.9	0.2	7.90	7.89	7.91	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	23-Jul	744	744	744	0	84.2	84.1	84.4	0.2	8.14	8.13	8.14	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	13-Aug	746	746	746	0	84.2	84.1	84.4	0.2	7.89	7.88	7.91	0.02	-	-	-	-	-	-	-	-	-	-	-	-
	16-Sep	743	743	743	0	78.1	77.8	78.5	0.4	8.03	8.00	8.05	0.03	-	-	-	-	-	-	-	-	-	-	-	-
	14-Oct	754	754	754	0	87.0	86.8	87.3	0.3	9.88	9.87	9.89	0.01	-	-	-	-	-	-	-	-	-	-	-	-
2016	18-May	747	747	747	0	81.9	81.7	82.0	0.2	8.30	8.30	8.30	0.00	-	-	-	-	-	-	-	-	-	-	-	-
	15-Jun	744	744	744	0	80.0	79.9	80.2	0.2	8.23	8.22	8.24	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	13-Jul	757	757	757	0	79.4	79.3	79.5	0.1	7.89	7.87	7.92	0.03	103	103	103	0	777	777	777	0	20	20	20	0
	17-Aug	749	749	749	0	84.4	84.1	84.6	0.3	7.77	7.75	7.79	0.02	-	-	-	-	-	-	-	-	-	-	-	-
	14-Sep	747	747	747	0	81.0	80.9	81.2	0.2	8.16	8.15	8.17	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	12-Oct	747	747	747	0	98.0	97.6	98.5	0.5	11.70	11.63	11.75	0.06	-	-	-	-	-	-	-	-	-	-	-	-
2017	10-May	742	742	742	0	76.9	76.6	77.3	0.4	8.94	8.92	8.96	0.02	-	-	-	-	-	-	-	-	-	-	-	-
	14-Jun	752	752	752	0	89.6	89.5	89.7	0.1	9.03	9.01	9.05	0.02	-	-	-	-	-	-	-	-	-	-	-	-
	12-Jul	749	749	749	0	87.1	87.0	87.1	0.1	8.02	8.01	8.03	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	09-Aug	748	748	748	0	80.0	79.5	80.3	0.5	7.13	7.13	7.13	0.00	-	-	-	-	-	-	-	-	-	-	-	-
	13-Sep	749	749	749	0	83.7	83.5	83.8	0.2	8.21	8.20	8.22	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	11-Oct	751	751	751	0	91.6	91.6	91.7	0.1	10.05	10.04	10.06	0.01	-	-	-	-	-	-	-	-	-	-	-	-
2018	10-May	748	748	748	0	96.5	95.8	97.0	0.6	10.99	10.97	11.02	0.03	-	-	-	-	-	-	-	-	-	-	-	-
	05-Jun	744	743	744	0	85.3	85.2	85.4	0.1	8.86	8.85	8.87	0.01	-	-	-	-	-	-	-	-	-	-	-	-
	04-Jul	753	753	753	0	82.4	82.2	82.6	0.2	7.99	7.97	8.02	0.03	-	-	-	-	-	-	-	-	-	-	-	-
	09-Aug	-	-	-	-	90.7	90.0	91.9	1.0	8.25	7.85	8.87	0.55	-	-	-	-	-	-	-	-	-	-	-	-
	12-Sep	744	744	744	0	93.8	92.1	95.7	1.8	9.41	9.24	9.62	0.19	-	-	-	-	-	-	-	-	-	-	-	-
	05-Oct	-	-	-	-	84.8	84.1	85.9	1.0	9.75	9.65	9.80	0.08	-	-	-	-	-	-	-	-	-	-	-	-

[1] Average of three replicates (n=3) on each date unless otherwise indicated.

Blue shading indicates that the more conservative guideline (DO instantaneous minimum of 9.0 mg/L) for the protection of buried embryo/alevins has not been achieved. Note that the guideline for life stages other than buried embryo/alevins is met (DO instantaneous minimum of 5.0 mg/L).

Dashes (-) indicate that no data was collected.

Table 12. Quinsam River (QUN-WQ) general water quality variables measured at ALS labs during Years 1 to 5 (2014 to 2018).

Year	Date	Alkalinity, Total (as CaCO3) mg/L				Conductivity (lab) µS/cm				Total Dissolved Solids mg/L				Total Suspended Solids mg/L				Turbidity (lab) NTU				pH (lab) pH units			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	23-May	31.7	31.5	31.8	0.2	94.8	94.1	95.4	0.9	69	68	70	1	<1	<1	<1	0.0	0.59	0.52	0.65	0.09	7.77	7.77	7.77	0.00
	18-Jun	41.0	40.8	41.1	0.2	139.5	139.0	140.0	0.7	96	96	96	0	<1	<1	<1	0.0	0.42	0.40	0.44	0.03	7.87	7.87	7.87	0.00
	22-Jul	42.4	42.4	42.4	0.0	140.0	139.0	141.0	1.4	103	101	105	3	<1	<1	<1	0.0	0.46	0.44	0.47	0.02	7.73	7.65	7.81	0.11
	19-Aug	42.1	41.9	42.3	0.3	156.0	146.0	166.0	14.1	96	95	96	1	<1	<1	<1	0.0	0.70	0.47	0.93	0.33	7.81	7.57	8.05	0.34
	24-Sep	35.0	35.0	35.0	0.0	109.0	109.0	109.0	0.0	71	67	74	5	<1	<1	<1	0.0	0.56	0.50	0.62	0.08	7.55	7.52	7.58	0.04
	04-Nov	23.7	23.5	23.8	0.2	71.3	70.7	71.8	0.8	59	53	64	8	<1	<1	<1	0.0	0.74	0.71	0.77	0.04	7.61	7.59	7.63	0.03
2015	12-May	40.8	40.6	41.0	0.3	143.0	143.0	143.0	0.0	91	89	93	3	<1	<1	<1	0.0	0.38	0.37	0.39	0.01	7.79	7.78	7.80	0.01
	17-Jun	43.9	43.8	43.9	0.1	157.0	157.0	157.0	0.0	97	94	100	4	<1	<1	<1	0.0	0.41	0.40	0.42	0.01	7.91	7.90	7.92	0.01
	23-Jul	52.9	51.7	54.0	1.6	206.0	206.0	206.0	0.0	120	120	120	0	<1	<1	<1	0.0	0.49	0.49	0.49	0.00	8.00	7.99	8.01	0.01
	13-Aug	48.8	48.0	49.6	1.1	175.0	173.0	177.0	2.8	124	120	127	5	<1	<1	<1	0.0	0.36	0.30	0.42	0.08	7.78	7.70	7.85	0.11
	16-Sep	46.2	46.0	46.3	0.2	178.0	177.0	179.0	1.4	145	116	173	40	<1	<1	<1	0.0	0.40	0.38	0.42	0.03	7.94	7.94	7.94	0.00
	14-Oct	34.0	33.9	34.1	0.1	130.0	129.0	131.0	1.4	94	92	96	3	<1	<1	1.6	0.4	0.47	0.40	0.53	0.09	7.55	7.52	7.58	0.04
2016	18-May	35.4	35.1	35.6	0.4	131.5	131.0	132.0	0.7	85	85	85	0	<1	<1	<1	0.0	0.49	0.38	0.59	0.15	7.83	7.80	7.86	0.04
	15-Jun	34.3	33.9	34.7	0.6	130.5	130.0	131.0	0.7	87	86	88	1	<1	<1	<1	0.0	0.45	0.44	0.46	0.01	7.78	7.77	7.78	0.01
	13-Jul	36.6	36.5	36.7	0.1	110.0	109.0	111.0	1.4	70	67	72	4	<1	<1	1.5	0.4	1.17	1.14	1.19	0.04	7.68	7.67	7.68	0.01
	17-Aug	35.5	35.4	35.5	0.1	137.5	137.0	138.0	0.7	87	86	88	1	<1	<1	1.1	0.1	0.46	0.44	0.47	0.02	7.51	7.50	7.51	0.01
	14-Sep	35.3	35.1	35.4	0.2	139.0	139.0	139.0	0.0	84	83	84	1	<1	<1	<1	0.0	0.46	0.45	0.46	0.01	7.71	7.70	7.72	0.01
	12-Oct	30.6	30.4	30.8	0.3	118.5	114.0	123.0	6.4	83	81	84	2	<1	<1	<1	0.0	0.72	0.72	0.72	0.00	7.70	7.69	7.71	0.01
2017	10-May	32.4	32.2	32.6	0.3	105.5	104.0	107.0	2.1	90	72	107	25	2.1	1.7	2.4	0.5	0.59	0.55	0.62	0.05	7.71	7.69	7.72	0.02
	14-Jun	41.1	41.1	41.1	0.0	145.5	145.0	146.0	0.7	99	95	102	5	<1	<1	<1	0.0	0.54	0.53	0.54	0.01	7.94	7.93	7.94	0.01
	12-Jul	44.3	43.5	45.0	1.1	148.0	147.0	149.0	1.4	93	92	94	1	1.4	1.3	1.4	0.1	0.57	0.53	0.61	0.06	7.91	7.89	7.93	0.03
	09-Aug	43.8	43.7	43.9	0.1	161.0	160.0	162.0	1.4	102	101	103	1	<1	<1	<1	0.0	0.61	0.54	0.68	0.10	7.80	7.79	7.80	0.01
	13-Sep	43.2	42.7	43.7	0.7	162.0	162.0	162.0	0.0	103	98	107	6	<1	<1	<1	0.0	0.46	0.44	0.47	0.02	7.91	7.91	7.91	0.00
	11-Oct	45.4	45.1	45.6	0.4	169.0	169.0	169.0	0.0	127	125	128	2	<1	<1	<1	0.0	0.41	0.41	0.41	0.00	7.63	7.62	7.63	0.01
2018	10-May	27.8	27.8	27.8	0.0	93.2	92.7	93.6	0.6	70	69	70	1	<1	<1	<1	0.0	0.46	0.43	0.48	0.04	7.59	7.57	7.60	0.02
	05-Jun	41.3	40.9	41.7	0.6	149.5	149.0	150.0	0.7	97	96	98	1	1.4	1.1	1.6	0.4	0.48	0.45	0.50	0.04	7.85	7.84	7.85	0.01
	04-Jul	38.7	38.4	39.0	0.4	132.5	132.0	133.0	0.7	93	87	98	8	1.4	1.3	1.5	0.1	0.58	0.54	0.62	0.06	7.78	7.76	7.79	0.02
	09-Aug	41.2	41.1	41.2	0.1	132.0	132.0	132.0	0.0	88	88	88	0	<1	<1	1.1	0.1	0.64	0.52	0.75	0.16	7.84	7.84	7.84	0.00
	12-Sep	37.0	36.8	37.1	0.2	110.0	110.0	110.0	0.0	78	73	82	6	<3	<3	<3	0.0	0.38	0.32	0.43	0.08	7.81	7.80	7.82	0.01
	05-Oct	31.0	30.9	31.0	0.1	105.5	104.0	107.0	2.1	78	77	78	1	<1	<1	1.3	0.2	0.44	0.43	0.44	0.01	7.65	7.61	7.68	0.05

[1] Average of three replicates (n=3) on each date unless otherwise indicated. A single data listed under Avg. indicates n=1.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

Table 13. Quinsam River (QUN-WQ) low level nutrients measured at ALS labs during Years 1 to 5 (2014 to 2018).

Year	Date	Ammonia, Total (as N) µg/L				Orthophosphate (as P) µg/L				Nitrate (as N) µg/L				Nitrite (as N) µg/L				Total Phosphorus (P) µg/L			
		Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD	Avg[1]	Min	Max	SD
2014	23-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	13.8	13.5	14.0	0.4	<1.0	<1.0	<1.0	0.0	3.9	3.8	3.9	0.1
	18-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	29.7	29.2	30.1	0.6	<1.0	<1.0	<1.0	0.0	2.8	2.7	2.9	0.1
	22-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	31.6	31.3	31.9	0.4	<1.0	<1.0	<1.0	0.0	2.9	2.6	3.2	0.4
	19-Aug	<5.2	<5.0	5.3	0.2	<1.0	<1.0	<1.0	0.0	17.1	17.0	17.1	0.1	<1.0	<1.0	<1.0	0.0	4.8	4.6	5.0	0.3
	24-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	21.2	20.7	21.6	0.6	<1.0	<1.0	<1.0	0.0	4.3	3.9	4.6	0.5
	04-Nov	5.1	5.1	5.1	0.0	<1.0	<1.0	<1.0	0.0	24.6	24.0	25.1	0.8	<1.0	<1.0	<1.0	0.0	3.7	2.9	4.4	1.1
2015	12-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	23.0	22.9	23.1	0.1	<1.0	<1.0	<1.0	0.0	2.9	2.5	3.3	0.6
	17-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	23.8	23.6	23.9	0.2	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	23-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	29.9	29.3	30.5	0.8	<1.0	<1.0	<1.0	0.0	<2.1	<2.0	2.1	0.1
	13-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	41.0	40.6	41.3	0.5	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	16-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	14.0	13.9	14.1	0.1	<1.0	<1.0	<1.0	0.0	<2.2	<2.0	2.3	0.2
	14-Oct	9.0	8.8	9.2	0.3	<1.0	<1.0	<1.0	0.0	36.0	35.6	36.3	0.5	<1.0	<1.0	<1.0	0.0	4.6	4.4	4.8	0.3
2016	18-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	16.3	16.1	16.4	0.2	<1.0	<1.0	<1.0	0.0	3.5	3.0	3.9	0.6
	15-Jun	<5.0	<5.0	<5.0	0.0	1.45	1.2	1.7	0.4	15.2	14.4	16.0	1.1	<1.0	<1.0	<1.0	0.0	3.3	2.7	3.9	0.8
	13-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	16.7	16.3	17.1	0.6	<1.0	<1.0	<1.0	0.0	4.6	4.2	4.9	0.5
	17-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	24.0	23.9	24.1	0.1	<1.0	<1.0	<1.0	0.0	3.8	3.0	4.6	1.1
	14-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	18.5	18.4	18.5	0.1	<1.0	<1.0	<1.0	0.0	2.6	2.5	2.7	0.1
	12-Oct	9.5	9.2	9.8	0.4	<1.0	<1.0	<1.0	0.0	38.8	38.6	39.0	0.3	<1.0	<1.0	<1.0	0.0	5.5	5.4	5.5	0.1
2017	10-May	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	13.5	13.0	14.0	0.7	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	14-Jun	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	17.8	17.7	17.8	0.1	<1.0	<1.0	<1.0	0.0	<2.0	<2.0	<2.0	0.0
	12-Jul	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	20.4	20.1	20.6	0.4	<1.0	<1.0	<1.0	0.0	2.9	2.4	3.3	0.6
	09-Aug	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	18.1	17.7	18.5	0.6	<1.0	<1.0	<1.0	0.0	2.4	2.3	2.5	0.0
	13-Sep	<5.0	<5.0	<5.0	0.0	<1.0	<1.0	<1.0	0.0	12.3	12.1	12.5	0.3	<1.0	<1.0	<1.0	0.0	<2.1	<2.0	2.2	0.0
	11-Oct	23.7	22.9	24.5	1.1	<1.0	<1.0	<1.0	0.0	47.4	47.0	47.8	0.6	<1.0	<1.0	<1.0	0.0	3.8	3.6	3.9	0.2
2018	10-May	<5	<5	<5	0.0	<1	<1	<1	0.0	9.6	8.5	10.6	1.5	<1	<1	<1	0.0	2.7	2.6	2.7	0.1
	05-Jun	<5	<5	5	0.3	<1	<1	<1	0.0	16.6	16.2	16.9	0.5	<1	<1	<1	0.0	3.1	2.9	3.3	0.3
	04-Jul	<5	<5	<5	0.0	<1	<1	<1	0.0	13.5	13.1	13.9	0.6	<1	<1	<1	0.0	5.5	4.9	6.0	0.8
	09-Aug	<5	<5	<5	0.0	<1	<1	<1	0.0	21.6	21.5	21.6	0.1	<1	<1	<1	0.0	3.9	3.7	4.0	0.2
	12-Sep	<5	<5	<5	0.0	<1	<1	<1	0.0	30.4	30.2	30.5	0.2	<1	<1	<1	0.0	3.3	3.1	3.5	0.3
	05-Oct	16.8	16.7	16.9	0.1	<1	<1	1.5	0.4	21.6	21.3	21.8	0.4	<1	<1	<1	0.0	4.7	4.2	5.2	0.7

[1] Average of two replicates (n=2) on each date.

Parameters that have a concentration below the detection limit are assumed to have a concentration equal to the detection limit for calculation purposes.

3. QUALITY CONTROL/QUALITY ASSURANCE

Table 14. Hold time exceedances for water samples analyzed by ALS Environmental recorded during 2014–2018.

Description[1]	Site	Sampling Date	Recommended Hold Time (days)	Actual Hold Time (days)
Physical Tests				
Total Suspended Solids	SAM-WQ	17-May-16	7	8
Anions and Nutrients				
Nitrite in Water by Ion Chromatography	QUN-WQ	19-Aug-14	3	8
Total Dissolved P in Water by Colour	SAM-WQ	17-Jun-14	3	6
Nitrate in Water by IC (Low Level)	QUN-WQ	10-May-18	3	5

[1]All samples for all sites and sample dates exceeded the recommended hold time for pH of 0.25 hours

Table 15. Results of field blank and trip blanks for water samples analysed by ALS Environment, 2014–2018.

Year	Date	Site	Type of Sample	Alkalinity, Total (as CaCO3) mg/L	Ammonia, Total (as N) µg/L	Conductivity µS/cm	Orthophosphate (as P) µg/L	Nitrate (as N) µg/L	Nitrite (as N) µg/L	Total Dissolved Solids mg/L	Total Phosphorus (P) µg/L	Total Suspended Solids mg/L	Turbidity NTU	pH pH units
2014	21-May	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.60
		SAM-WQ	Trip Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.54
	23-May	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.60
		QUN-WQ	Trip Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.64
	17-Jun	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.44
		SAM-WQ	Trip Blank	<2.0	6.08	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.48
	18-Jun	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.47
		QUN-WQ	Trip Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.45
	22-Jul	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.69
		QUN-WQ	Trip Blank	<2.0	2.71	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.76
	23-Jul	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.50
		SAM-WQ	Trip Blank	<2.0	50.2	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.47
	18-Aug	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.50
		SAM-WQ	Trip Blank	<2.0	88.5	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.05
	19-Aug	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.91
		QUN-WQ	Trip Blank	<2.0	38.7	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.17
	23-Sep	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.28
		SAM-WQ	Trip Blank	<2.0	81.6	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.03
	24-Sep	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.45
		QUN-WQ	Trip Blank	<2.0	55.1	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.41
	03-Nov	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.75
		SAM-WQ	Trip Blank	<2.0	87.7	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.73
	04-Nov	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.70
		QUN-WQ	Trip Blank	<2.0	99.5	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.75
2015	12-May	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.84
		QUN-WQ	Trip Blank	<2.0	11.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.80
	13-May	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.50
		SAM-WQ	Trip Blank	<2.0	18.8	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.77
	16-Jun	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.32
		SAM-WQ	Trip Blank	<2.0	43.6	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.22
	17-Jun	QUN-WQ	Field Blank	<2.0	<5.0	3.2	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	6.22
		QUN-WQ	Trip Blank	<2.0	58.5	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.91
2016	17-May	SAM-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.70
		SAM-WQ	Trip Blank	<2.0	12.1	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.74
	18-May	QUN-WQ	Field Blank	<2.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.62
		QUN-WQ	Trip Blank	<2.0	5.90	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.58
2018	10-May	QUN-WQ	Field Blank	<1.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.53
		QUN-WQ	Trip Blank	<1.0	<5.0	<2.0	<1.0	<5.0	<1.0	<10	<2.0	<1.0	<0.10	5.3

Appendix B. Supplementary Results of Analysis of Invertebrate Drift Data

TABLE OF CONTENTS

LIST OF TABLES

1. SALMON RIVER

1.1. Invertebrate Drift Results (Summary Table)

Table 1. Salmon River invertebrate drift mean density, biomass, Simpson's diversity index (family level), richness and CEFI. Each drift net was analyzed separately in 2014, while nets were combined into one sample in subsequent years.

All Taxa (Aquatic, Semi-Aquatic, and Terrestrial)													
Year	Date	Number of Replicates	Density (#/m^3)			Biomass (mg/m^3)			CEFI Index†			Simspon's Diversity Index (1-λ)‡	Richness (# of Families)‡
			Mean	S.D.	C.V.	Mean	S.D.	C.V.	Mean	S.D.	C.V.		
2014	21-May	5	0.85	0.26	30.06	0.11	0.03	31.09	0.37	0.01	1.89	0.86	74
	3-Jun	5	0.92	0.24	25.77	0.12	0.03	29.09	0.34	0.01	2.78	0.91	80
	11-Jun	5	0.72	0.29	40.33	0.04	0.01	27.14	0.34	0.01	1.96	0.89	48
	17-Jun	5	1.10	0.37	34.00	0.06	0.03	49.98	0.37	0.01	1.99	0.85	59
	26-Jun	5	0.86	0.33	38.49	0.10	0.11	113.95	0.35	0.01	2.04	0.89	55
	23-Jul	5	1.48	0.52	35.28	0.06	0.03	45.09	0.34	0.01	3.72	0.82	38
	18-Aug	5	3.11	1.43	46.04	0.07	0.03	41.65	0.34	0.01	1.65	0.75	37
	23-Sep	5	1.28	0.21	16.20	0.04	0.01	23.50	0.36	0.01	2.85	0.91	37
	3-Nov	5	0.89	0.21	23.50	0.06	0.01	18.80	0.37	0.01	2.83	0.89	76
2015	13-May	1	1.12	-	-	0.07	-	-	0.34	-	-	0.92	47
	16-Jun	1	3.32	-	-	0.07	-	-	0.35	-	-	0.84	45
	8-Jul	1	2.27	-	-	0.04	-	-	0.33	-	-	0.77	29
	15-Jul	1	2.03	-	-	0.04	-	-	0.32	-	-	0.67	30
	22-Jul	1	3.66	-	-	0.06	-	-	0.33	-	-	0.65	26
	28-Jul	1	1.77	-	-	0.06	-	-	0.32	-	-	0.78	32
	12-Aug	1	0.91	-	-	0.03	-	-	0.33	-	-	0.74	35
	17-Sep	1	1.19	-	-	0.05	-	-	0.35	-	-	0.82	30
	15-Oct	1	1.20	-	-	0.04	-	-	0.37	-	-	0.82	39
2016	3-May	1	0.84	-	-	0.08	-	-	0.36	-	-	0.84	34
	10-May	1	1.38	-	-	0.10	-	-	0.39	-	-	0.62	49
	17-May	1	1.02	-	-	0.08	-	-	0.36	-	-	0.79	35
	24-May	1	1.22	-	-	0.25	-	-	0.35	-	-	0.83	40
	14-Jun	1	1.86	-	-	0.13	-	-	0.35	-	-	0.83	46
	12-Jul	1	4.63	-	-	0.05	-	-	0.33	-	-	0.38	37
	16-Aug	1	1.32	-	-	0.08	-	-	0.35	-	-	0.88	37
	11-Oct	1	4.38	-	-	0.24	-	-	0.38	-	-	0.91	44
2017	9-May	1	0.76	-	-	0.17	-	-	0.37	-	-	0.89	37
	13-Jun	1	0.53	-	-	0.11	-	-	0.34	-	-	0.91	31
	11-Jul	1	1.09	-	-	0.06	-	-	0.36	-	-	0.85	36
	8-Aug	1	1.99	-	-	0.10	-	-	0.36	-	-	0.89	30
	15-Aug	1	1.17	-	-	0.07	-	-	0.36	-	-	0.91	29
	22-Aug	1	0.88	-	-	0.04	-	-	0.35	-	-	0.91	32
	30-Aug	1	0.88	-	-	0.06	-	-	0.35	-	-	0.89	29
	12-Sep	1	0.78	-	-	0.02	-	-	0.36	-	-	0.86	33

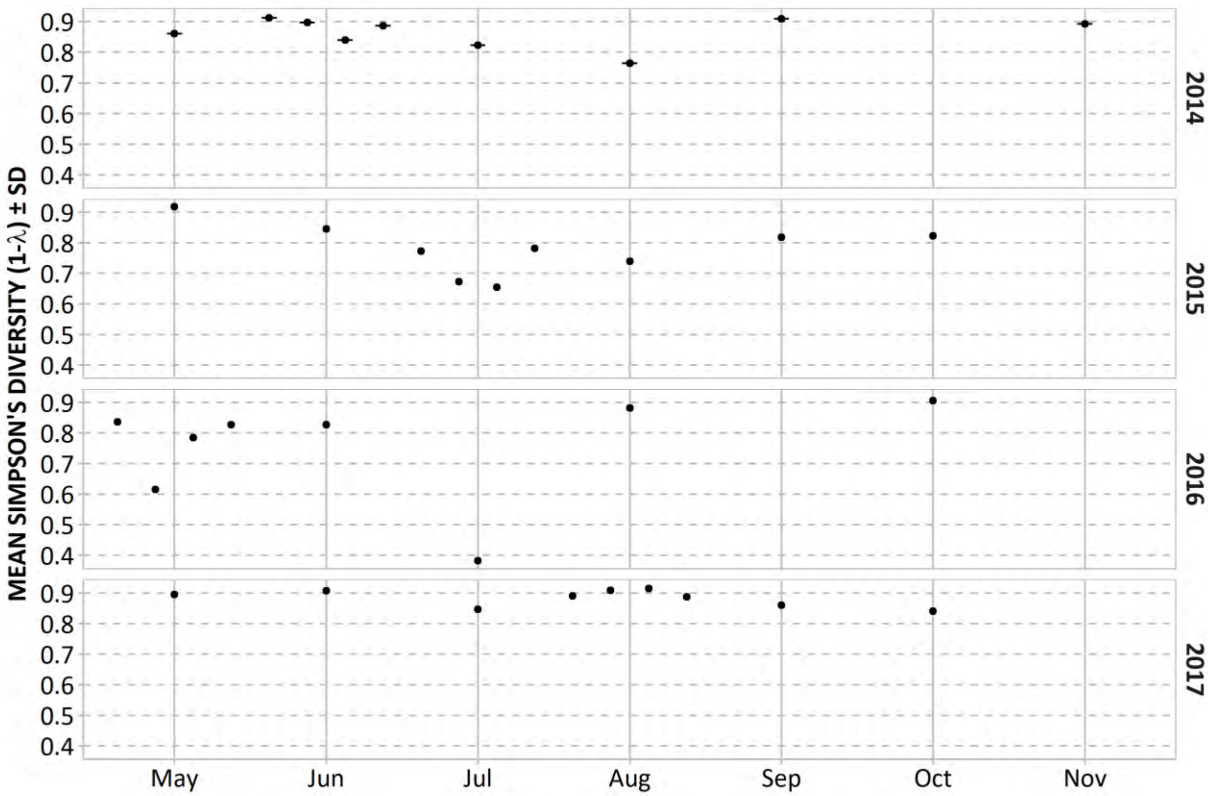
† Calculation considers only aquatic taxa

‡ Replicates were averaged where applicable prior to calculating metric

1.2. Simpson's Family Level Diversity (1-λ)

Simpson's family level diversity values ranged from 0.38 in July 2016 to 0.92 in May 2015, with a mean value of 0.82 and no clear seasonal cycle or trend over time (Figure 1).

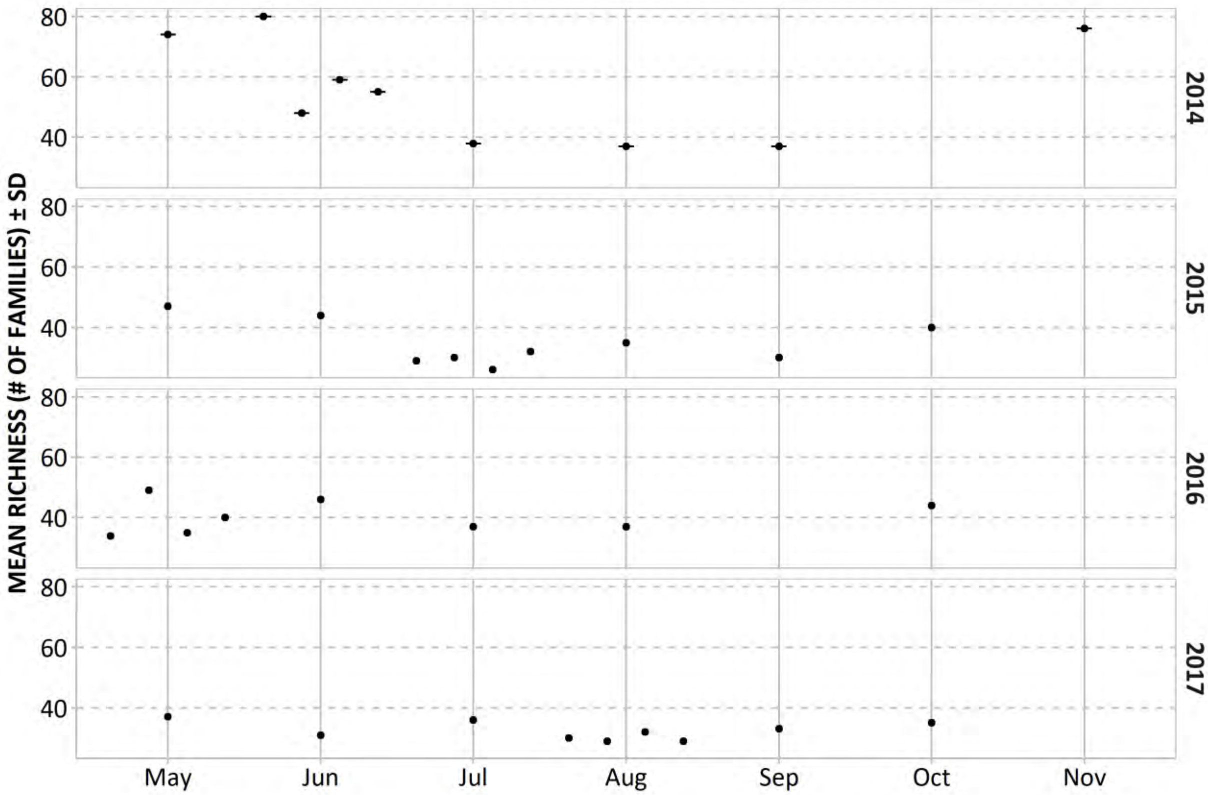
Figure 1. Simpson's diversity (family level) in the Salmon River.



1.3. Richness (# of Families)

Mean family richness ranged from 26 families (Jul 2015) to 80 families (June 2014), with no clear seasonal trend (Table 1). The average number of families declined from 56 in 2014 to 32 in 2017. This decline is largely due to several high values in 2014 (Figure 2).

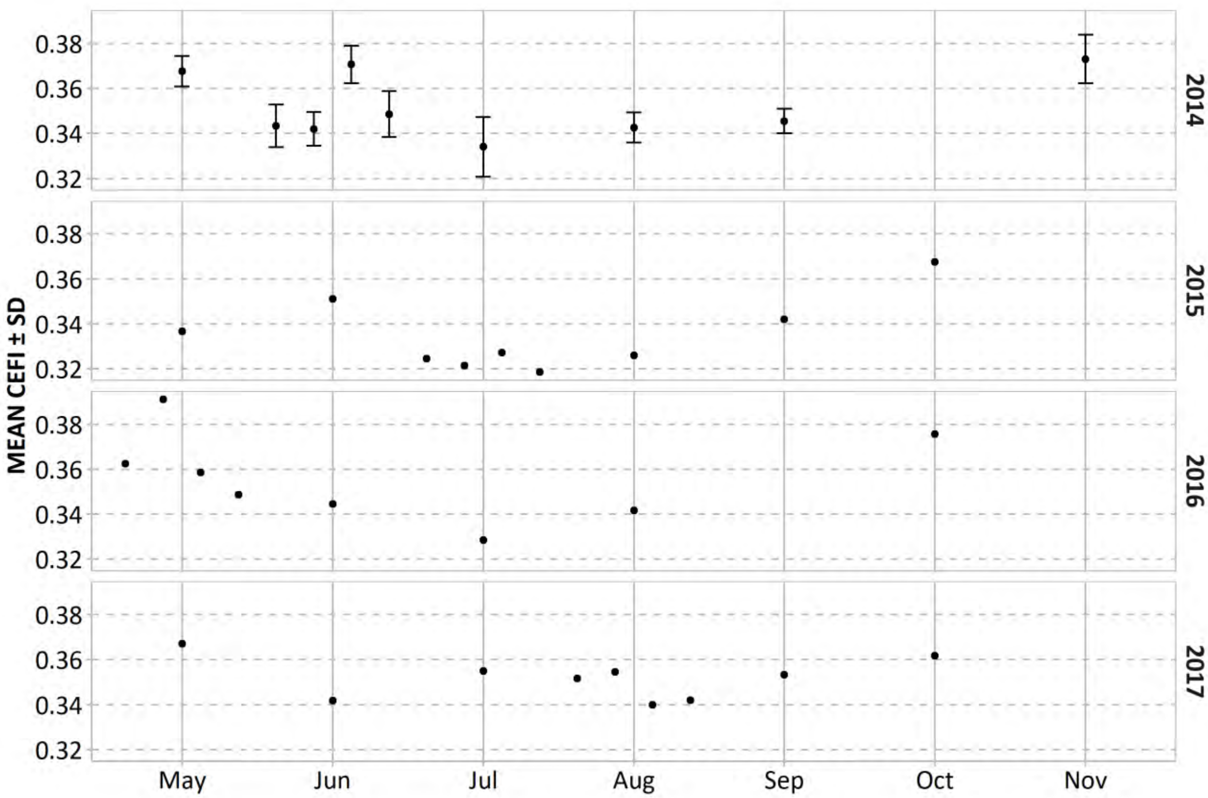
Figure 2. Richness (number of families) in the Salmon River.



1.4. Canadian Ecological Flow Index

The CEFI index describes the velocity preferences of aquatic invertebrates (Armanini *et al.* 2011). Low CEFI values are described as <0.25 (Armanini *et al.* 2011) and all CEFI values in the Salmon River were greater than this threshold (Table 1), indicating that the invertebrate community in the Salmon River comprises species with a preference for moderate to high current velocity. CEFI values ranged from 0.28 in July 2015 to 0.39 in May 2016 (Figure 3). CEFI values were generally lowest in mid-summer, indicating a shift to taxa that are less dependent on high current velocity (Armanini *et al.* 2011).

Figure 3. Canadian Ecological Flow Index (CEFI) for the Salmon River.



1.5. Cluster Analysis

The results of the cluster analysis (based on density data) are provided in the dendrogram in Figure 4. Density data from the highest available taxonomic resolution were analyzed on each sample date. Results are presented for all samples collected to date. Black lines indicate branching of groups with a dissimilar community composition at a 5% significance level (SIMPROF test); red lines denote groups that are not significantly different in their community composition at a 5% significance level (SIMPROF test).

The analyses show seasonal differences in community composition. The invertebrate drift community compositions of samples collected in the middle of the growing season (July, August, and September) are generally similar to each other and dissimilar to samples collected early (May and June) and later (October and November) in the growing season. In 2016, invertebrate composition in May, June, and October are more dissimilar than any other sampling periods. With the exception of 2016, invertebrate drift community early and late in the growing season are generally more similar. Samples collected at weekly intervals during individual months (rotated each year) are generally similar; this indicates that single samples collected during individual months are representative of that specific month.

The multi-dimensional scaling (MDS) of the Bray Curtis similarity matrix (generated from density data at the highest taxonomic resolution available in the dataset) is shown in an ordination plot in Figure 5. Points that are close together represent samples that are similar in community composition, while points that are far apart correspond to samples with different community composition. The MDS plot was generated using density data from each sample date. The MDS has a stress value of 0.18. Stress values ≤0.1 correspond to a good ordination with negligible possibility of a misleading interpretation with respect to differences in community composition among samples (Clarke and Warwick 2001). Stress values between 0.1 and 0.2 provide a useful 2-dimensional MDS representation as long as there is agreement in groupings between dendrograms (i.e., Figure 4) and the MDS plot (i.e., Figure 5) (Clark and Warwick 2001). The relationships displayed by the MDS plot support those described above in relation to the dendrogram. In particular, this provides further support for the distinction in community composition between the middle of the growing season (July to September) and the beginning and end of the growing season (May to June and October to November). Figure 5 also supports the discussion in relation to biomass results as it shows that the community composition in some samples collected 2016 (Year 3) was unusual (note outlier diamond symbols).

Figure 4. Salmon River cluster analysis results on the Bray-Curtis similarity matrix, by date.

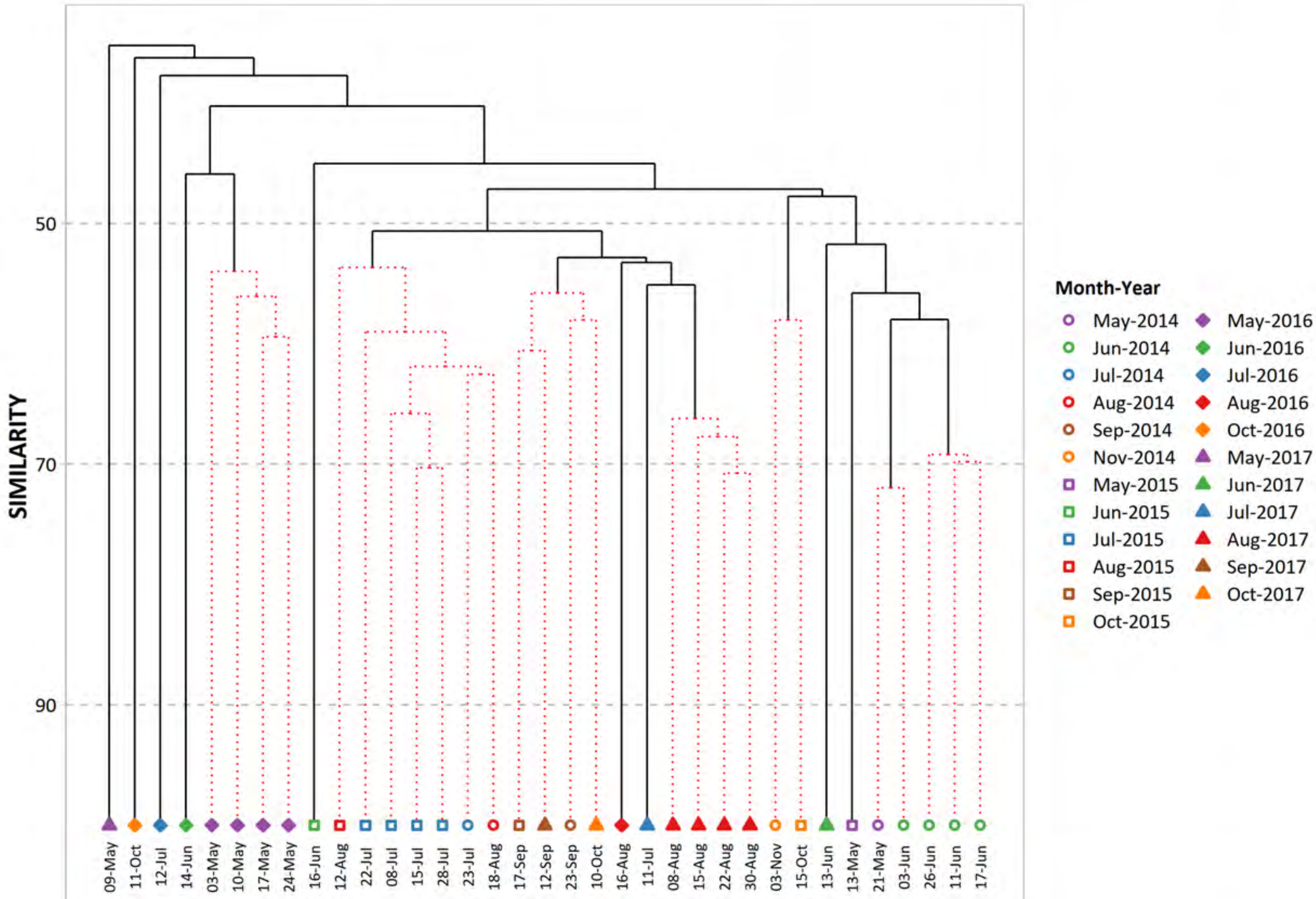
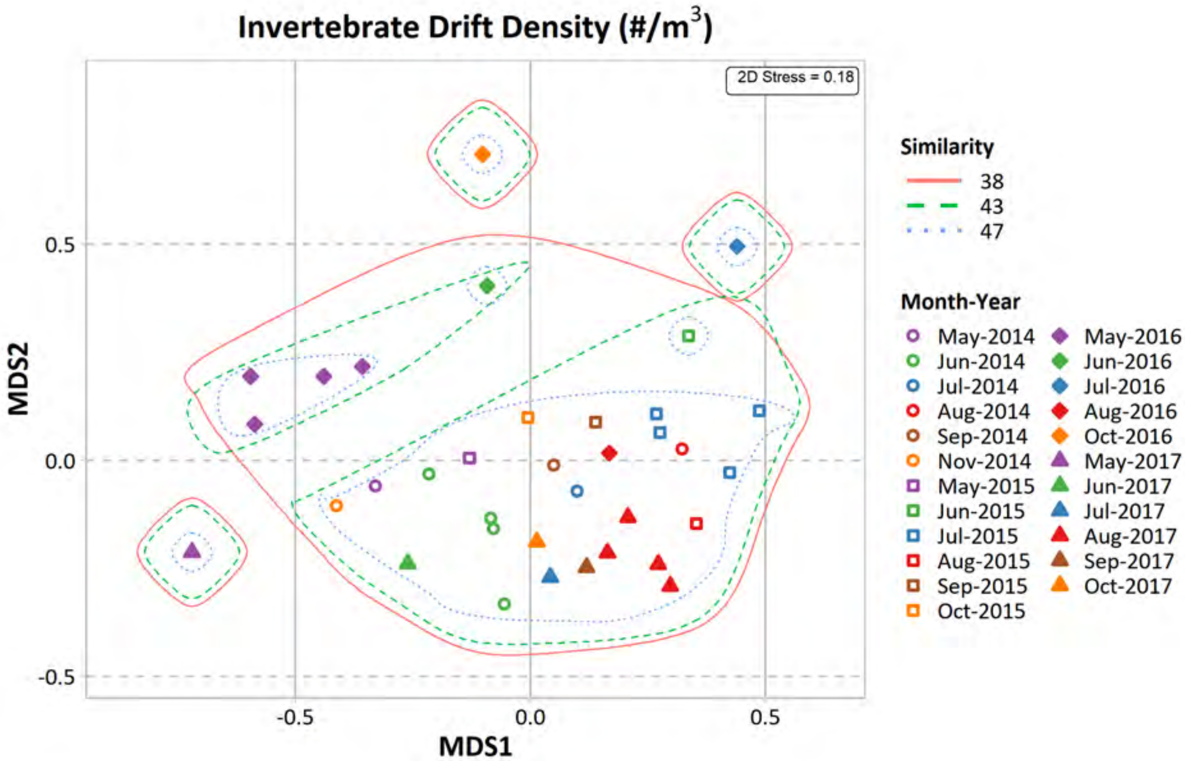


Figure 5. Salmon River non-metric, multi-dimensional scaling ordination plot by date.



2. QUINSAM RIVER

2.1. Invertebrate Drift Results (Summary Table)

Table 2. Quinsam River invertebrate drift mean density, biomass, Simpson's diversity index (family level), richness and CEFI. Each drift net was analyzed separately in 2014 for density, biomass and CEFI, while nets were combined into one sample per site for biodiversity metrics (Family richness, Simpson's diversity) and for all metrics in subsequent years.

All Taxa (Aquatic, Semi-Aquatic, and Terrestrial)													
Year	Date	# of Replicates	Density (#/m^3)[1]			Biomass (mg/m^3)[1]			CEFI Index[†1]			Simpson's Diversity Index (1-λ)[2]	Richness (# of Families)[2]
			Mean	S.D.	C.V.	Mean	S.D.	C.V.	Mean	S.D.	C.V.	Mean	Mean
2014	23-May	5	0.96	0.12	12.6	0.20	0.04	21.2	0.38	0.01	2.9	0.84	66
	04-Jun	5	2.73	0.22	8.1	0.34	0.06	17.5	0.36	0.02	4.5	0.78	66
	12-Jun	5	2.57	0.31	12.0	0.20	0.05	26.9	0.36	0.01	2.4	0.74	65
	18-Jun	5	3.11	0.65	20.9	0.16	0.06	36.8	0.36	0.01	1.6	0.76	63
	27-Jun	5	2.48	0.46	18.7	0.14	0.05	33.2	0.35	0.01	2.1	0.81	70
	22-Jul	5	4.19	0.73	17.5	0.14	0.02	14.1	0.36	0.00	0.6	0.82	60
	19-Aug	5	6.88	3.27	47.5	0.16	0.02	15.7	0.35	0.01	1.9	0.66	59
	24-Sep	5	2.36	0.85	35.9	0.09	0.03	35.6	0.32	0.01	3.4	0.81	52
	04-Nov	5	0.65	0.22	33.3	0.07	0.02	33.5	0.33	0.01	1.6	0.92	80
2015	12-May	1	1.38	-	-	0.21	-	-	0.35	-	-	0.78	52
	17-Jun	1	4.41	-	-	0.19	-	-	0.34	-	-	0.65	50
	09-Jul	1	6.38	-	-	0.32	-	-	0.34	-	-	0.74	61
	16-Jul	1	2.52	-	-	0.28	-	-	0.35	-	-	0.81	73
	23-Jul	1	4.38	-	-	0.12	-	-	0.33	-	-	0.76	53
	29-Jul	1	4.57	-	-	0.14	-	-	0.34	-	-	0.64	39
	13-Aug	1	4.34	-	-	0.08	-	-	0.31	-	-	0.78	42
	16-Sep	1	1.71	-	-	0.12	-	-	0.35	-	-	0.79	33
	14-Oct	1	2.06	-	-	0.12	-	-	0.34	-	-	0.87	50
2016	04-May	1	2.49	-	-	0.20	-	-	0.36	-	-	0.78	38
	11-May	1	1.87	-	-	0.15	-	-	0.36	-	-	0.79	43
	18-May	1	2.82	-	-	0.22	-	-	0.35	-	-	0.78	48
	25-May	1	3.72	-	-	0.25	-	-	0.34	-	-	0.82	59
	15-Jun	1	3.25	-	-	0.24	-	-	0.33	-	-	0.82	40
	13-Jul	1	5.33	-	-	0.15	-	-	0.31	-	-	0.66	41
	17-Aug	1	1.76	-	-	0.10	-	-	0.33	-	-	0.77	53
	14-Sep	1	3.55	-	-	0.22	-	-	0.30	-	-	0.81	37
	12-Oct	1	1.71	-	-	0.13	-	-	0.35	-	-	0.92	53
2017	10-May	1	1.63	-	-	0.33	-	-	0.36	-	-	0.85	44
	14-Jun	1	4.13	-	-	0.18	-	-	0.37	-	-	0.71	28
	12-Jul	1	3.66	-	-	0.10	-	-	0.35	-	-	0.76	39
	09-Aug	1	4.84	-	-	0.25	-	-	0.34	-	-	0.75	46
	16-Aug	1	4.37	-	-	0.10	-	-	0.34	-	-	0.68	33
	23-Aug	1	3.29	-	-	0.17	-	-	0.33	-	-	0.81	40
	31-Aug	1	2.38	-	-	0.09	-	-	0.35	-	-	0.77	45
	13-Sep	1	2.46	-	-	0.10	-	-	0.34	-	-	0.80	31
	11-Oct	1	1.18	-	-	0.06	-	-	0.34	-	-	0.83	30
2018	10-May	1	1.21	-	-	0.08	-	-	0.35	-	-	0.74	32
	05-Jun	1	2.58	-	-	0.16	-	-	0.32	-	-	0.69	35
	04-Jul	1	3.97	-	-	0.17	-	-	0.34	-	-	0.78	40
	09-Aug	1	3.67	-	-	0.15	-	-	0.34	-	-	0.85	47
	04-Sep	1	1.35	-	-	0.09	-	-	0.36	-	-	0.84	46
	12-Sep	1	2.04	-	-	0.14	-	-	0.37	-	-	0.84	35
	21-Sep	1	1.94	-	-	0.13	-	-	0.33	-	-	0.91	28
	26-Sep	1	1.76	-	-	0.17	-	-	0.36	-	-	0.90	56
	05-Oct	1	1.19	-	-	0.09	-	-	0.35	-	-	0.89	47

† Calculation considers only aquatic taxa

1 Replicates were averaged where applicable prior to calculating metric

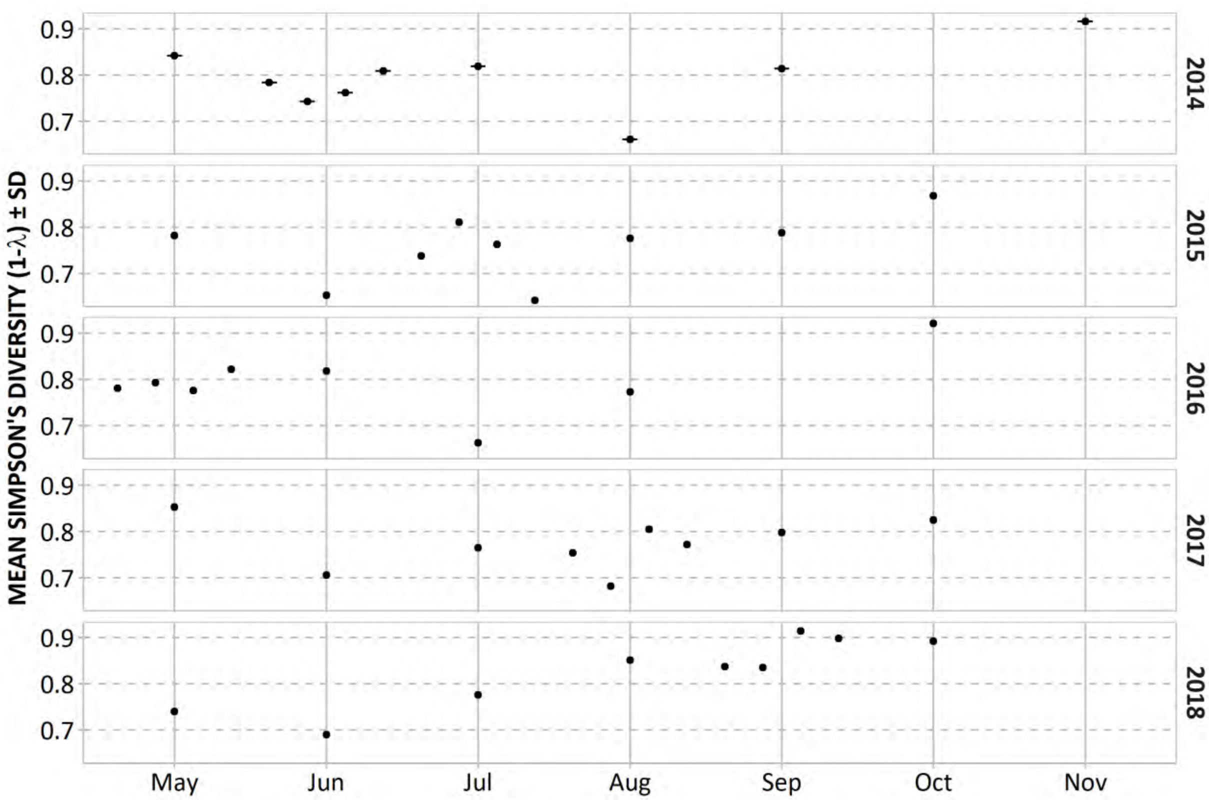
2 Net data were combined into a single sample for the site prior to calculating metric

2.2. Simpson's Family Level Diversity (1-λ)

Mean Simpson's family level diversity values varied throughout Year 5 with no clear seasonal pattern (Table 2). Diversity ranged from a minimum of 0.69 on June 5, 2018 to a maximum of 0.91 on September 21, 2018.

Mean Simpson's diversity in Year 5 was within the range of values measured in previous years (0.64 – 0.93), and there was no apparent trend in this metric over the five-year monitoring period (Figure 6).

Figure 6. Drift invertebrate Simpson's Diversity in the Quinsam River throughout 2014 – 2018.

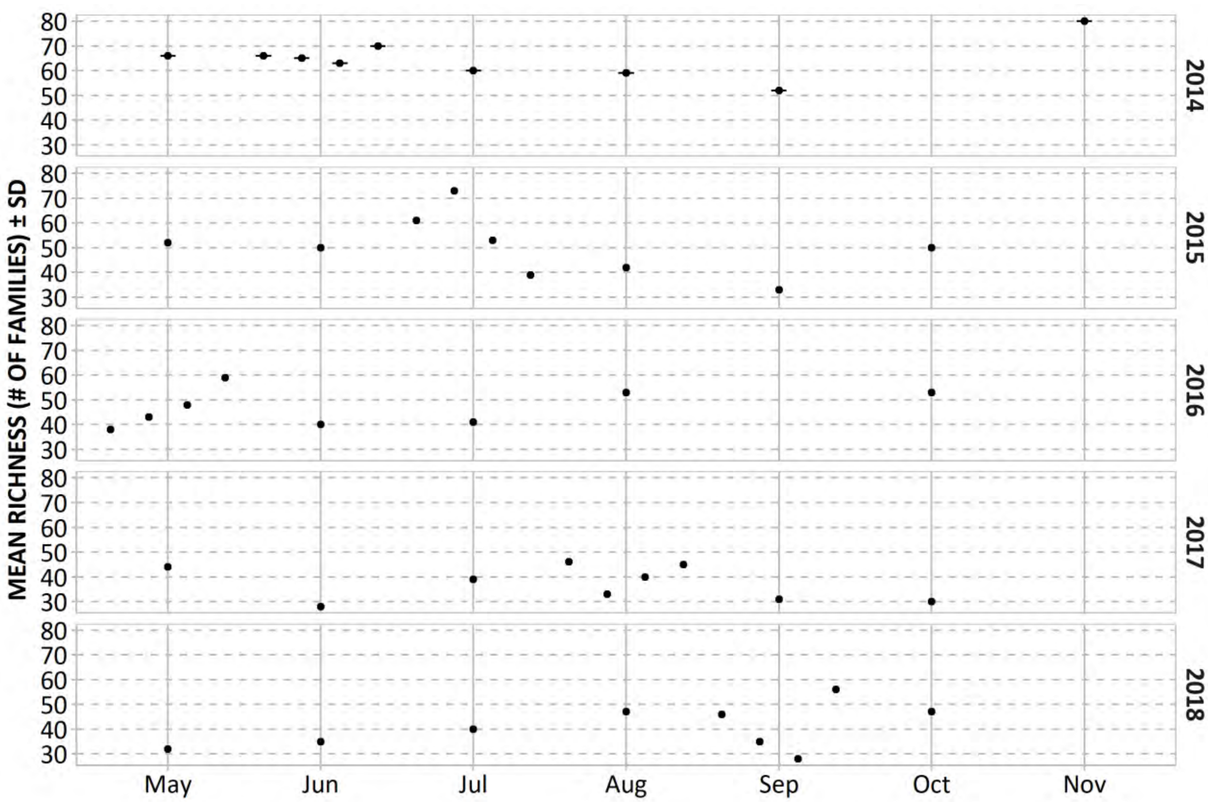


2.3. Richness (# of Families)

Mean family richness measured in Year 5 ranged from 28 to 56 families across sampling dates (Figure 7). There was no clear seasonal pattern, with the lowest and highest values being observed in consecutive weekly sampling dates during September.

Family richness in Year 5 was higher than Year 4 (28–46 families) but it was lower than previous years (Figure 7). Year 1 family richness was greater than 50 families on all 9 sampling dates and reached a maximum of 80 families. In Year 2, family richness was greater than 50 families on six of nine dates with a maximum of 73. For the final two monitoring years (Years 4–5), family richness was below 50 families on 17 of 18 dates and reached minima of 28 families in both years.

Figure 7. Drift invertebrate family richness in the Quinsam River throughout 2014 – 2018.

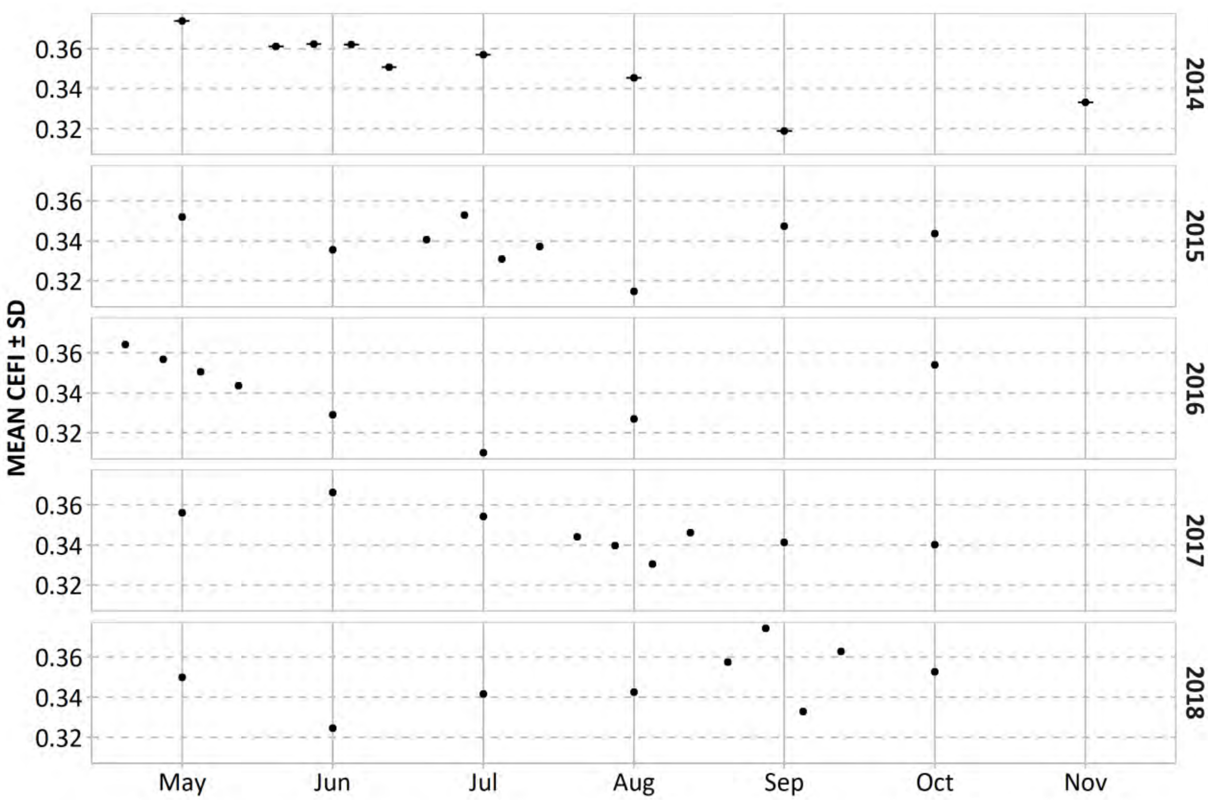


2.4. Canadian Ecological Flow Index

The results for 2018 are in the range 0.32 – 0.37, which are above the 0.25 threshold of low CEFI values (Armanini *et al*. 2011). In Year 5, the lowest CEFI value occurred in June while the maximum value was observed in September. These results showed no clear seasonal patterns throughout Year 5.

The Year 5 results were within the range observed in previous years (0.30–0.38), as CEFI has remained relatively stable over the five-year monitoring period (Figure 8). In each year, the annual maximum has been in the range of 0.35–0.37 while the annual minimum has varied only modestly within the range of 0.30–0.33.

Figure 8. CEFI index values for drift invertebrates in the Quinsam River throughout 2014 – 2018.



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2.5. Cluster Analysis

The results of the cluster analysis (based on density data) are provided in a dendrogram (Figure 9). This dendrogram was derived from density data (using the highest available taxonomic resolution) on each sample date. Black lines indicate branching of groups with a dissimilar community composition at a 5% significance level (SIMPROF test); red lines denote groups that are not significantly different in their community composition at a 5% significance level (SIMPROF test).

The dendrogram shows that the invertebrate communities in the Quinsam River first divide into groups based on seasonality at a relatively low similarly threshold (<50); i.e., these groups are the most different from each other. Here, the data generally cluster into three groups representing the early season (May, June), mid-season (July, August) and late season (September, October) invertebrate communities. Within these groups, clustering is primarily explained by temporal proximity as samples from the same month commonly cluster together, followed by other samples from that year, and then samples from other years. As such, the dendrogram shows that the largest differences in similarity are driven by broad seasonal patterns, while smaller differences result from temporal separation.

The MDS of the Bray Curtis similarity matrices provides an alternative visualization of these results with an ordination plot (Figure 10). The resulting MDS has a stress value of 0.20, where stress values ≤0.1 correspond to a good ordination with negligible possibility of a misleading interpretation, while stress values between 0.1 and 0.2 provide a useful two-dimensional MDS representation as long as there is agreement between the dendrogram (Figure 9) and the MDS plot (Figure 10) (Clark and Warwick 2001). The relationships displayed by the MDS plot support those described above in relation to the dendrogram, with samples clustering by season at low similarity thresholds and by date at higher similarity thresholds.

Figure 9. Quinsam River cluster analysis results on the Bray-Curtis similarity matrix.

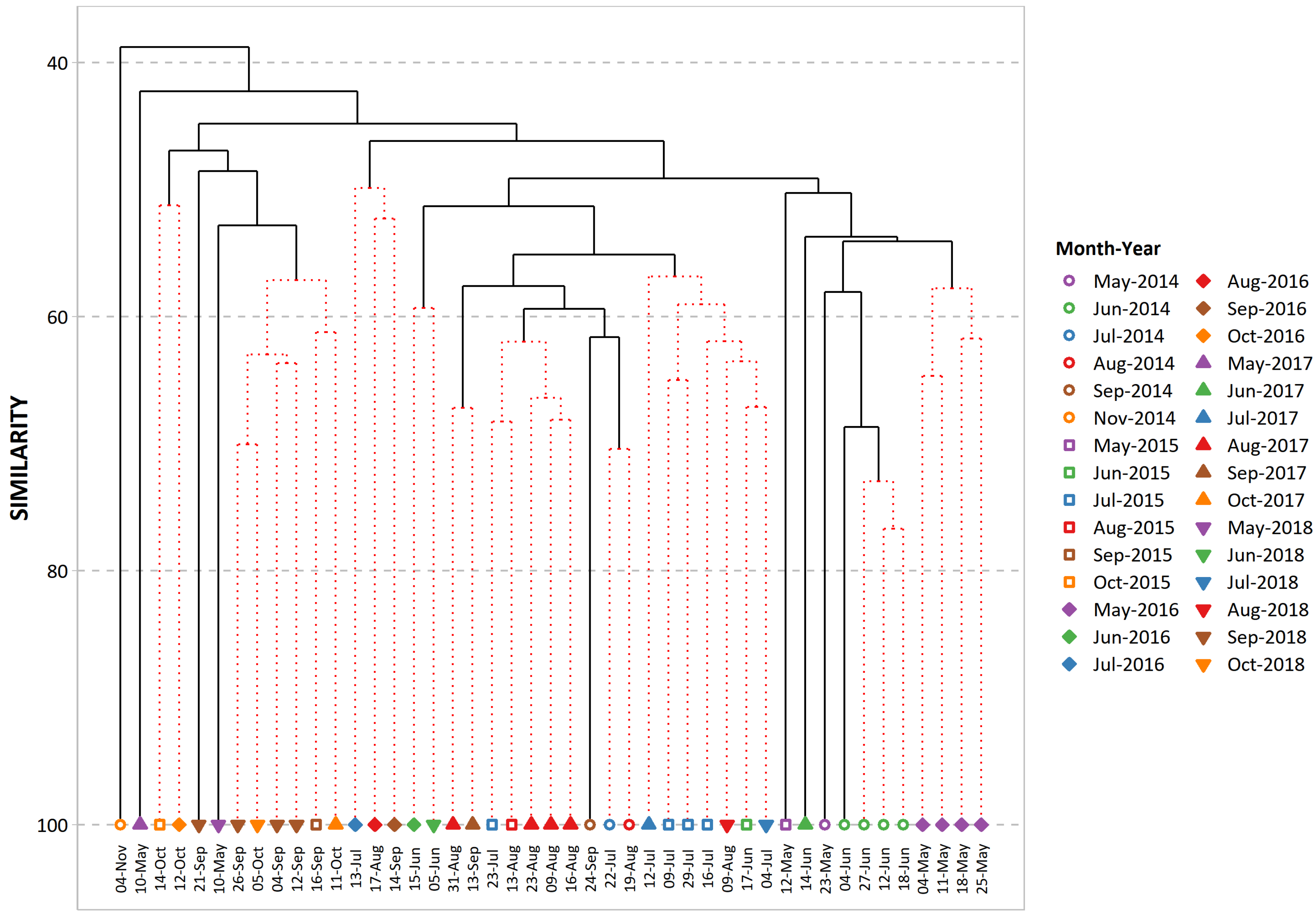
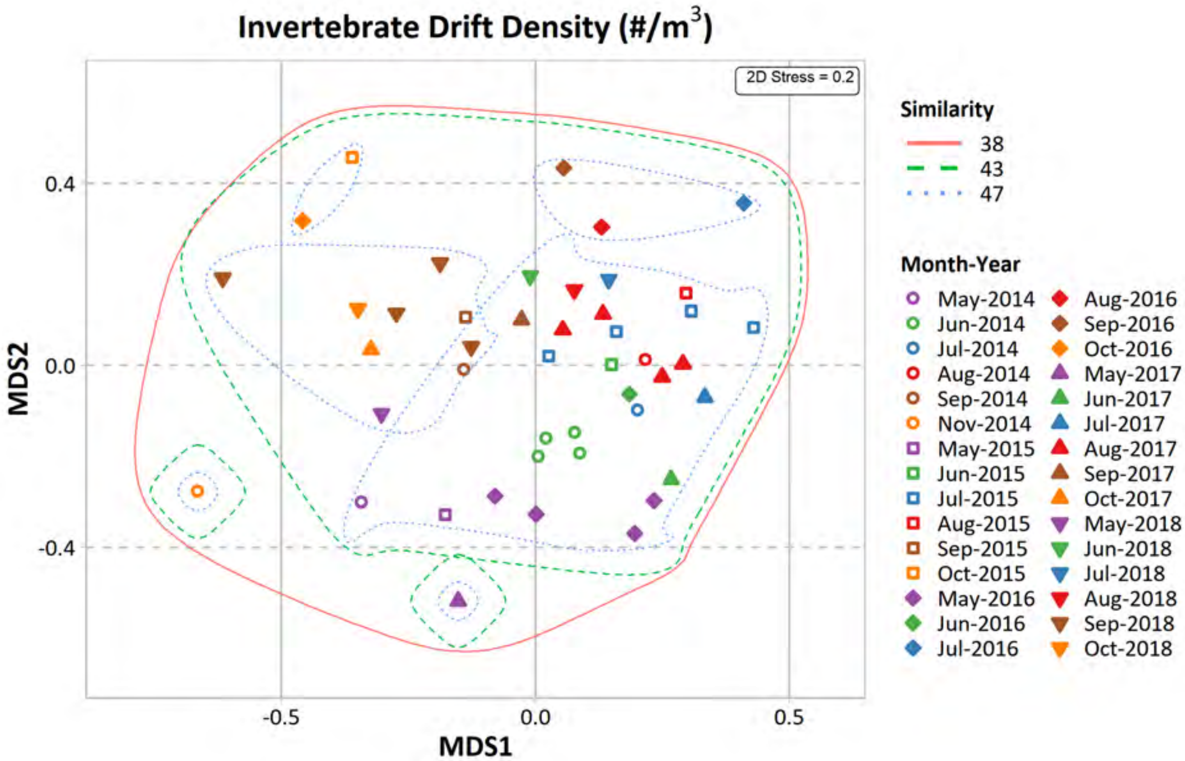


Figure 10. Quinsam River non-metric multi-dimensional scaling ordination plot by date.



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