Bridge River Project Water Use Plan

Seton Sockeye Salmon Smolts Monitoring Program

Implementation Year 6

Reference: BRGMON-13

2018 Monitoring Report

Study Period: April 2018 to June 2018

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Executive Summary

St'át'imc and BC Hydro have worked together since 2006 to devise practical methods to monitor, and subsequently reduce, sockeye smolt mortality at the Seton Generation Station. This mortality is a consequence of smolt entrainment into the power canal and subsequent smolts passage through the turbine of the Seton Generating Station. Smolt mortality rates have been monitored since 2006 with only 2016 data missing due to high flows. Thus, 2018 is the 13th year the BRGMON-13 monitoring program. In 2018, we compiled data from past years and provided a comprehensive analysis of results to date.

Following many years of testing various methods to reduce smolt mortality, BC Hydro and St'át'imc agreed to monitor the feasibility of nightly shutdowns of the power canal to divert smolts through the Seton Dam. Since the assumed mortality of smolts traveling through the turbine is 17% and the assumed mortality of smolts crossing Seton Dam is 2%, shutdowns are thought to be an effective way to reduce mortality of out-migrating sockeye smolts. Refinements to power canal shutdown timing and frequency is based on the experience gained with long-term monitoring.

The St'át'imc Settlement Agreement (2011) stipulates a 5% target for smolt mortality and the Bridge-Seton Water Use Plan (WUP) (BC Hydro 2011) attempts to achieve this goal by specifying Seton Generating Station shutdowns and diverting smolts over Seton Dam. As per the WUP, shutdowns occur nightly from 20:00 – 02:00 between April 20 and May 20 each year. The goal of the BRGMON-13 program is to monitor the effectiveness of this operation at diverting smolts and limiting smolt mortality to the 5% target. The management hypothesis is that the nightly shutdowns divert >80% of the sockeye smolts out-migrating from Seton Lake over Seton Dam.

The specific BRGMON-13 Management Questions are:

1) What proportion of total sockeye outmigrants from Seton Lake will pass through Seton Dam powerhouse when the powerhouse is shut down each night between 20 April and 20 May?
2) How is this proportion affected by the total release [of water] from Seton Dam and the configuration of dam discharge facility used to release water?
3) Are there refinements to the seasonal timing of powerhouse shutdowns to improve fish protection efficiency or reduce lost power generation opportunities?

The monitoring program for outmigration of sockeye smolts in the Seton River uses in-river traps and a mark-recapture program to estimate the population size of smolts traveling downstream from Seton Lake to the Fraser River. Smolts are captured downstream of Seton Dam, marked with a unique coloured dye and released either below Seton Dam or above Seton Dam. The recapture of smolts released below Seton Dam is used to estimate yearly capture efficiencies and where possible yearly population estimates. A comparison of recaptures of smolts released above and below Seton Dam are used to estimate entrainment. Prior to 2011, smolts were only released below Seton Dam and thus these comparisons were not made.

Estimates of smolt migration timing has been accomplished by placing an incline plane or rotary screw trap in the Seton River during the spring migration of smolts. Sampling was done in two time periods, day and night in order to assess the impact of nightly shutdowns.

Since 2008, mortality yearly estimates of out-migrating smolts have ranged from 0 to 14%. The highest mortality was seen in 2008 (13.8%) and lowest rates seen in 2017 (0%). Mortality exceeded the 5% mortality target in 5 out of 7 years where nightly shutdowns were used to manage smolt mortality. In 2014 and 2017, the Seton Generating Station was shut down during migration so mortality was 0% and no estimates were completed in 2016 due to high discharges.

In 2018, a total of 6,997 sockeye smolts were captured between April 28 and June 20. The incline plane trap was used from 15 April until 10 May. Because of flows >60cms, the rotary screw trap was used from 7 May to 21 June. There were very few captures early on and capture rates declined dramatically by the end of June suggesting sampling was sufficient at both the start and end of the migration. The mortality rate for sockeye smolts in 2018 was 7%.

Modifications to the timing of seasonal and nightly shutdowns of the Seton Generation Station could be used to improve the success of diverting >80% of out-migrating sockeye smolts over the Seton Dam. Targets are missed in some years because the shutdown period ends too early in the sockeye migration period, and/or because it ends too early in the morning. The proportion of smolts traveling over Seton Dam instead of down the power canal could be improved by extending the dates and times of partial shutdowns, or improvements in smolt mortality could be made by using a series of full shutdowns during the peak of the sockeye run.

Increasing monitoring and mark-recapture efforts combined with trials of extended partial shutdown periods or adding a full shutdown period could all be used to further refine the timing and duration of nightly shutdowns. Further, due to higher spring discharges that have occurred in recent years, increased mark-recapture efforts to look at capture efficiency and diversion rates is needed to determine exactly how high discharge influences the basic assumptions of the program. At a minimum monitoring should continue in April, May and early June of each year with two rotary screw traps and a much larger mark-recapture programs, dying many more fish and releasing then consistently through the migration, should be part of future efforts.

BRGMON-13 Status of Objectives, Management Questions and Hypotheses after Year 13 (2018)

Study Objectives	Management Questions	Management Hypotheses	Management Question Status 2006 - 2018
1.0 to assess the effectiveness of powerhouse shutdown to reduce total mortality of sockeye salmon smolts leaving Seton Lake. 2.1 to collect data on the relative abundance, timing and biological characteristics of sockeye salmon smolts leaving Seton Lake, 2.2 to assess the effect of powerhouse shutdown and dam release on fish attraction flows and fish bypass conditions at Seton Dam, 2.3 to assess the relationship between dam release and the proportion of fish entering the Dam approach channel and passing the dam into Seton River. 2.4 to better understand the migration of other salmon species, all species captured during sampling will be enumerated.	1. What proportion of total sockeye outmigrants from Seton Lake will pass through Seton Dam when the powerhouse is shutdown each night (20:00 – 02:00) between 20 April and 20 May?	H_{1A}: Nightly powerhouse shutdowns (accompanied by >25 m^3s^{-1} dam release) conducted 2000 to 0200 between April 20 and May 20 will result in >80% of sockeye smolts being diverted to Seton River from Seton Lake. H_{2A}: More than 90% of the smolts leave Seton Lake between April 20 and May 20. H_{3A}: More than 90% of the smolts leave Seton Lake between the hours of 2000 h and 0200 h.	In 2018, an estimated 35.5% of the smolt migration (122,556 out of 345,076 smolts) were entrained in the power canal and traveled through the Seton Generating Station. Thus, during the 6-hour nightly period (20:00 to 02:00 each night) between 20 April and 20 May, 222,520 smolts (64.5%) traveled over the Seton Dam. Smolt diversion rates and mortality can be estimated for 10 years between 2008 and 2018. Shutdowns occurred in 8 of 11 years and in 6 of these years (2008, 2009, 2010, 2012, 2018) , <80% of the out-migrating smolts population were re-routed over Seton Dam and resulted in mortality >5%. Common amongst these 5 years was a large smolt migration in the hours outside the shutdown window (02:00h to 20:00h) and a greater proportion of smolts migrating later in the season. The Station was shutdown in two years (2014 and 2017) and mortality was 0% in these years. Shutdowns occurred in 2016 but no data are available due to high discharges.
	2. How is the proportion of sockeye outmigrants leaving during shutdowns affected by total release from the Seton dam and the configuration of dam discharge facilities used to release water?	--	There are large uncertainties associated with capture efficiency at high discharge (>60cms) that make it impossible to assess Management Question #2 because capture efficiencies are low and mark-recapture estimates poor. Continued monitoring should occur using rotary screw traps operating in tandem in the Seton River to achieve higher capture efficiencies. Additional effort on mark-recapture trials should focus on releasing many smolts (>1000) during all sampling periods where estimates are required. Uncertainties increase when discharge from Seton Dam is high. Management Question #2 has not been addressed to date.
	3. Are there refinements to the seasonal timing or daily timing of powerhouse shutdowns to improve fish protection efficiency or reducing lost power generation opportunities?	--	Operational modifications (nightly shutdowns) are effective in half the years (see above). Shutdowns should be extended into late May or early June and should occur from 20:00 h to 04:00 h until predictions can be made that will refine shutdown times to reflect year and stock specific conditions. Additionally, full shutdowns could be used during the peak of smolt migration especially in years with more daily migrants (of that could be predicted). Fish protection efficiency could be improved by extending shutdowns to late May and early June to increase diversion rates of smolts so that management targets are met with certainty each year.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION

Sockeye salmon (*Oncorhynchus nerka*) are the largest population of Pacific salmon in the Seton River system, which includes pink (*O. gorbuscha*), coho (interior coho, *O. kisutch*), chinook salmon (mid-Fraser, stream-type, summer, *O. tshawytscha*) as well as steelhead (*O. mykiss*) and Gwenish (deep water spawning Black Kokanee, *O. nerka*). There are also significant populations of bull trout (*Salvelinus confluentus*) in Seton and Anderson Lakes, both of which are important predators. However, sockeye is by far the most plentiful salmonid in the Seton-Anderson system with migrations typically numbering in the thousands of fish each year.

Sockeye smolts in the Seton-Anderson watershed, originate from two spawning areas: Gates Creek and Portage Creek. Gates Creek sockeye comprise part of the early summer sockeye returns, while Portage Creek sockeye are late-run stocks migrating upstream in fall. As part of the Bridge-Seton Hydro power project, the Seton River Dam, power canal and Generating Station were constructed in 1956. Their construction placed a significant barrier to salmon migration in the Seton River and mitigating these effects is a substantial component of BC Hydro operations (Figure 1.1). Sockeye face impediments to migration both when returning in the summer and fall (see BRGMON-14, Harrower et al. 2019), but also in the spring when smolts migrate downstream from Seton and Anderson lakes to the Fraser River.

The Seton Dam, along with Seton and Anderson Lakes, and Gates and Portage Creeks are part of the traditional territory of the St’át’imc Nation including the Cayoose, Lillooet, Seton Lake, and Anderson Lake Bands. The St’at’imc Nation and BC Hydro have a long history of working together to, among other things, devise practical methods for mitigating sockeye salmon smolt mortality. The St’át’imc Settlement Agreement (2011) between St’át’imc, BC Hydro and the British Columbia government stipulates 5% entrainment mortality target for sockeye smolts migrating from Seton Lake to the Fraser River. Likewise, the Bridge River Water Use Plan (BC Hydro 2011) stipulates: “*In an effort to decrease the mortality of sockeye smolts migrating past Seton Dam and Seton Generating Station, the Seton Generating Station will conduct partial (6+ hr) or blanket (24 hr) daily shut downs during smolt out migration between April 20th and May 20th. The frequency and duration of the shutdowns along with the expected benefits in reducing mortality will be reported to the Comptroller of Water Rights annually. The objective of the shut downs is to target an annual smolt mortality of 5% or less or such other target agreed upon by BC Hydro and the St’át’imc.*”

To estimate entrainment mortality of sockeye smolts during the Gates and Portage Creek sockeye outmigration, a yearly monitoring program estimates the timing of smolt outmigration and the proportion of smolts entrained in the Seton power canal. These estimates are combined with a continual reassessment of the monitoring program at different levels of water discharge. As per the St’át’imc Settlement Agreement (2011), the monitoring program is intended to refine the period and timing of powerhouse shutdowns used to re-route out-migrating smolts down the Seton River. An ancillary benefit of the monitoring program is the yearly documentation of out-migrating sockeye population size and estimate the assumed mortality of smolts entrained in the power canal.

The specific BRGMON-13 Management Questions are:

1) What proportion of total sockeye outmigrants from Seton Lake will pass through Seton Dam powerhouse when the powerhouse is shut down each night between 20 April and 20 May?
2) How is this proportion affected by the total release [of water] from Seton Dam and the configuration of dam discharge facility used to release water? and
3) Are there refinements to the seasonal timing of powerhouse shutdowns to improve fish protection efficiency or reduce lost power generation opportunities?

The specific BRGMON-13 management alternative hypotheses are:

H_{A1}) Nightly powerhouse shutdowns (accompanied by an >25 m^3/s dam release) conducted 20:00 h to 02:00 h between 20 April and 20 May will result in >80% of the sockeye smolts being diverted to Seton River from Seton Lake.

H_{A2}) More than 90% of the smolts leave Seton Lake between 20 April and 20 May.

H_{A3}) More than 90% of the smolts leave Seton Lake between the hours of 2000 h and 0200 h.

1.1 BACKGROUND

The largest sources of mortality for out-migrating sockeye smolts in the Seton system presumably comes from three causes: 1) smolts can be eaten by bull trout; 2) smolts can be entrained into the Seton Generating Station; and 3) smolts can die while traveling over Seton Dam. Bull trout congregate at constrictions at the end of Seton Lake, the entrance to the power canal and Seton Dam, or at the Seton Generation Station penstock. These are presumably all areas where large numbers of smolts mass before crossing these structures. Bull trout have been observed congregating in these areas during April and May when sockeye smolts are migrating downstream (Burnett and Parkinson 2018). There are no estimates of the proportional mortality that occurs from bull trout predation. Predation mortality on smolts can be significant in other systems (Furey et al. 2015)

Smolts can also die as they pass the Seton Generating Station and are thought to perish because of extremely rapid changes in pressure there (Ruggles and Murray 1983). Like bull trout mortality, there are no direct estimates of smolt motility at the Seton Generating Station. The current estimate of 17% is an assumed mortality estimate from a previous IPSFC study conducted on the Ruskin Plant on the Stave River (Groves and Higgins 1995; Levy et al. 2008, Andrew and Geen 1958). This estimate includes direct mortality and latent mortality from injuries, cumulative stress, disease and predation (presumably from species such as bull trout). The Ruskin Plant study used a similar turbine and design to the Seton Generating system and thus mortality estimate used there were thought appropriate. However, the hydroelectric infrastructure on the Stave River system has a very different configuration than the infrastructure in the Seton River system. Most smolts at the Seton Dam likely die from gas bubble disease caused by the supersaturation of gases in water flowing through the turbine (Ruggles and Murray 1983). Likewise, smolts can also die while crossing the Seton Dam itself. Smolt populations are estimated to undergo 2% mortality while traveling through the Seton Dam fish ladder, fish water release gate or siphons (Groves and Higgins 1995).

Various methods have been attempted to reduce entrainment mortality (Sneep et al. 2011). Louver lines, bubble curtains, screens, and a diversion canal have all been proposed or attempted methods used to divert out-migrating smolts away from the power canal and ultimately Seton Generating Station. Since smolts are assumed to follow the route with the largest volume of water, most smolts travel down the power canal when the Seton Generating Station is operating (Levy et al. 2008). No method of diverting smolts away from the power canal has been successful other than closing off the power canal and shutting down the Seton Generating Station. To reduce impact to the Seton Generating Station, shutdowns are timed to occur only when the majority of smolts are migrating. By refining shutdown times to coincide specifically with smolt outmigration behavior, impacts to generation are reduced (BC Hydro 2011).

Net mortality is dependent on the route smolts follow. Shutdowns are successful in reducing smolt mortality at the Seton Generating Station because of the difference in mortality of smolts traveling to the Fraser River via the power canal versus the Seton River. If smolts are not entrained in the power canal, and subsequently the Seton Generating Station, and instead pass the Seton Dam into Seton River, the assumption is that mortality would be reduced from 17% to 2%, increasing survival to the Fraser River when flows are below 80 cms (Levy et al. 2008).

This differential mortality assumption has never been tested, nor has the extent of bull trout mortality in relation to hydroelectric facilities on either of the two routes. It is entirely possible, since bull trout have been observed congregating in the Seton Generation Station penstock (Burnett 2018 WUP meeting presentation, Burnett and Parkinson 2018), that bull trout eat a significant portion of sockeye smolts either in the power canal or at the Seton Dam. One might expect less bull trout mortality when smolts travel down the Seton River because there are typically fewer bull trout here and there is not another structure, such as the Generating Station Penstock (Burnett and Parkinson 2018, Furey et al. 2015).

1.2 MONITORING PROGRAM

The Seton River sockeye smolt monitoring program has been implemented annually since 2006, when operational modifications (i.e., Seton Generation Station shutdowns) were begun to reduce entrainment of sockeye smolts into the power canal and their subsequent mortality at the Seton Generating station. The exception was in 2016 when discharges greater than the WUP target hydrograph precluded any monitoring until new techniques could be developed to safely operate a fish trap, and in 2014 and 2017 when the Seton Generating Station was shut down for the entire out-migration period. The primary purpose of the monitoring program is to assess the effectiveness of the shutdowns and refine both the seasonal duration and daily timing of the shutdowns where possible (Settlement Agreement 2011; BC Hydro 2012).

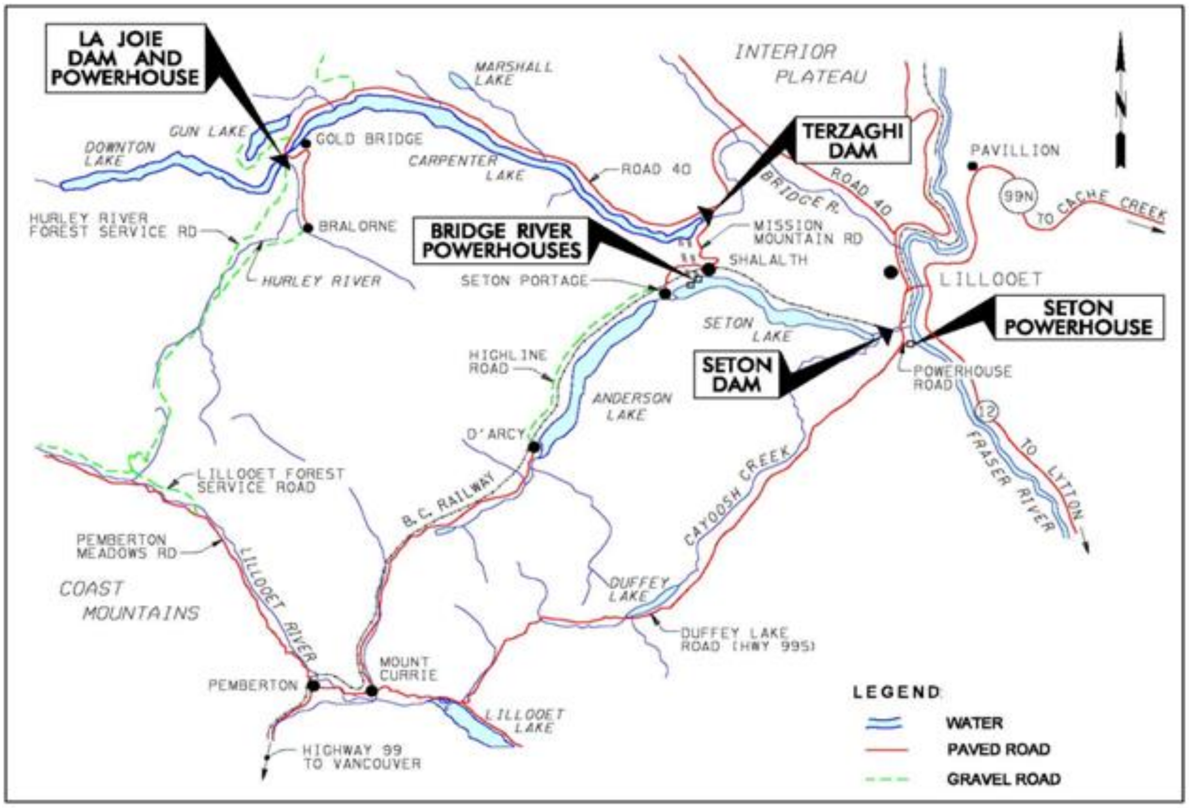

Figure 1.1. Location of BC Hydro facilities in the Bridge/Seton watersheds.

The monitoring program consists of a mark-recapture population estimation program run above and below the Seton Dam which informs management questions from the Bridge River Water Use Plan BRGMON-13 Terms of Reference (BC Hydro 2012). Population estimates are derived for smolts from mark-recapture trials and are used to determine the proportion of smolts traveling either down the power canal or past the Seton Dam (Management Question #1). Discharge measurements from BC Hydro are compared to monitoring data to examine how capture efficiency and thus the effectiveness of the monitoring program changes with discharge (Management Question #2). The monitoring program is also used to determine yearly run timing and the daily migration behavior of smolts (Management Question #3) and refine shutdown timing based on these data (BC Hydro 2012; Settlement Agreement 2011). There are several ancillary benefits derived from the monitoring program: 1) smolt size is monitored and assessed relative to population size, 2) hourly temperature and light condition data are compiled (early reports only), and 3) training for St'át'imc members and capacity building in the St'át'imc community.

Beginning in 2016, discharge in the Seton River have exceeded the WUP target hydrograph as a result of power facility maintenance in the Bridge-Seton system. BC Hydro has released excess water into the Seton River, with discharge that has exceeded 85 cms during the period when sockeye smolts are migrating from spawning grounds to the Fraser River. Typical discharge during this period has generally been between 30 and 50 cms. High levels of discharge are predicted to occur for the foreseeable future. This has some implications for monitoring including the need for a different fish trap and to account for reduced capture efficiency of fish traps at higher discharge levels.

Safe and effective methods for monitoring at high discharge have already been tested. In addition to declining capture and recapture success of smolts with increasing discharge, safe operation of the incline plane smolt trap is no longer possible due to the high discharge. It is also unsafe to operate a fish trap in the power canal. In 2016, a rotary screw trap was tested downstream of Seton Dam. Testing was completed in 2016, and in 2017 and 2018 the rotary screw trap was the primary fish trap used.

This is the 13th year of a long-term and continuing sockeye smolt monitoring program in the Seton River. This report attempts to summarize information from all years. However, further information including methods are contained in the previous reports that cover the 12-year monitoring period (Table 1.1). These reports are available from BC Hydro upon request as are several other reports key the findings of this report (Burnett and Parkinson 2018, Levy et al. 2008, Groves and Higgins 1995). The 2012 and previous reports contain a complete description of methods that have been consistently followed since 2006.

Table 1.1. Table of yearly monitoring reports prepared for the sockeye smolt monitoring program and BRGMON-13.

Date	Authors	Title
2018	W.L. Harrower, B. Adolph, R. Ledoux	Seton River Sockeye Smolt Monitoring: Implementation Year 13
2017	R. Ledoux and S. Lingard	Seton River Sockeye Smolt Monitoring: Implementation Year 12
2016	No annual report. Inconclusive data due to high discharge.	
2015	J. Hopkins, B. Adolph and D.A. Levy	Seton River Sockeye Smolt Monitoring: Implementation Year 10
2014	J. Hopkins, B. Adolph and D.A. Levy	Seton River Sockeye Smolt Monitoring: Implementation Year 9
2013	B. Adolph and D.A. Levy	Seton River Sockeye Smolt Monitoring: Implementation Year 8
2012	J. Sneep, B. Adolph and D.A. Levy	Seton Sockeye Smolt Monitoring in 2012 with a summary of historical data
2011	J. Sneep,S. Hall and Lillooet Tribal Council	Seton River Sockeye Smolt Monitoring Program: 2011 sampling results
2010	J. Sneep	Seton River Sockeye Smolt Monitoring Program: 2010 sampling results
2009	D.A. Levy and J. Sneep	Effectiveness of Seton Powerhouse shutdowns for reducing entrainment mortality of sockeye salmon smolts during 2009
2008	D.A. Levy, J. Sneep and S. Hall	Effectiveness of Seton Powerhouse shutdowns for reducing entrainment mortality of sockeye salmon smolts during 2008
2007	D.A. Levy and J. Sneep	Effectiveness of Seton Powerhouse shutdowns for reducing entrainment mortality of sockeye salmon smolts during 2007
2006	D.A. Levy and J. Sneep	Effectiveness of Seton Powerhouse shutdowns for reducing entrainment mortality of sockeye salmon smolts during 2006

2.0 METHODS

2.1 SETON DAM DISCHARGE

Records of Seton Dam discharge were provided by BC Hydro Power Records from 20 April to the 30 June. Data from 2006 to 2018 are compared graphically where data was available. Seton Dam discharge is calculated as the sum of discharge from the fish water release gate, radial gate and all five siphons. Data were generally available as hourly discharge from Seton Dam and Seton Generating Station; however, in 2014, 2017, and 2018 data were only available as daily averages. All data was compiled as average daily discharge and plotted.

2.2 SMOLT CAPTURE

To estimate the routing, timing and magnitude of the smolt outmigration, a fish trap was placed each year immediately downstream of the Seton Dam. Between 2006 and 2015 this was an inclined plane trap and in 2017 and 2018 a rotary screw trap was used because of high discharges. Fish traps were installed approximately 300 to 500 m downstream of the Seton Dam immediately adjacent to the Naxwit day-use area. The 2016 sample was only a trial of the rotary screw trap and there was no data available.

To capture sockeye smolts migrating down the Seton River in 2018, a six-foot diameter rotary screw trap was installed in the Seton River between 15 April and 21 June 2018. The trap was monitored by a crew of two to three fisheries technicians. Salmon smolts were identified to species and counted four times a day by a crew of two to three technicians. Smolts were released downstream of the trap unless they were retained for mark-recapture trials.

Traps were checked and cleaned hourly for 20-hours each day. Crews worked in two 10-hour shifts, one shift during the day from 10:00 h to 20:00 h, and one at night from 20:00 h to 06:00 h each day. To get an estimate of yearly smolts size, the fork length on approximately 40 smolts per shift was measured before smolts were released back into the river. Fork length can be related to the mass of smolts using an allometric equation ($y = 0.196e^{0.0401x}$) from Table 73 in Foerster 1968 (Hopkins et al. 2015). Smolts were anesthetized prior to measurements. Fork lengths were recorded to the nearest millimeter (mm) and weight was recorded to the nearest tenth of a gram (g). To determine the relationship between fork length and smolt abundance, a generalized linear model was fit (R package lme4) with year included as a random effect. Model fit statistics including a pseudo-R^2 value for the marginal effects (fixed effects only) were reported. Both straight line and polynomial equations were fit to the data and only the model with a significantly better fit was retained.

2.3 MARK-RECAPTURE TRIALS

To estimate trap efficiency, determine routing proportions, and estimate yearly smolt population sizes a portion of each night's catch were retained marked and released upstream the following day. Knowing the total number of marked smolts, the number of marked smolts that were re-captured and the total number of smolts caught (marked and unmarked), allows us to use standard mark-recapture methods to estimate population sizes of smolts passing this location (Ricker 1975, Krebs 1989, Ogle et al. 2018). By releasing smolts with unique marks in different locations, such as above and below Seton Dam, comparisons can be made on the size of population, mortality, routing. In some years, up to 600 smolts per 10-hour daily shift were retained and marked for release. Smolts were marked with either Bismark Brown Y (0.9g) dye or Neutral Red dye (0.7g) mixed into a 20 L bucket full of water, representing 0.045 g/l or 0.035 g/L for each dye colour, respectively.

In 2018, a total of 700 smolts were marked and released during two mark-recapture trials. One trial released smolts during the day and one trial released smolts at night. The first trail occurred on 10 May 2019 at 17:45 when 300 smolts were captured and released, 150 smolts were marked brown and released above the dam at the end of Seton Lake and 150 smolts were marked red and released at the end of the Seton Dam fishway. The second trial occurred on 14 May 2018 when at 10:30, 200 smolts were dyed brown and released above the dam and 200 smolts were dyed red and released below the dam.

Pooling, in the Peterson method of estimating population abundance, refers to combing all mark-recapture trials into a single estimate of trap efficiency and generating a single population estimate for the entire study period. The pooled Petersen estimator uses average capture efficiency from all mark-recapture trials in each year to adjust estimates and confidence intervals. Capture efficiency can vary significantly across the juvenile salmon migration windows due to varying environmental conditions. The Peterson model is sensitive to heterogeneity in capture efficiency (Seber 1982). Therefore, variable capture efficiency across a migration period can result in significant bias in population estimates using pooled methods (Seber 1982; Schwarz and Taylor 1988). However, because the capture efficiency of fish traps in the Seton River is so low and releases of a small number of fish occurred on only two occasions, estimates must be pooled. All analysis was completed in R software (R Development Core Team 2018) and the Fisheries Stock Analysis Package (Ogle et al. 2018).

2.4 CAPTURE EFFICIENCY

Management question #2 (BC Hydro 2012) requires an assessment of capture efficiency of smolt enumeration methods across a range of dam discharge values. Thus, in each year since 2006 mark-recapture trials were used to assess capture efficiency of the either the inclined plane trap (2006 to 2016) or the rotary screw trap (from 2017 onward). Capture efficiency is simply calculated as the proportion of marked smolts captured over the total number of smolts released during mark-recapture trials.

The methods used in 2018 are the same basic methods as those followed since 2006 and modified in 2011. Beginning in 2006, mark-recapture trials were used only to assess the efficiency of inclined plan trap. Smolts were captured with an inclined plane trap placed in the Seton River downstream of the dam. Smolts from each night’s catch were retained and held in an aerated holding box for 24 hours. After recovery, marked smolts were released upstream of the trap in the Seton Dam tailrace downstream of the fish ladder. These released smolts were primarily used to estimate capture efficiency.

2.5 ESTIMATING ROUTING PROPORTIONS

Management question #1 (BC Hydro 2012) requires an estimate of the number of smolts traveling down the power canal. In 2008, an inclined plane trap was fished in the power canal and mark-recapture experiments revealed that approximately 84% of smolts migrate down the power canal and 16% pass through the dam into the Seton River when the plant is operating (Levy et al 2008). Subsequent to 2008 trapping in the power canal was not allowed due to safety concerns. Thus, except for 2011 and 2012, the proportions of 84% of smolts migrating down the power canal and 16% passing through the dam when the plant is in operation have been used to estimate sockeye population sizes and mortality.

In 2011 and 2012, mark-recapture studies were conducted whereby smolts were stained brown or red and released either into the approach channel above the dam, or into the river at the base of the fish ladder. In 2011, the recapture of smolts released into the approach channel of Seton Dam was very protracted (24 – 111 hours after capture) and thus the operation of the plant switched between shutdown and operation several times over the recapture period. As a result, Sneep et al. (2012) estimated that over the duration of the 2011 study 66% of smolts migrated down the river, and 34% of smolts migrated down the power canal. These proportions were applied to all data regardless of whether the plant was in operation or not (Table 1.2). In 2012, Sneep et al (2013) assumed that when the Generating Station was not operating, 69% of smolts migrated down the Seton River and 31% migrated down the power canal. When the Generating Station was in operation 31% of smolts migrated down the river and 69% migrated down the power canal.

Below is a basic summary of the procedures applied to estimate the number of smolts migrating down the Seton River during the day (station operating) and night (during shutdowns) and down the power canal. The steps outlined below are what we used in 2018 to estimate the number of smolts migrating down the Seton River and the power canal. We also used these methods to estimate the number of migrating smolts in the previous years (i.e., since 2006) so that a comparison with a standard method for calculating population sizes could be implemented in future. Our methods are documented in scripts using R rather than using spreadsheets. Methods were compared and discussed in personal conversations with Dave Levy and Jeff Sneep. Table 1.2 provides details on the differences in methods used between years and are the likely the reason for differences in population estimates between our results and those found in previous years.

Methods used to estimate the population size:

1) *Estimate the number of smolts missed while the trap is not in operation.* Because netting and counting smolts and cleaning and maintaining the trap creates periods during each shift when the trap is not actively fishing, an estimate of the number of smolts missed is needed to calculate the population sizes. This is especially true when debris loads or smolt catches are large and miss fishing times can average 10 minutes/hour or up to 16% of the scheduled sampling time. Thus, to estimate the number of unsampled smolts, Sneep et al. (2012) first estimated the smolt catch rate per minute for each sampling hour. Each hourly catch rate was then multiplied by the number of minutes of non-fishing time between adjacent trap sets to estimate the number of smolts potentially missed. The number of smolts potentially missed per sampling hour was only calculated for the hours on-shift (10:00 to 06:00). Missed smolts were not estimated for the off-shift hours (06:00 to 10:00) as it was assumed that the number of smolts migrating during this period was insubstantial relative to the other periods. The number of smolts missed while the trap was out of operation was not calculated in all years. See Table 1.2 for more details on which years the number of smolts missed was not estimated.

2) *Estimate the total number of fish passing the trap per hour.* This was done by dividing the hourly catch totals (number of fish in size class 1 + number of fish in size class 2 + number of fished missed) by the recapture rate (calculated through mark-recapture trials) to obtain smolt population estimates corrected for recapture rate.

3) *Estimate mortality due to passing through the dam.* In most years mortality through the dam was assumed to be 2% (Table 1.2) following Groves and Higgins (1995). Therefore, multiply the estimated total number of fish passing the trap (step 2) by 0.02.

4) *Estimate the total number of fish passing down the Seton River*. This was done by adding the population size estimates in step 2 to the estimate of mortality due to passing through the dam (step 3).

5) *Estimate the power canal population on an hourly basis.* For each hour that the plant was in operation the number of smolts passing down the Seton River (estimated in step 2) was divided by the percentage of the population that pass through the Seton Dam (e.g., 16%) and then multiplied by the percentage that pass down the power canal (e.g., 84%) (see Table 1.2 for alternative values used in different years). When the plant is not in operation the number of smolts migrating down the power canal was generally assumed to be zero, except in 2011 and 2012 (Table 1.2).

6) *Sum the hourly values to obtain daily and nightly population estimates*.

7) *Estimate turbine mortality* by multiplying the hourly power canal population by 0.17 (assumed mortality rate used since 2006; Groves and Higgins 1995).

8) *Obtain total yearly mortality rates* by summing the hourly turbine (step 7) and dam (step 3) mortalities.

Table 2.2. Summary of proportions used to estimate smolt population sizes in each of the years. Missed smolts refers to smolts not sampled due to the trap being out of operation for cleaning or fish counting. In 2016 no sampling was done due to high flows. In 2006 to 2015 an inclined plane trap was used and in 2017 and 2018 a rotary screw trap was used.

	Power canal not in operation		Power canal in operation		Mortality		Did the population size estimate include missed smolts?
Year	Smolts migrating down the River (%)	Smolts migrating down the Power Canal (%)	Smolts migrating down the River (%)	Smolts migrating down the Power Canal (%)	Seton River (%)	Power Canal (%)	
2006	100	0	16	84	2	17	Y
2007	100	0	16	84	2	17	Y
2008	100	0	16	84	2	17	Y
2009	100	0	16	84	2	17	Y
2010	100	0	16	84	2	17	Y
2011	34	66	34	66	2	17	Y
2012	69	31	31	69	2	17	Y
2013	100	0	16	84	0	17	N
2014	100	0	16	84	0	17	N
2015	100	0	16	84	2	17	Y
2016	Flows too great to sample						
2017	100	0	Not in operation		2	17	N
2018	100	0	16	84	2	17	Y

2.6 Season and Daily Migration Timing

Management question #3 (BC Hydro 2012) requires an assessment of the seasonal and daily migration timing of the smolt outmigration. To estimate migration timing a fish trap (either inclined plane or rotary screw) was operated continuously from April to June each year, and the raw capture data from the trap was compiled to provide estimates of the timing and magnitude of daily and seasonal run timing. The trap was operated longer than the expected migration and longer than the Seton Generating Station shutdown window to ensure the entire outmigration was enumerated.

There are two daily periods of smolt migration: nighttime and daytime. Nighttime refers to the period when the generation station is shutdown, and daytime refers to the time when the generation station is operating. These times differ both within and between years but roughly correspond to the 6-hour period between 20:00 and 02:00 for nighttime operations (shutdowns) and correspond to the 18-hour period between 02:00 and 20:00 for daytime operations (generation).

In 2018, after discussions with BC Hydro staff, the calculation of summaries was altered to better align with Management question #3 (BC Hydro 2012). The cumulative proportion of daytime and nighttime migrants in each day was calculated as a proportion of the overall catch at the Seton River fish trap. This is different than previous years where the cumulative proportion of only the nighttime and daytime populations was estimated. This change was made to better reflect what proportion of the total population was migrating either during the day or at night and thus specifically reflect the wording in the Terms of Reference (BC Hydro 2012).

2.7 SMOLT MORTALITY

Because captures were generally tracked hourly, by day and by night the total smolt population estimate was the sum of smolts in the Seton River and power canal during the day and at night. The annual smolt mortality estimate is made by applying a fixed rate of 17% mortality direct to the estimated number of smolts migrating down the power canal. This mortality rate was derived from estimated of mortality on a similar turbine at the Ruskin Plant on the Stave River (Groves and Higgins 1995).

The overall smolt percent mortality is estimated by dividing the estimated number of smolts that died, by the estimated outmigration run size determined with mark-recapture estimates. Mark-recapture estimates can be used to determine the estimated number of smolts that die. Estimates described above determine the run size during the day or outside the shutdown window that are entrained and experience 17% mortality. The remining smolts that travel over the Seton Dam at night from 20 April (100th day of the year) to 20 May (140th day of year) experience a mortality rate of 2%. These two estimates are summed together and divided by the total run size estimate to provide a proportional estimate of mortality by year. This number is often compared to the 5% smolt mortality target (Settlement Agreement 2011).

2.8 ESTIMATING ROUTING PROPORTION AND POPULATION SIZES WITH MARK-RECAPTURE DATA

In the Seton River mark-recapture trials, i.e., capturing and marking fish and then releasing them above and below the dam, can be used for three things: 1) estimating capture efficiency, 2) estimating routing proportions, 3) estimating population size. Generally, previous reports only use mark-recapture data to estimate capture efficiencies, then assume routing proportions, and then apply mortality assumptions to estimate population size. The exception is 2011 and possibly 2012 where mark-recapture trials were used to estimate the proportion of smolts traveling down the power canal, and the proportion of smolts traveling over the Seton Dam, i.e., routing proportions. In 2018, we hoped to calculate the routing proportions using mark-recapture trials, but so few fish released above and below the dam were recaptured that we could not develop an estimate. Instead we only used the mark-recapture trial data to estimate capture efficiencies as was done in previous years. We also hoped to back calculate the routing proportions for previous years but were not able to compile an adequate and consistent data set from mark-recapture trials from every year where monitoring was performed. Our calculations rely on the capture efficiency estimate in each year provided in the reports to make our annual calculations.

Table 2.1. Summary of basic calculations used to answer Bridge-River Water Use Plan BRGMON-13 Management Questions.

Metric	Calculation	Data used to derive estimate	Management Question addressed
Raw capture data	Proportion of daytime and nighttime migration relative to total number of captures.	Raw capture numbers	Refine dates and timing of shutdowns (MQ#1)
Capture efficiency	Number of recaptures ÷ total number marked smolts for a time period	Marked fish released and recaptured both above and below dam	Assess capture efficiency relative to discharge and population size (MQ#2) and correct proportional routing assumptions (2011 only) (MQ #3)
Number of smolts in the Seton River	Estimated number of smolts captured at night between 20 April and 20 May (during shutdowns)	Raw capture data and capture efficiency	Refine dates and timing of shutdowns (MQ#1)
Number of smolts entrained in power canal	(Estimated number of smolts captured when Generating Station operating x 0.84) ÷ 0.16	Raw capture data and capture efficiency (at 80 cms, Levy et al. 2008)	Refine dates and timing of shutdowns (MQ#1)
Yearly mortality rate	(Number entrained in power canal x 0.17 + number in Seton River x 0.02) ÷ Total number of smolts	Population estimates above and estimates of mortality (from Groves and Higgins 1995).	Assessing management targets (Settlement Agreement 2011) and estimating mortality and proportional routing (MQ #3)
Yearly population estimate	Sum of daily population estimates in Seton River and Power Canal	Sum of number in Seton River, number entrained in power canal, and estimated mortality (could use mark-recapture if data were sufficient)	Estimating outmigration run size (MQ#3)

To ensure mark-recapture data is more useful moving forward we performed a power analysis to estimate the minimum number of fish that would need to be marked and released at different capture efficiencies and population sizes. For this simulation we assumed three known population sizes of 125 000 (minimum Seton River population size obtained in 2008), 1 000 000 (mean Seton River population size across all years) or 3 200 000 (maximum Seton River population size obtained in 2012). We also assumed that the capture efficiencies of recapturing fish would always be between 1% and 20%. Lastly, we assumed that the number of marked fish ranged between 100 and 15 000 fish.

Using these assumed values, we applied the pooled Petersen population estimate method calculated by the equation provided by Ricker (1975) to estimate the number of recaptured fish and then from this calculate the 95% confidence intervals around the population estimate at various levels of capture efficiency and different population sizes. This allowed us to estimate the number of marked fish required to achieve 25% accuracy in our mark-recapture population estimate and any particular level of capture efficiency. Krebs (2014) suggests that for management purposes a moderate level of accuracy is desired in mark-recapture estimates (± 25%). This accuracy can be calculated using the following formula:

$$A = \pm 100\ \frac{Estimated\ population\ size - True\ population\ size}{True\ population\ size}$$

The Ricker equation to estimate population size is as follows:

N = MC/R

where N = population size
M = number smolts marked
C = number smolts captured in the sample
R = number of recaptures

And the 95% confidence intervals were calculated using the normal approximation confidence intervals method following Krebs (2014) defined by the formula:

$$\frac{R}{C} \pm 1.96 * \sqrt{\frac{\left(1-\frac{R}{M}\right)\frac{R}{C}\left(1-\frac{R}{C}\right)}{C-1}} + \frac{1}{2C}$$

We provide these simulations to present a power analysis as to what kinds of sample sizes of marked fish are required for different capture efficiencies and smolt population sizes. We hope these estimates will inform and future work.

An example may more clearly demonstrate the methods we used to estimate the number of marked fish in any time periods that would allow an accurate measure of population size. Firstly, as an example assume a known population size of 1 000 000 fish, a capture efficiency of 5% and that we capture and marked 1000 fish. Then using the above equations: N = 1 000 000, M = 1000, R = 1000 * 0.05 = 50, and C = NR/M = 1 000 000 * 50 / 1000 = 50 000. Knowing each of these values allows us to estimate the 95% confidence intervals around the known 1 000 000 population size estimate. The 95% confidence interval equation supplied above estimates R/C and we plug this value into equation N=MC/R. Thus, we estimate the true population size to likely lie between 781 228 and 1 351 415. Thus, for a moderate level of accuracy, we would want our 95% confidence intervals of the estimated population size to be within this range i.e. for the population estimate to be larger than 750 000 and less than 1 250 000. For the above calculation the lower limit of the population estimate meets the 25% threshold, but the upper limit is above the 25% accuracy limit and we should mark more fish. Our actual calculations and result of our simulations are provided in the Results Section 3.7.

3.0 RESULTS

3.1 SETON DAM DISCHARGE

Discharge is monitored and recorded at the Seton Dam by BC Hydro. Discharge between mid-April and late-June smolt migration fluctuated between 10 cms and 100 cms during the smolt migration periods, with some differences between years (Figure 3.1). Typically, discharge stayed between 25 cms and 40 cms during the sockeye smolt migration, 20 April to 20 May. However, since 2016 discharge has been above 60 cms. In 2018, there were five ramp-ups and two ramp-downs by BC Hydro in the Seton River during the smolt migration.

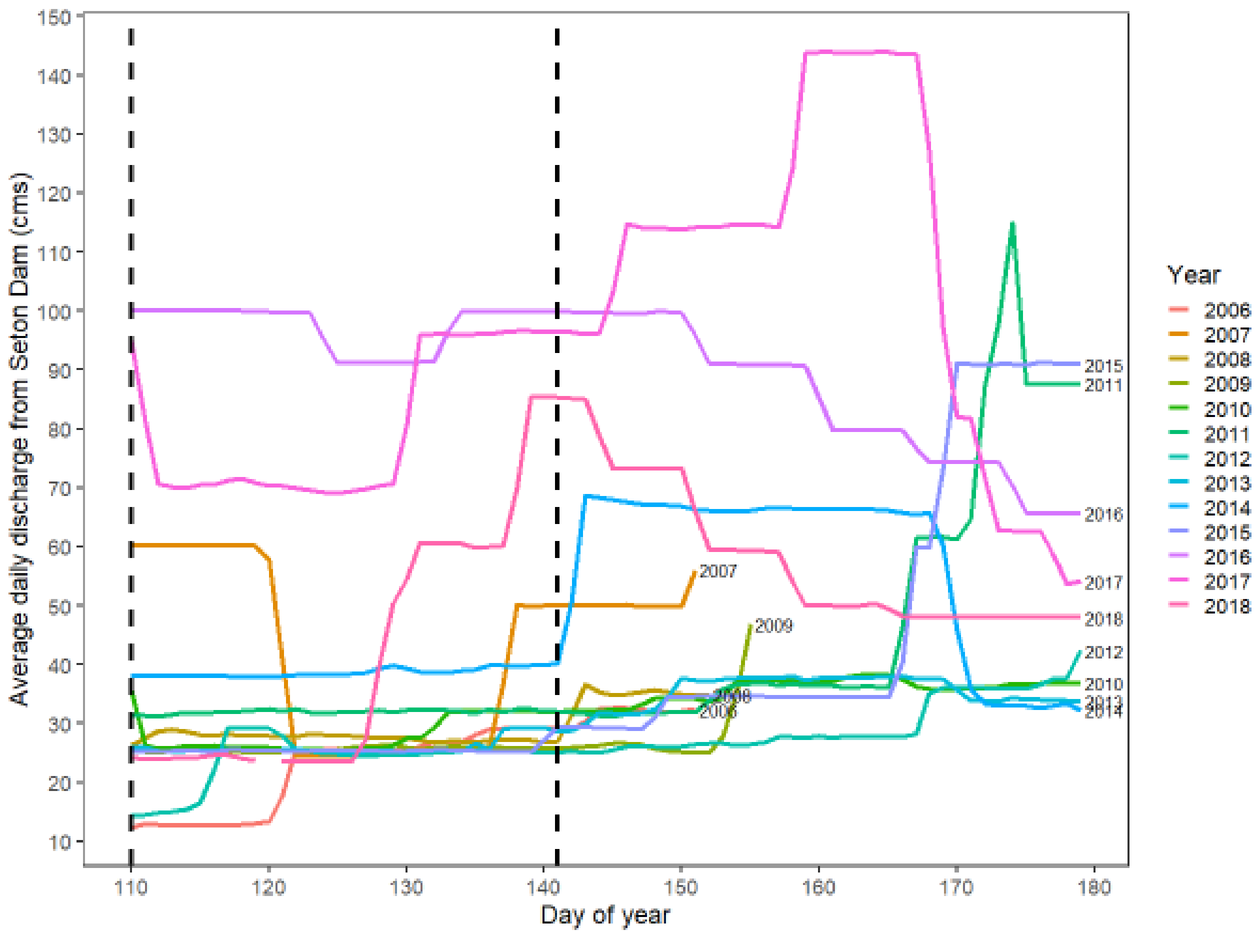

Figure 3.1. Seton River Dam discharge during and immediately after the sockeye smolt migration period from 2006 to 2018. Average daily discharge from Seton Dam shown for each day of the year. The period of operational modifications by BC Hydro, where the Seton Generating Station is shut down for 6-hours each night are show with dotted lines. The nightly shutdowns begin on the 20 April (Day 110) and run until 20 May (Day 141). Yearly discharge is plotted till the 30June (Day 181) where data are available.

3.2 SMOLT CAPTURE

The rotary screw trap was operated a total of 67 days in 2018, from the 14 April till the 21 June 2018 (Table 3.1), which was the longest trapping session to date. The extension to 21 June

2018 was due to the BC Hydro Entrainment monitoring program for Coho and Chinook smolts. The average number of trapping days between 2006 and 2018 was 49.9 days (SE = 2.50, range = 43 – 67). The total catch of sockeye smolts in 2018 was 6,997 and was one of the lowest catches recorded (Table 3.2, Figure 3.2), about 1/10th the norm. The mean annual smolt size was 66,779 (SE = 22,064.5) which was highly variable between years and skewed upwards (median = 41,449). This is due to large run sizes in some years, particularly in 2012. For comparison, in the 13 years of monitoring the highest catches were observed in 2012 (249,979) and lowest other than 2018 was in 2008 (8,694). Like other years, catches of sockeye smolts in 2018 during the night (6,243; 89%) was much higher than during the day (754; 11%) which follows the typical pattern of out-migration.

Table 3.1. Duration of smolt trapping on the Seton River from 2006 to 2018 including the first date of trapping, last date and the number of days the trap was fished. No trapping was done in 2016 due to high discharge. An inclined plane trap was used from 2006 to 2016, and a rotary screw trap was used in 2017 and 2018.

Year	Trapping Start Date	Trapping End Date	Monitoring Duration (days)
2006	21 April	03 June	43
2007	18 April	31 May	43
2008	19 April	31 May	42
2009	16 April	04 June	49
2010	15 April	16 June	62
2011	15 April	30 May	45
2012	15 April	30 May	45
2013	19 April	02 June	44
2014	14 April	30 May	46
2015	15 April	15 June	61
2016	-	-	-
2017	10 April	01 June	52
2018	15 April	21 June	67

Other species of Pacific Salmon were also captured in 2018 monitoring program. Sockeye were by far the largest number of smolts captured and were 63% of the total catch (11,154 total) of all species. The smolt catch included: 526 coho (5%), 206 chinook (2%), and 3,425 pink salmon (31%).

Table 3.2. Total and maximum daily catches of sockeye smolts between 2006 and 2018. Daytime trapping was not done in 2006 and 2007. Almost no trapping was done in 2016 due to high discharge. An inclined plane trap was used from 2006 to 2016, and a rotary screw trap was used in 2017 and 2018.

Year	Total Catch	Total Nighttime Catch	Total Daytime Catch	Daytime - Nighttime Ratio	Maximum 1-Day Catch (nighttime)	Maximum 1-Day Catch (daytime)
2006	34,143	34,143	---------	---------	6,705	---------
2007	43,450	43,450	---------	---------	7,059	---------
2008	8,694	7,026	1,668	0.19	632	731
2009	18,048	13,486	4,562	0.25	1,641	717
2010	27,335	20,532	6,803	0.25	3,096	2,167
2011	144,128	136,388	7,740	0.05	12,177	1,561
2012	249,979	129,153	120,826	0.48	40,574	45,817
2013	16,330	15,534	796	0.05	1,540	141
2014	39,492	34,447	5,045	0.15	5,706	592
2015	77,055	69,980	7,075	0.10	23,518	1,200
2016	-	-	-	-	-	-
2017	43,209	41,653	1,556	0.04	6,112	439
2018	6997	6,243	754	0.12	760	73

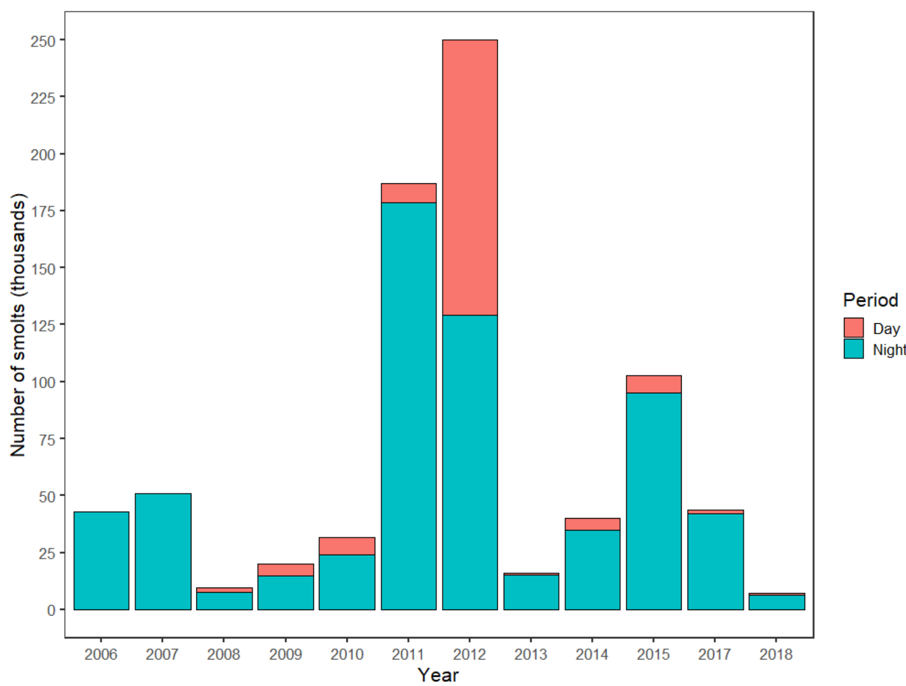

Figure 3.2. Smolt catches in daytime and nighttime periods between 2006 - 2017. There was no daytime sampling undertaken in 2006 and 2007, and trapping was not completed in 2016 due to high flows. An inclined plane trap was used in 2006 to 2015 and a rotary screw trap in 2017 and 2018.

Length-frequency distributions of annual fork length from smolts captured in the Seton River had a single peak in all years (Figure 3.3). Mean fork length over 13 years of sampling was 99 mm (SE = 2.9; range = 93 to 120 mm). In four out of twelve years (2006, 2011, 2012, and 2015), the distribution of fork lengths was smaller than 100 mm. In four years (2009, 2014, 2017, 2018), fork lengths were larger than over 100 mm. In 2018, sockeye smolts ranged from 65 to 135 mm mean = 120 (SE=0.7). This makes smolts in 2018 some of the largest measured.

Sockeye smolt length has varied among years and size is largely dependent on smolt population size. Variation in smolt length occurred primarily between and not within years (Figure 3.3). The largest smolts were captured in 2009 (Table 3.3) and smallest smolts occurred in 2012. Mean size of sockeye smolts in 2018 (1201 mm, SE = 0.74, N = 1907) which fell within the range of all other years (2005 – 2017, 2016 exempt). The relationship between fork length and smolt abundance was statistically significant (χ^2 = 18.8, p-value <0.001, marginal R^2= 0.24, conditional R^2 = 0.37) and the slope of this line is negative demonstrating a density dependent relationship in smolt length. A polynomial equation fit the data no better than a straight-line equation (χ^2 =1.1, p-value = 0.294).

Table 3.3. Mean fork lengths of age-1 sockeye smolts captured in the Seton River between 2006 – 2018. Sampling was not competed in 2016 due to high flows and thus a very low number of smolts were measured. From 2006 to 2015 an inclined plane trap was used to capture smolts and in 2017 and 2018 a rotary screw trap was used.

Year	Mean	SE	Number
2006	93.7	0.36	1,300
2007	96.0	0.45	1,274
2008	98.8	0.25	1,586
2009	108.0	0.24	2,035
2010	103.6	0.26	1,906
2011	94.7	0.17	2,499
2012	77.2	0.11	2,915
2013	99.6	0.32	1,602
2014	100.8	0.18	2,743
2015	94.4	0.15	3,313
2016	76.5	2.4	10
2017	102.4	0.39	1,763
2018	120.1	0.74	1,907

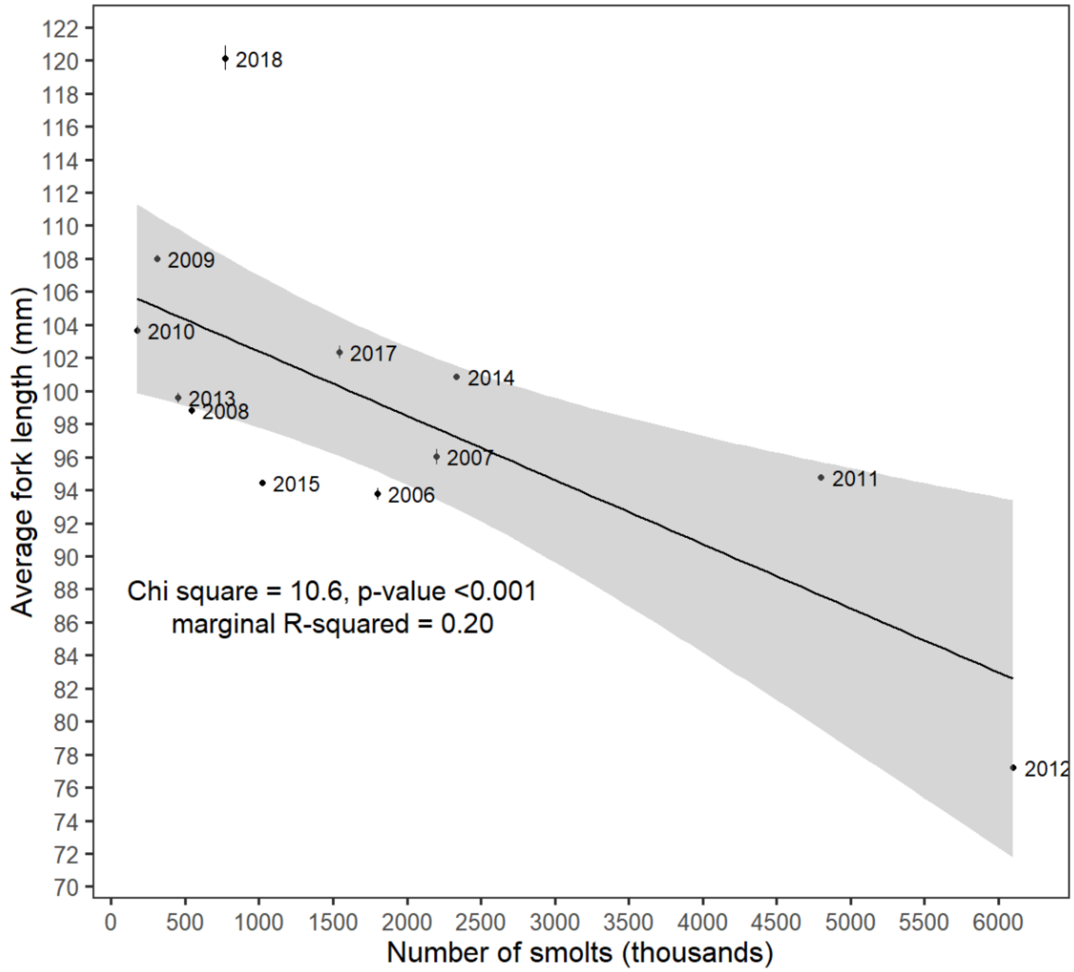

Figure 3.3. Mean fork length of sockeye smolts in the Seton River between 2006 – 2018, with standard errors. Data from 2016 due to the very few smolts measured that year, excessively high flows precluded sampling. From 2006 to 2015 an inclined plane trap was used to capture smolts and in 2017 and 2018 a rotary screw trap was used. Model fit statistics are from a generalized linear mixed model with year as a random variable (N = 22,936).

Gates and Portage creek smolt migrations occur at slightly different times. In 2015, a small number of smolts (N = 200) were sampled and assigned to stocks using genetic techniques at the DFO lab in West Vancouver (Hopkins et al. 2015). In 2015, it appeared that the peak in the Portage Creek smolt migration occurred 5 days later than the Gates Creek migration.

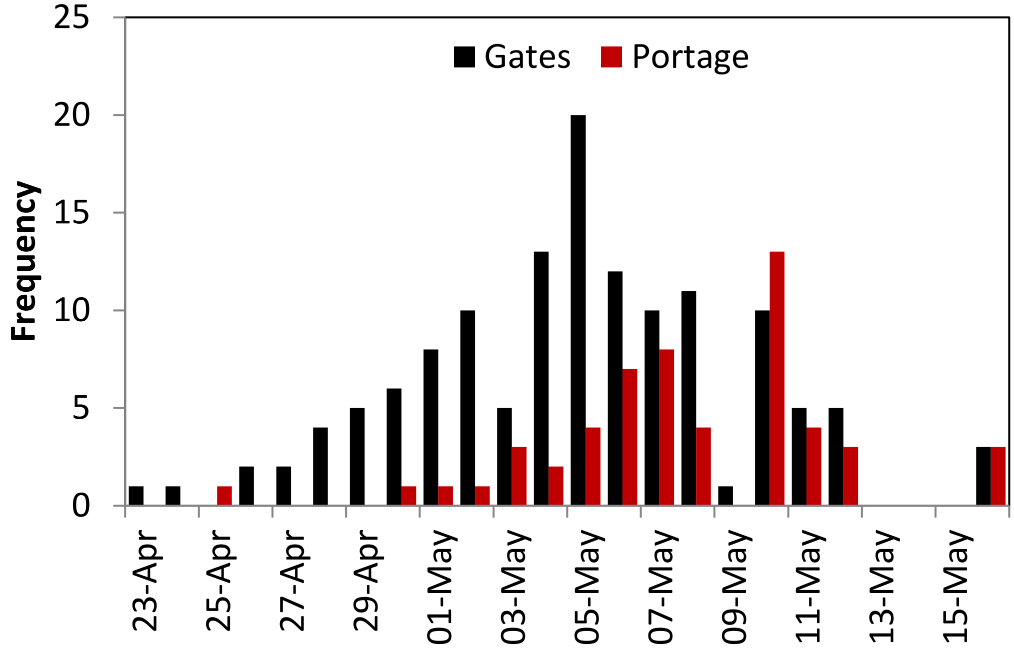

Figure 3.4. Stock assignment from 200 sockeye smolts with genetic population assignment from DFO labs in 2015. Seven to ten smolts were sampled each night. (figure adapted from Hopkins et al. 2015 report).

3.3 CAPTURE EFFICIENCY

The 2018 estimate of smolt abundance fell in the mid-range of values observed for all other years of study (2006 - 2017) (Tables 3.4, 3.5); however, capture efficiency was very low and at the low end of the range of capture efficiencies estimated in the past years.

Table 3.4. Summary of nighttime mark-recapture experiment results (stratified by discharge) from the Seton River IPT, 2006 to 2017 (2016 exempt).

Study Year	Seton River Q ($m^3 \cdot s^{-1}$)	# of Trials	# of Marks Released	# of Marks Recaptured	Capture Efficiency (%)
2006	25 to 30	1	311	22	7.07
2007	25 to 30	1	416	26	6.25
-	50+	3	1049	60	5.72
2008	25 to 30	3	1034	82	7.93
-	31 to 35	1	660	38	5.76
2009	25 to 30	4	2310	212	9.18
2010	25 to 30	3	1012	105	10.38
2011	31 to 35	7	1517	90	5.93
2012	25 to 30	5	602	68	11.31
2013	25 to 30	2	248	18	7.87
2014	25 to 50	4	904	52	5.75
2015	25 to 50	3	630	55	8.73
2016	-	-	-	-	-
2017	64 to 115	5	1001	28	2.80
2018	11 to 85	4	700	22	3.14

Capture efficiency is highly dependent on discharge (Figure 3.5). Capture efficiencies were generally low and only a small number of smolts were recaptured (median = 54, mean = 63, Table 3.4). There was especially low capture efficiency in years when Seton Dam discharge was above 60 cms. Capture efficiency and increases when the number of recaptures increases (LR test, Chi = 61.6, p<0.001) and when the number of marked smolts increases (LR test, Chi = 47.3, p<0.001). The number of marks and recaptures can be increased by adding another fish trap or by marking more fish.

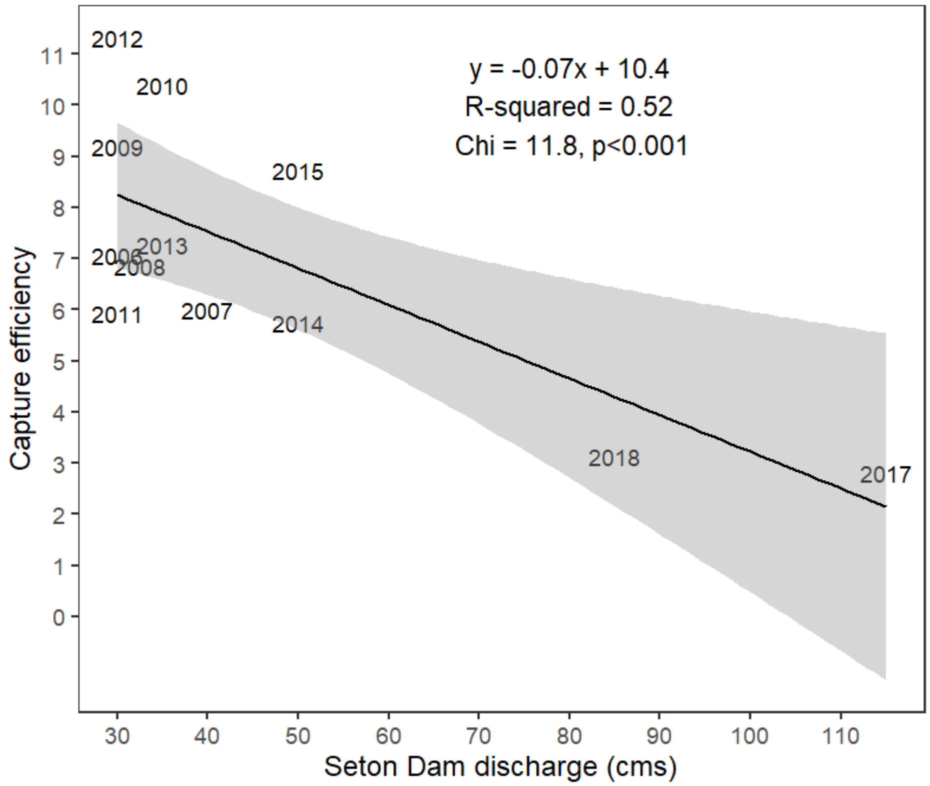

Figure 3.5. Recapture efficiency at different levels of discharge from the Seton dam. In 2016 flows were so high that a monitor could not occur. In 2006 to 2015 an inclined plane trap was used for monitoring and in 2017 and 2018 a rotary screw trap was used for monitoring.

3.4 ESTIMATING ROUTING PROPORTIONS

We estimated the populations sizes for all years 2006 – 2018 using standard methods and based on the routing assumptions estimated the number of fish traveling in the Seton River during the night and day and those traveling down the power canal (Table 3.5).

Table 3.5. Total population estimates using standardized method across years for Seton-Anderson sockeye smolts (2016 exempt). Population sizes are rounded to the nearest 100 fish. Day sampling in 2006 and 2007 was not completed. In 2016 no sampling was done due to high flows. In 2006 to 2015 an inclined plane trap was used and in 2017 and 2018 a rotary screw trap was used.

Study Year	Seton River (Night)	Seton River (Day)	Power Canal (Day + Night)	Total Estimated Smolt Population
2006	618,400	*	515,100[a]	1,133,500[a]
2007	890,800	*	658,900[a]	1,549,700[a]
2008	106,600	19,000	409,000	534,600
2009	166,400	99,500	38,100	304,000
2010	237,100	117,400	49,400	403,900
2011	3,076,600	102,600	1,657,300	4,836,500
2012	1,547,600	1,661,400	1,680,900	4,889,900
2013	213,800	16,700	260,500	491,000
2014	691,800	181,500	0(shut down for maintenance)	873,300
2015	987,200	83,800	688,000	1,759,000
2016	-	-	-	-
2017	1,689,500	95,700	0 (not in operation)	1,785,200
2018	216,400	25,900	278,400	520,700

* Daytime sampling in 2006 and 2007 was not systematic and therefore we do not provide estimates of daytime population sizes for these years.
[a] population estimates are based on nighttime sampling numbers only

3.5 SEASONAL AND DAILY MIGRATION ESTIMATES

In 2018, sockeye smolt outmigration spanned the period between mid-April through the termination of sampling in June. Time-density plots of total catch for day and night periods indicated the 2018 migration was not abnormal but did group with five of the runs which did not have peak numbers migrating until later in the year (Figure 3.6). In 2008, 2009, 2012, and 2018 it took until after 1 May to have more than 50% of the smolts past the dam. In 2010, the first half of the year migrated quickly but the second half of the run slowed. Common to these five years (2008, 2009, 2010, 2012, and 2018) is that that nightly shutdowns of the Seton Generating Station ended prior to 80% of that years run completing. Notable in 2012 is that this run was very large and a larger than normal portion of smolts traveled during the day.

In contrast to nightly proportions, daytime migration never amounted to most of the migration. However, the years in which the highest proportion of smolts migrated during the day were the same years in where the cumulative targets of 80% migration during the shutdown window were not met. This included 2008, 2009, 2010, 2012 and to a certain extent 2018. The years 2014 and 2018 were quite similar, 2014 had a higher proportion of daytime migrants but the migration peaked earlier than 2018.

The median migration dates in 2018 were 9 May for nighttime migrants and 11 May for daytime migrants. Median migration dates are 2 May (nighttime) and 9 May (daytime) for all other years (2005 - 2015) combined (Figure 3.7). The migration in 2017 was early. Median outmigration timing, across all 12 years, indicates daytime migrations occur about one week later in the outmigration period when compared to nighttime migrations. In 5 years (2008, 2009, 2012, 2013, and 2018) a larger portion of the run is in daily migration and this typically occurs later in the season.

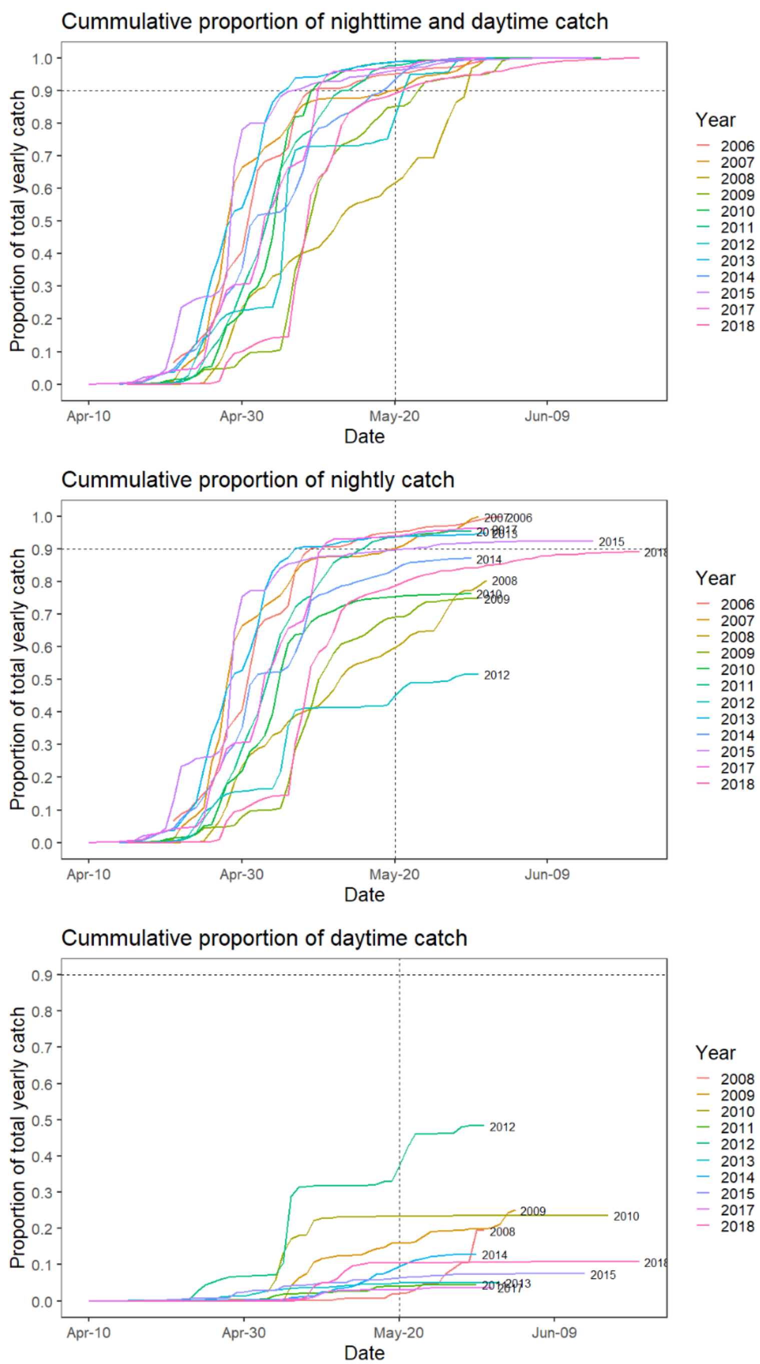

Figure 3.6. Time-density plots for total catch (top panel), nighttime (middle panel) and daytime (bottom panel) proportional catches. Proportions were calculated as proportion of total catch for each year. The end of nightly shutdowns (May 20th) is indicated with a vertical dashed line. Shutdowns begin on April 10th. Likewise, the point in which 90% of the outmigration is completed is indicated with a horizontal dashed line.

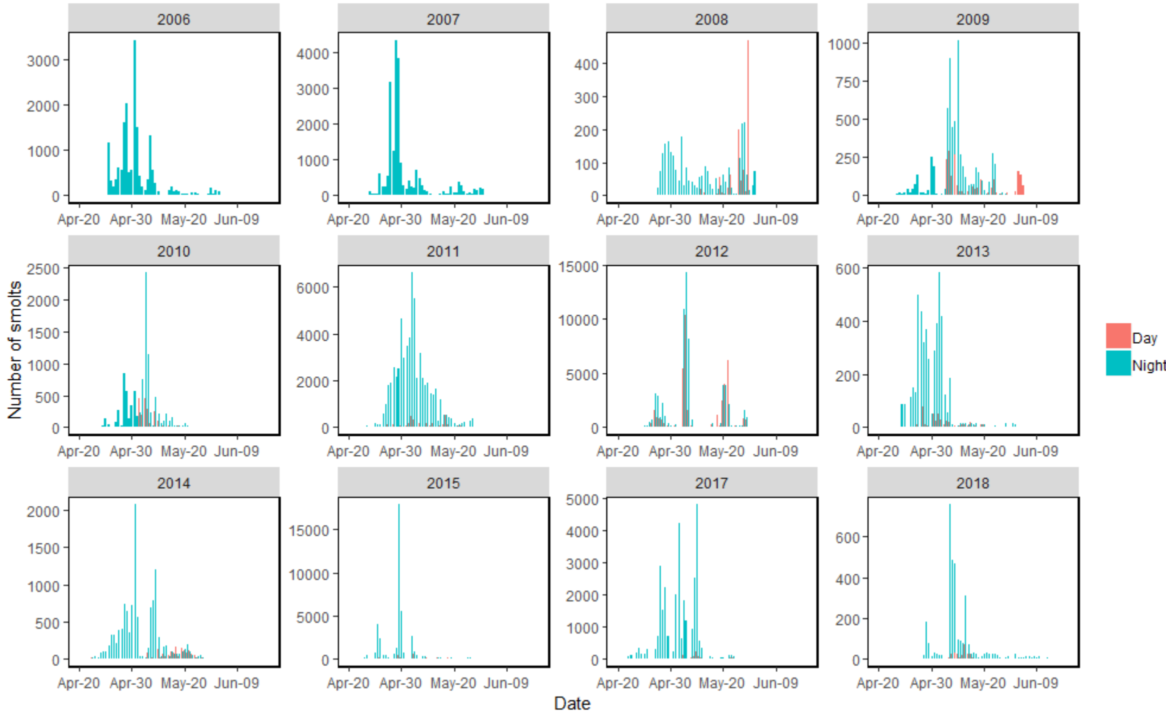

Figure 3.7. Frequency of sockeye smolt catches at trap below Seton Dam over time for 2006 – 2018. 2016 is not included because sampling was not completed due to high discharges. An inclined plane trap was used from 2006 to 2016, and a rotary screw trap used in 2017, and 2018. No daytime trapping occurred in 2006 and 2007.

The largest number of smolt cross Seton Dam from 20:00 h to 04:00 h each night (Figure 3.8). Typically, a small number of fish continue to travel over the dam during the day but the peak in the daily migration occurs near midnight.

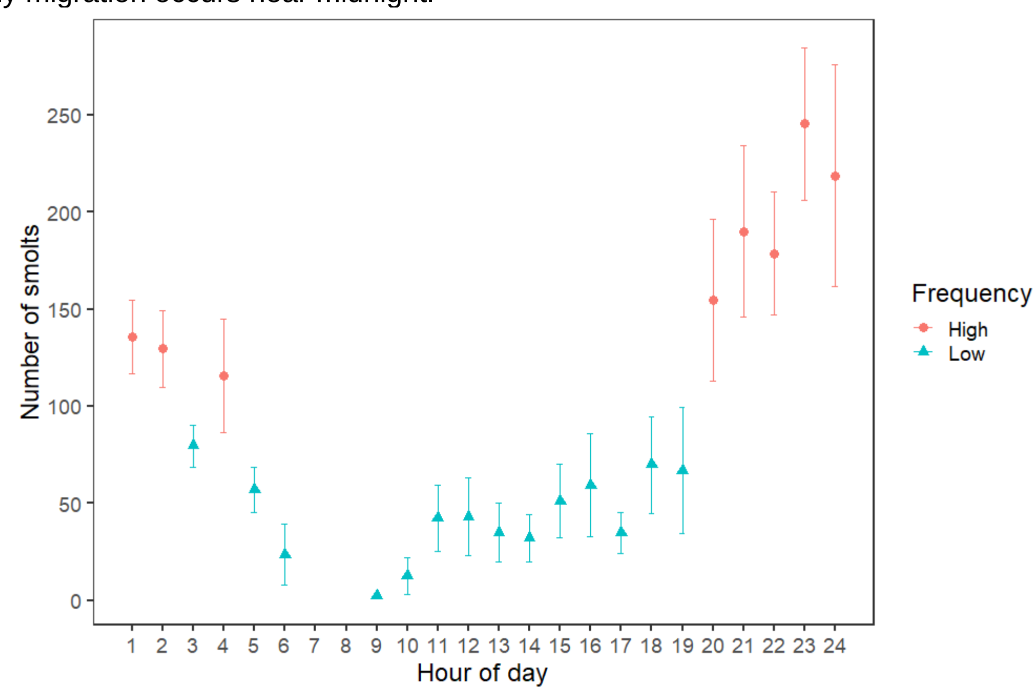

Figure 3.8. Average number of smolts per day from 2008 to 2018 captured at the fish trap below Seton Dam. From 2008 to 2015 an inclined plane trap was used to capture smolts and in 2017 and 2018 a rotary screw trap was used. Hourly means and standard errors are shown. Circles represent hours with >100 smolts captured, triangle represent hours with <100 smolts.

3.6 SMOLT MORTALITY

Total mortality for smolts entrained through the Seton Generating Station has varied among years (Figure 3.9) and has not typically met the 5% mortality target. Since 2009, five out of nine years (56%) had higher than 5% mortality (2016 was not sampled). However, maintenance outages preclude operation mitigations in two of those years (2014 and 2017). Thus in years when the smolt mitigation measures were in effect five out of seven (71%) of years when operational modifications failed to meet targets. The lowest mortality rate observed in years where the generating station was operational during the smolt migration window was 3.8% in 2010. The highest mortality rate of 13.5 % was observed in 2008.

In 2018, the estimated mortality was 52,170 smolts or 7% of the estimated population size of 520,700.

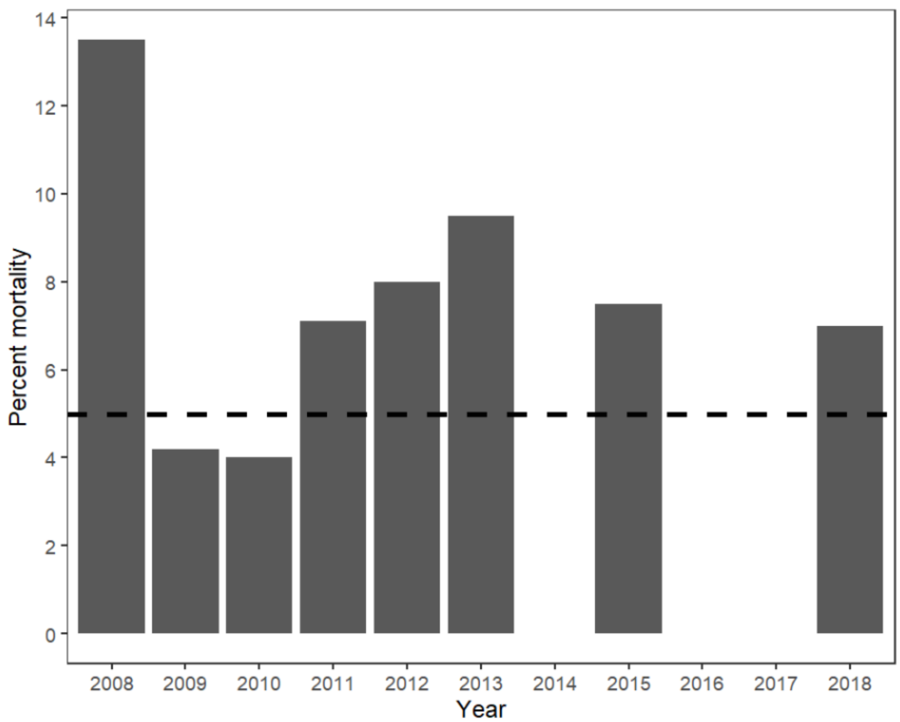

Figure 3.9. Sockeye smolt mortality estimates (2008 - 2018). In 2014 and 2017 the Seton Generating station was shut down for the entire smolt migration period and the mortality rate was 0%. In 2016 there was no sampling due to high flows. From 2008 to 2015 and inclined plane trap was used to sample smolts and in 2017 and 2018 a rotary screw trap was used. The horizontal dashed line indicates the smolt mortality target outlined in the St'át'imc Settlement Agreement (2011).

3.7 MARK RECAPTURE SIMULATION

To estimate the sample sizes of marked fish needed to accurately predict the smolt population size we conducted a simulation study. Figure 3.10 shows that the size of the error bars decline as the number of fish caught, marked and released in the mark recapture study increases. Furthermore, as capture efficiency increases the number of marked fish needed to accurately estimate population size declines. Table 3.7 provides more details on the minimum number of fish needed to be marked for a population size estimate with 25% accuracy at various capture efficiencies.

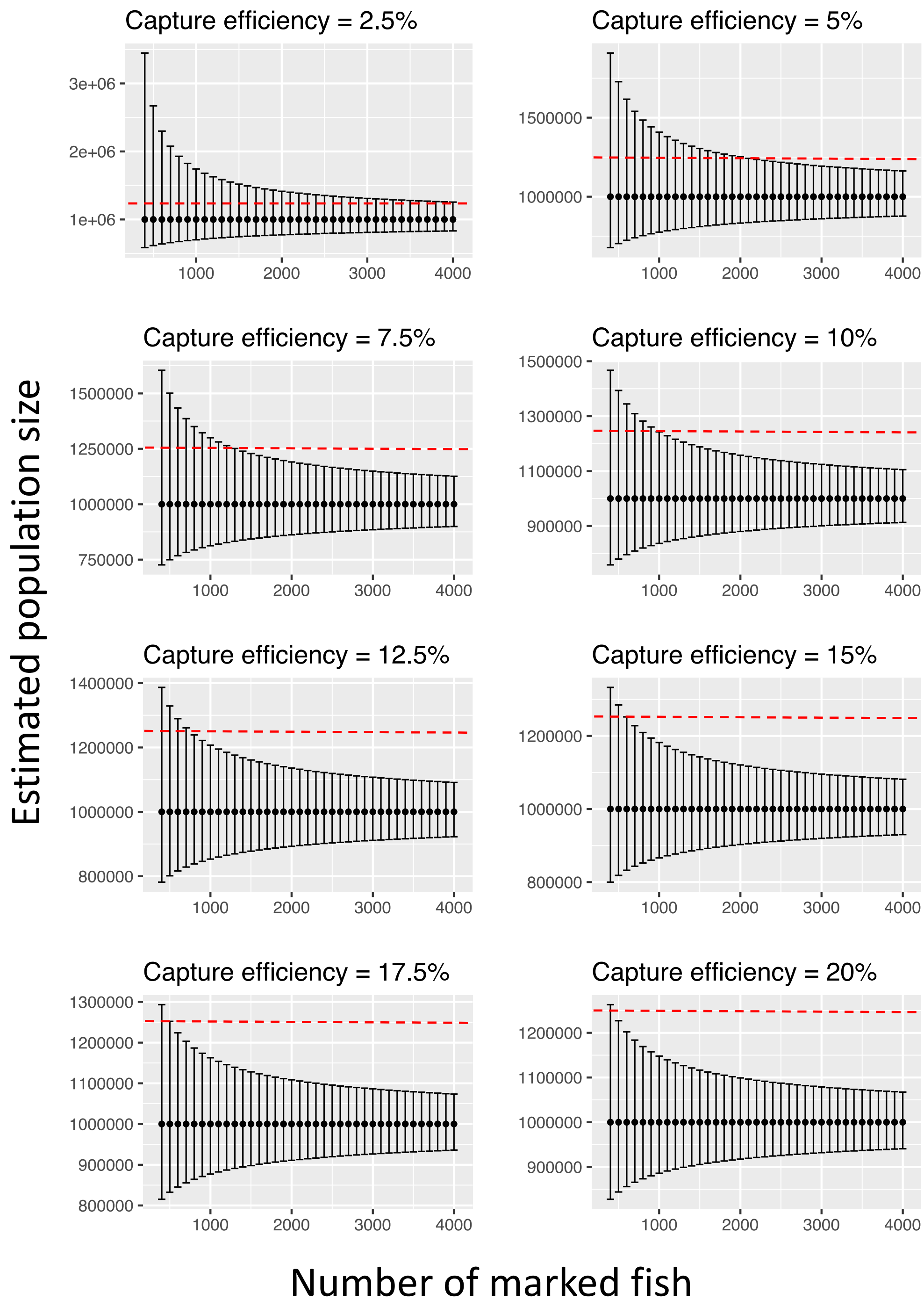

Figure 3.10. Mark recapture simulation results showing the accuracy of the population estimate according to the number of fish marked for various capture efficiencies. Black points are the estimated population size with 95% confidence intervals. The red dashed line indicates where the population estimate has an accuracy of 25%. A population estimate with 95% confidence intervals smaller than the red dashed line show that the estimate is likely within 25% of the true population size.

Figure 3.10 suggests that at a capture efficiency of 10%, which is considerably higher than the current level, there needs to be >1000 marked fish release in each period where a mark-recapture estimate is desired. This would include pooled estimates of daytime and nighttime migration, or any smaller time periods during migration. For example, to properly estimate weekly population sizes and thus estimate overall mortality during the day and the night during the entire migration with a capture efficiency of 10%, >1000 marked fish need to be released each week during both day and night (>2000 fish total). This includes releases both above and below the dam (>4000 fish total). Admittedly, this is a much larger number than the current numbers being released. Reducing capture efficiencies dramatically increases the number of fish that need to be marked and released. Thus, far only two years (2012 and 2010) have estimated capture efficiencies greater than 10%. Further, population size also influences the number of fish that must be marked. To get a sense of how populations size influences the number of marked fish, we estimated the number of marked fish required to estimate populations at three populations sizes at various capture efficiencies (Table 3.7). Again, >1000 fish per time period (daytime, nighttime, weekly) are required at capture efficiencies below 10%. At low capture efficiencies, the accuracy of population size are much more sensitive to the number of marked fish than at higher capture efficiencies.

Table 3.5. Mark recapture simulation results showing the number of fish needed to be marked at varying capture efficiencies and population sizes to obtain a population estimate with an accuracy of 25%. The number of marked fish is rounded to the nearest 10 and suggest that at a specific capture efficiency this number of fish or more need to marked to obtain a reasonable population estimate. Capture efficiency is the proportion of marked fish re-caught after release.

Capture efficiency (%)	Number of marked fish required for 25% accuracy at various population sizes		
	Pop size = 125 000	Pop size= 1 000 000	Pop size = 3 200 000
1	9730	10370	10430
3	3340	3410	3420
5	1990	2010	2010
7	1400	1410	1410
9	1070	1080	1080
11	860	860	860
13	710	720	720
15	610	610	610
17	520	520	520
19	460	460	460
21	410	410	410

4.0 DISCUSSION

The BRGMON-13 program in 2018 demonstrated that the current sockeye smolt monitoring can be accomplished in high flows using methods only somewhat modified from previous years. Continued monitoring will allow the ongoing assessment of management questions, refinement of operational modifications (i.e., shutdowns) to reduce smolt mortality, and achievement of smolt mortality targets. Ongoing monitoring will also continue to provide needed data on smolt migration behavior and survival at discharge levels >60 cms, an aspect of monitoring only begun in 2017.

Despite successes, there are several challenges with the BRGMON-13 program that could be addressed to increase the certainty that management questions are sufficiently addressed. The changes to the program would help provide better information to support decisions around operational changes that could help meet the mortality target outlined in the Bridge River Water Use Plan Terms of Reference (BC Hydro 2012) and make refinements operations so that mortality would meet objectives in the St’at’imc Settlement Agreement (2011). Below is a discussion of the results with respect to each management question.

Management question #1: What proportion of smolts traveled through the Seton Dam during nightly shutdowns?

Many of the years that relied on operational modifications to meet both the management objectives outlined in the Water Use Plan and in St’at’imc Settlement Agreement (2011) did not meet those objectives. Some change in the implementation of the shutdown duration and timing would allow most, if not all, years with shutdowns to meet the management objectives.

Gates and Portage Creek sockeye smolts typically migrate through the Seton Generating Station or Dam nightly between 20 April and 1 June. In years with lower discharge (<60 cms; 2006 to 2015), the peak in migration generally occurs in late April or the beginning of May. However, in some years (2008, 2009, 2010, 2012, 2018) the migration is less pronounced, occurs during the day, and occurs later in the year. The larger daytime migration that occurs in the 18-hours where the Seton Generating Station is operating results in greater entrainment in the Generating Station and thus higher mortality. The later outmigration generally results in fewer than 80% of smolts traveling across Seton Dam with its reduced mortality. In more recent years when discharge is higher (>60cms; 2017 and 2018), the typical diel migration pattern seems to be maintained but there are only two years of monitoring at high discharge and capture efficiencies are very low. Management question #1 would benefit from a detailed statistical analysis aimed at predicting years with greater variability in peak timing and more daytime migrants.

Management question # 2: How is this proportion affected by total release from the Seton dam and the configuration of dam discharge facilities used to release water?

Management Question #2 has not been addressed to date. There are large uncertainties associated with capture efficiency at high discharge (>60cms) that make it impossible to assess differences in the proportion of smolts diverted with different Seton Dam discharge and different discharge configurations. Uncertainties are due to low capture efficiencies and poor mark-recapture estimates.

Continued monitoring should occur using rotary screw traps operating in tandem in the Seton River to achieve higher capture efficiencies. Additional effort on mark-recapture trials should focus on releasing many smolts (>1000) during all sampling periods where estimates are required.

Management question #3: Are there any refinements to seasonal timing that can help reduce smolt mortality or improve power generation opportunities?

There are several opportunities to refine operational modifications (i.e., nightly shutdowns) and reduce smolt mortality. The extent of nightly shutdowns could be extended into late May or early June to reduce the mortality. This could especially affect Portage Creek sockeye smolt outmigration, that occurs later in the migration period that Gates Creek. Additionally, full shutdowns could be added for a week at or just past peak migration in early May. Any change to the start of shutdowns in late April will likely reduce the proportion of smolts migrating during shutdowns and increase mortality. The daily timing of shutdowns could be extended to be 2 – 4 hours longer during the day and thus capture more of out-migrating smolts, especially in years with higher daytime migration. Alternatively, current shutdowns only cover a small 6-hour portion of the day (20:00 to 02:00) and could be extended.

Outside the management questions, 2018 has provided some unique insights into the monitoring program. Discharge in 2018 was again higher than the WUP target hydrograph and required the use of a six-foot rotary screw trap to fish sockeye smolts from the Seton River. At approximately 7,000 the number of smolts captured in 2018 was the smallest number on record. Because of high flows, the capture efficiency was one of the lowest recorded, similar to 2017. However, the mean fork length of smolts (120 mm) was one of the largest. The previously observed density dependent relationship between smolt size and population size suggests that despite low capture efficiency, the 2018 outmigration population size was low.

Only two mark-recapture trials, one during the day and one at night, were completed in 2018. There was a very low re-capture rate likely due to the low capture efficiency of using only a single rotary screw trap in a river with relatively high discharge (>60 cms). Mark-recapture estimates need to be completed weekly in both day and at night as the limited effort expended on mark-recapture trials in 2018 is insufficient. An increased number and frequency of trials along with an increased number of smolts in each trail (to >1000 individuals) would greatly improve the effectiveness of mark-recapture trials in estimating capture efficiency, population size, and routing proportions. We were unable to compile a data set and report mark-recapture estimates in a manner that reported this error so instead we report a simulation that outlines future needs. For example, the extremely low number of recaptures in 2018 (N = 22) means that estimates are highly uncertain and generally should be interpreted with extreme caution, this was not the only year with a very low number of recaptures.

Maintaining relatively high capture efficiencies in either the inclined plane trap or rotary screw trap are essential in developing good estimates of smolt population size. Since these estimates are the foundation of the proportion routing information and subsequently the mortality estimates, capture efficiency underlies the entire monitoring process and the ability to determine if the management questions are being met. At high flows a single six-foot rotary screw trap is insufficient to initially capture a large enough portion of the population or subsequently recapture enough smolts to derive adequate estimates of population size, routing proportions, or mortality. Moving forward, every effort should be made to add a second rotary screw trap operating in tandem to the first. The goal should be to have recapture rates >15%; however, this estimate could be refined based on a power analysis of the mark-recapture program.

Previous monitoring reports (Sneep et al. 2011) suggest some problems with the current monitoring program. In particular, time stratified methods have been developed to deal with the bias incurred from pooling mark-recapture data (Darroch 1961; Plante 1990). These methods require that marking trials be spread throughout the migration period and are currently difficult to use because of the low number of recaptures.

Three external factors must be addressed in refining shutdown timing: 1) high discharge, 2) climate impacts on outmigration smolts, and 3) impacts to species other than sockeye. The refinement process outlined above are from data collected with relatively low flows. After any refinement of the shutdown window is done, continued monitoring at high flows (>60 cms at Seton Dam) will be required to ensure that smolt outmigration timing matches data from previous years. Changes in discharge may govern daily and seasonal migration timing or alternatively changes in temperature could govern timing. For example, summer and late-run sockeye populations (i.e., Gates and Portage Creek) could use different temperature cues to time the start of migration. This could produce the staggered migration pattern seen in 2015. If higher discharge results in altered water temperatures this could change migration patterns. There could also be a consistent move to higher water temperatures due to climate change which results in altered outmigration patterns, these alterations could be stock specific. Again, continued monitoring and stock identification would help elucidate these conditions.

Coho and Chinook smolts are captured during the sockeye monitoring and the outmigration for these species occurs after sockeye. There are also pink salmon migrating during this time. Like Portage Creek sockeye (Endangered 2017), coho (Interior coho – Threatened 2016) and Chinook (mid-Fraser, stream-type, summer, Threatened 2018) populations have been recommended for listing under the Canadian Species At Risk Act (SARA) by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The conservation status of the Gates Creek sockeye population has been previously identified by the International Union for the Conservation of Nature (IUCN, Endangered, Rand et al. 2012). Regardless of official conservation status of these stocks, all sockeye, coho, and Chinook stocks have been identified as imperiled in some way by internationally recognized groups of scientists. Current shutdowns only target sockeye but could be extended to encompass more of the coho and Chinook outmigration in June. Any refinement of the sockeye shutdown schedule should be cognizant of the conservation status and need to reduce mortality on imperiled coho and Chinook.

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