Bridge-Seton Water Use Plan

Seton Sockeye Salmon Smolts Monitoring Program

Implementation Year 8 (2020)

Reference: BRGMON-13

Study Period: April to June, 2020

InStream Fisheries Research
1211A Enterprise Way
Squamish, BC V8B 0T6

St’át’imc Eco-Resources
PO Box 103
Lillooet, BC V0K 1V0

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INSTREAM FISHERIES RESEARCH INC.

BRGMON-13 Seton Sockeye Salmon Smolts Monitoring Program

Implementation Year 8 (2020)

Stephanie Lingard, Katrina Cook*, Roxx LeDoux, and Caroline Melville

Prepared for:

St'át'imc Eco-Resources
PO Box 103
Lillooet, BC V0K 1V0

BC Hydro
6911 Southpoint Drive
Burnaby, BC V3N 4X8

Prepared by:

Instream Fisheries Research
1121A Enterprise Way
Squamish BC, V8B 0E8

*Corresponding author

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Executive Summary

The primary objective of the Seton Sockeye Salmon Smolts Monitoring Program (BRGMON-13) is to assess the effectiveness of powerhouse shutdown to reduce total mortality of Sockeye Salmon smolts leaving Seton Lake. The monitor also aims to collect data on the relative abundance, timing and biological characteristics of sockeye and assess the relationship between dam releases and the proportion of fish entering the approach channel and passing the dam into Seton River. The original experimental design of BRGMON-13 was not able to effectively address the management questions and a new approach was recommended. Monitoring in 2020 (Year 14 of 15) consisted of:

- Collecting Sockeye Salmon smolts in a fish trap approximately 500 m downstream of Seton Dam, using hourly captures as a proxy for hourly fish movements.
- Tagging smolts with Passive Integrated Transponder (PIT) tags to inform a Bayesian Time-Stratified Spline (BTSPAS) mark-recapture model to estimate Seton River smolt abundance and seasonal run timing.
- Using radio telemetry to assess movements of individual tagged fish out of Seton Lake and evaluate proportions passing via either the Seton Dam or the powerhouse.
- Standardized injury monitoring to evaluate potential effects of dam passage on fish condition.

We recommend further refining the monitoring approach and to continue evaluating injury and mortality among Sockeye Salmon smolts to validate assumptions of the current smolt protection strategy.

MQ1: What proportion of total Sockeye Salmon outmigrants from Seton Lake will pass through Seton Dam when the powerhouse is shut down each night (20:00 – 02:00) between April 20 and May 20?

Instead of 6-hour nightly shutdowns from 20:00 to 02:00, the powerhouse was shut down for 30 hours (20:00 Day 1 to 02:00 Day 3) every other day from April 20 to May 20. Despite these differences, collected data still informs migration timing through Seton Dam. MQ1 is guided by three hypotheses: that nightly powerhouse shutdowns conducted 20:00 h to 02:00 h between April 20 and May 20 will divert 80% of the population through Seton Dam (H_{1A}), that 90% of smolts migrate between April 20 and May 20 (H_{2A}), and 90% of smolts migrate between the hours of 20:00 and 02:00 (H_{3A}).

H_{1A} can neither be supported nor rejected because operations did not follow those specified. Additionally, routing proportions, from which the percentage diverted through the Seton Dam is derived, were determined from radio telemetry data. However, challenges with the radio telemetry array led to uncertain routing proportions. Nonetheless, evidence suggests that more fish migrated via the power canal than Seton Dam and the target was not met; 74% of fish were last detected within the power canal and thus were suspected to migrate via that route.

We reject the other two hypotheses. All sources of data, including movement derived from radio telemetry, raw capture data, and run timing determined from the stratified population estimate showed that most fish moved outside of shutdown hours and after May 20. BTSPAS model results best inform seasonal timing (H_{2A}) while raw capture data is best applied to H_{3A} regarding hourly migration timing. The BTSPAS model determined that 39% of smolts migrated during the seasonal shutdown window and that peak abundance occurred after May 20. With respect to hourly migration timing, 67% of raw catch was obtained during shutdown hours.

MQ2: How is this proportion [of total Sockeye Salmon outmigrants] affected by the total release [of water] from the Seton Dam and the configuration of dam discharge the facility used to release water?

An understanding of the proportion of fish moving at discrete time intervals and in response to differing discharge conditions is required to address this management question. The radio telemetry data provided insight into migration behaviour, but significant post release mortality among radio-tagged fish and concerns about performance of the array limited the sample sizes and precluded analyses of movement among operational conditions. Additionally, operational conditions were relatively consistent in 2020. Most water was released through Siphon 4 and total dam discharge remained between 30 and 40 m^3/s during the seasonal shutdown period.

Although there remains substantial uncertainty regarding how Seton Dam releases and/or the configuration of dam discharge facilities may influence routing proportions, radio telemetry results do show that powerhouse shutdowns may not be as successful at diverting fish away from the powerhouse as previously thought. Most fish migrated via the power canal when the powerhouse was operational. Even when the powerhouse was not operational, more fish migrated via the power canal than the Seton Dam. Given these results, monitoring of route selection and migration success among discharge configurations should be continued. A further consideration is that substantial data gaps remain regarding whether the dam is a safer fish passage structure than the powerhouse. It would be prudent to explore data gaps of mortality and post-passage injury prior to assessing how water release configurations influence routing proportions.

MQ3: Are there refinements to the seasonal timing or daily timing of powerhouse shutdowns to improve fish protection efficiency or reduce lost power generation opportunities?

Given that more radio-tagged fish migrated into the power canal than over the Seton Dam when the powerhouse was operational and not, the assumption that powerhouse shutdowns provide fish protection may be invalid. Further, injury monitoring revealed that smolts passing Seton Dam may experience greater injury and impairment than previously understood. Although extending shutdown timing both hourly and seasonally would better align with migration patterns (most fish movement over the Seton Dam occurred between 21:00 and 5:00 and after May 20), we cannot recommend that modifying the timing of powerhouse shutdowns would improve fish protection.

Injury and Mortality

Injury and mortality of smolts were first reported by Andrew and Green (1958) and formed the basis of the fixed mortality estimates applied to quantify annual Sockeye Salmon smolt mortality in BRGMON-13 (17% for powerhouse passage and 2% for dam passage). Unlike in previous years, entrainment rate in 2020 was obtained from radio telemetry data. Uncertainties in detection histories lead to four different routing scenarios with a range of possible entrainment rates from 21 to 89%. Applying the fixed mortality rates to the range of obtained routing proportions gives a range of mortality from 5 to 15%. We caution that scenarios had relatively low sample sizes; therefore, it is uncertain as to whether they are representative of true smolt migration patterns. Further work is recommended.

Injury monitoring was introduced mid-season in response to observations of injuries and deteriorating fish condition as the monitoring season progressed, as well as high pre- and post-tagging mortality. Physical injuries were observed on 58% of assessed fish. Scale loss was the most prevalent injury. More concerning is that injuries characteristic of barotrauma or gas bubble disease (e.g., eye hemorrhages, eye distension, internal bleeding) were also recorded within 3-8% of the weekly sample of fish. We recommend continued and rigorous monitoring of fish condition following passage through each conveyance structure. Additionally, assessments of pressure and shear forces fish may experience during passage and total gas pressure below the dam should be part of ongoing monitoring.

BRGMON-13 status of objectives, management questions, and hypothesis after Year 14 (2020)

Management Questions	Management Hypotheses	Year 14 (2020) Status
What proportion of total Sockeye outmigrants from Seton Lake pass through Seton Dam when the powerhouse is shutdown each night (20:00 – 02:00), April 20 and May 20?	H_{1A}: Nightly shutdowns (accompanied by >25 m3/s dam release) between 20:00 to 02:00, April 20 and May 20 will result in >80% of Sockeye smolts being diverted to Seton River.	We can neither reject nor support H_{1A} in 2020 because operations did not follow those specified. The powerhouse was shut down for 30 hours (20:00 Day 1 to 02:00 Day 3) every other day from April 20 to May 20. Radio telemetry was implemented in 2020 to assess movements out of Seton Lake and determine routing proportions. However, the resulting detection histories are uncertain. Such uncertainties are common when a new technology is deployed for the first time in a new study system, particularly in a dynamic system like the Seton Hydro-electric Facility. High pre- and post- tagging mortality further limited sample sizes and abilities to draw conclusions. The weight of evidence nonetheless suggests that more fish migrated via the power canal than Seton Dam and the target was not met. A range of routing proportions was produced from detection histories: 11-79% of Sockeye smolts were diverted to the Seton River through the duration of the tag monitoring period (i.e., not exclusive to the seasonal shutdown window). The percentage of fish diverted into Seton River during the nightly shutdowns between April 20 and May 20 has met the 80% target in seven of the 11 previous monitoring years with data. However, previous years' data are not comparable because methods differed substantially. In most years, marked fish were released above the dam and it was assumed that 100% of fish migrated down the Seton River when the powerhouse wasn't operational. Data collected in 2020 has revealed this assumption to be false.
	H_{2A}: > 90% of smolts leave Seton Lake between April 20 and May 20.	We reject H_{2A}, which new methods were used to address in 2020. Sockeye Salmon smolts collected in a fish trap approximately 500 m downstream of Seton Dam were tagged with Passive Integrated Transponder (PIT) tags and released below the dam. Recaptures informed a Bayesian Time-Stratified Spline (BTSPAS) mark-recapture model to estimate Seton River smolt abundance and seasonal run timing. The BTSPAS model determined that 39% of smolts migrated between April 20 and May 19, well below the 90% target. Peak abundance occurring between May 25 and 29, after the seasonal shutdown period. Across monitoring years, the 90% target has been met in eight of the 13 monitoring years during which data was collected. Therefore, there has been some support for H_{2A}. However, in previous years H_{2A} was informed by raw catch data, which is not as robust as the BTSPAS estimation. Estimates of seasonal migration timing may not be adequately represented by raw capture data because it does not account for variable capture efficiency due to seasonal changes in discharge.
	H_{3A}: More than 90% of the smolts leave Seton Lake between the hours of 2000 h and 0200 h.	We reject H_{3A}. As in previous years, hourly captures of Sockeye Salmon smolts in a fish trap approximately 500 m downstream of Seton Dam was used as a proxy for hourly fish movements. Although more fish were captured during shutdown hours than not, the percentage (67%) did not meet the stated target. Across monitoring years, the percentage of smolts captured during nightly shutdown hours has ranged from 38 to 83%. The 90% target has never been met and there has never been support for H_{3A}.

Management Questions	Management Hypotheses	Year 14 (2020) Status
How is this proportion affected by total release from the Seton dam and the configuration of dam discharge facilities used to release water?	NA	An understanding of the proportion of fish moving at discrete time intervals in response to discharge conditions is required to address this question, which was not possible in previous years. The introduction of radio telemetry in 2020 provided the first opportunity to do so. With high post-release mortality and uncertain detection histories, the available sample of radio-tagged fish that successfully migrated makes comparing migration characteristics among operational conditions difficult. Additionally, consistent discharge configurations throughout the shutdown period resulted in few discrete operations to compare; Siphon 4 discharged most water and total dam discharge remained between 30 and 40 m3/s during the seasonal shutdown period. Qualitative comparisons made with limited data suggest that when the powerhouse is operational, lower dam discharges could detract fish away from the power canal; most fish migrated into the power canal at dam discharges of 39 - 47 m^3/s and into the Seton River at dam discharges of 30 – 33 m^3/s. There are many uncertainties surrounding these comparisons. What is clear from 2020 results is that powerhouse shutdowns may not be as successful at diverting fish away from the power canal as previously thought. Most fish migrated via the power canal and when the powerhouse was operational. Even when the powerhouse was not operational, more fish migrated via the power canal than the Seton Dam. The study design employed prior to 2020 was not able to answer this management question.
Are there refinements to the seasonal timing or daily timing of powerhouse shutdowns to improve fish protection efficiency or reducing lost power generation opportunities?	NA	Under the assumption that powerhouse shutdowns improve fish protection, shutdown timing could be adjusted to better match smolt migration timing. The 2020 catch data shows similar trends in hourly movements as observed in previous monitoring years. Most fish movement over the Seton Dam occurred between 21:00 and 5:00 and after May 20. Collectively the 14 years of monitoring suggests that powerhouse shutdowns could be adjusted to better reflect migration timing and meet the targets outlined in the hypotheses. For example, in years with high Portage Creek smolt abundance the seasonal timing of shutdowns does not encompass the peak of their migration. Extending shutdown timing both hourly and seasonally would better align with migration patterns. However, radio telemetry data revealed that fish entered the power canal despite shutdowns. Therefore, powerhouse shutdowns may not serve to divert fish away from the powerhouse or provide fish protection.

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1. Introduction

1.1 Background

The Seton-Anderson watershed is part of the traditional territory of the St'át'imc Nation. Sockeye Salmon (*Oncorhynchus nerka*) are the largest population of Pacific salmon in the watershed, which also supports populations of Pink Salmon (*O. gorbuscha*), Coho Salmon (*O. kisutch*), Chinook Salmon (*O. tshawytscha*), Rainbow and Steelhead Trout (*O. mykiss*), Gwenish (deep-spawning black Kokanee, *O. nerka*) and Bull Trout (*Salvelinus confluentus*). Sockeye Salmon and other salmonids in the watershed are important as food, social and ceremonial resources for the St'át'imc people.

Sockeye Salmon in the Seton-Anderson watershed originate from two spawning areas: Gates Creek and Portage Creek. Gates Creek Sockeye Salmon are part of the early summer Sockeye Salmon run timing group which enter the Fraser River in early July and arrive at spawning grounds in mid-August. The Portage Creek population is a late migrating stock, entering the Fraser River in late-September, and spawning in Portage Creek primarily in mid-November (Patterson et al., 2007). These two Sockeye Salmon populations must migrate through the Seton Hydro-electric Facility both as adults returning to spawn (Roscoe et al. 2011; Burnett et al. 2014) and during smolt out-migration from Seton and Anderson lakes to the Fraser River. The Seton hydro-electric facility, constructed in 1956 as part of the Bridge-Seton hydro-electric complex, consists of the Seton Dam, power canal and Seton Generating Station, referred to as the 'powerhouse' (Figure 1.1).

Mortality among Sockeye Salmon smolts from passage via the powerhouse and Seton Dam conveyance structures was estimated shortly after construction; entrainment through the powerhouse resulted in the greatest mortality (Andrew and Green 1958; Ruggles and Murray 1983). Mortality of 17% was estimated for Sockeye Salmon smolts passing through the powerhouse, inclusive of direct mortality and latent mortality from injuries, cumulative stress, disease, and predation (Andrew and Green 1958). For passage through the Seton Dam fish ladder, fish water release gate (FWRG) or siphons, mortality was estimated to range from 1.7 to 7%, depending on the structure (Andrew and Green 1958). Although not tested, Andrew and Green (1958) suggested that operating the FWRG in the 'down' position would reduce mortality to 2% (across all conveyance structures combined) for Sockeye Salmon smolts passing Seton Dam. In response to this conclusion, the FWRG has since been operated in the "down" position during the smolt migration period. Mortality rate is assumed to be static across all discharges and no injury or mortality assessments have been conducted for the spillway operating gate in the dam. Additionally, predation is a known source of mortality for smolts, but accounting for how the Seton Hydro-electric facility may interact with predator/prey dynamics or other causes of natural mortality is beyond the scope of BRGMON-13.

The St'át'imc Nation and BC Hydro have a history of collaborating to mitigate smolt mortality. The St'át'imc Settlement Agreement of 2011 with BC Hydro stipulates a 5% entrainment mortality target for Sockeye Salmon smolts migrating from Seton Lake to the Fraser River. Louver lines, bubble curtains, screens, and a diversion canal have all been proposed or attempted as methods to divert out-migrating smolts away from the power canal, and ultimately the powerhouse (Groves and Higgins 1995; BC Hydro 2011). Shutdown of the powerhouse during peak smolt migration hours was selected as the optimal operational measure to protect smolts (BC Hydro 2011b). From 2006 to 2019 the hours of the nightly shutdown were 20:00 to 02:00 from April 20 to May 20. In 2020, operations were changed to 30-hour shutdowns from 20:00 on Day 1 to 02:00 on Day 3.

Monitoring of smolt entrainment through the powerhouse has been conducted since 2006. Until 2010 the program assessed the migratory behaviour of Sockeye Salmon smolts to develop operational strategies that reduced mortality. Since 2011, the program has been operated through the Bridge River Water Use Plan (WUP; BRGMON-13) to estimate the timing of smolt migrations, the proportion of fish entrained, and Sockeye Salmon smolt mortality rates as they pass through the various structures in the dam and powerhouse as they begin their seaward migration. As outlined in the Terms of Reference (TOR) for BRGMON-13 (BC Hydro 2011b), the monitoring program is intended to assess the effectiveness of powerhouse shutdowns to reduce total mortality of Sockeye Salmon smolts leaving Seton Lake. Secondary objectives of the monitoring program include: 1) to collect data on the relative abundance, timing and biological characteristics of Sockeye Salmon smolts leaving Seton Lake, 2) to assess the effect of powerhouse shutdown and dam release on fish attraction flows and fish bypass conditions at Seton Dam, and, 3) to assess the relationship between dam release and the proportion of fish entering the Dam approach channel and pass the dam into Seton River.

The BRGMON-13 Management Questions are:

1) What proportion of total Sockeye Salmon outmigrants from Seton Lake will pass through Seton Dam when the powerhouse is shutdown each night (20:00 h – 02:00 h) between April 20 and May 20?

2) How is this proportion affected by the total release from Seton Dam and the configuration of dam discharge facility used to release water?

3) Are there refinements to the seasonal timing or daily timing of powerhouse shutdowns to improve fish protection efficiency or reduce lost power generation opportunities?

Management question 1 has three associated alternative hypotheses:

H_{1a}) Nightly powerhouse shutdowns (accompanied by an >25 m^3/s dam release) conducted 20:00 h to 02:00 h between April 20 and May 20 will result in >80% of the Sockeye Salmon smolts being diverted to Seton River from Seton Lake.

H_{1b}) More than 90% of the smolts leave Seton Lake between April 20 and May 20.

H_{1c}) More than 90% of the smolts leave Seton Lake between 20:00 h and 02:00 h.

BRGMON-13 also estimates annual smolt mortality due to powerhouse entrainment and passage through Seton Dam. Combined annual smolt mortality estimates are compared to the 5% target outlined in the 2011 Settlement Agreement.

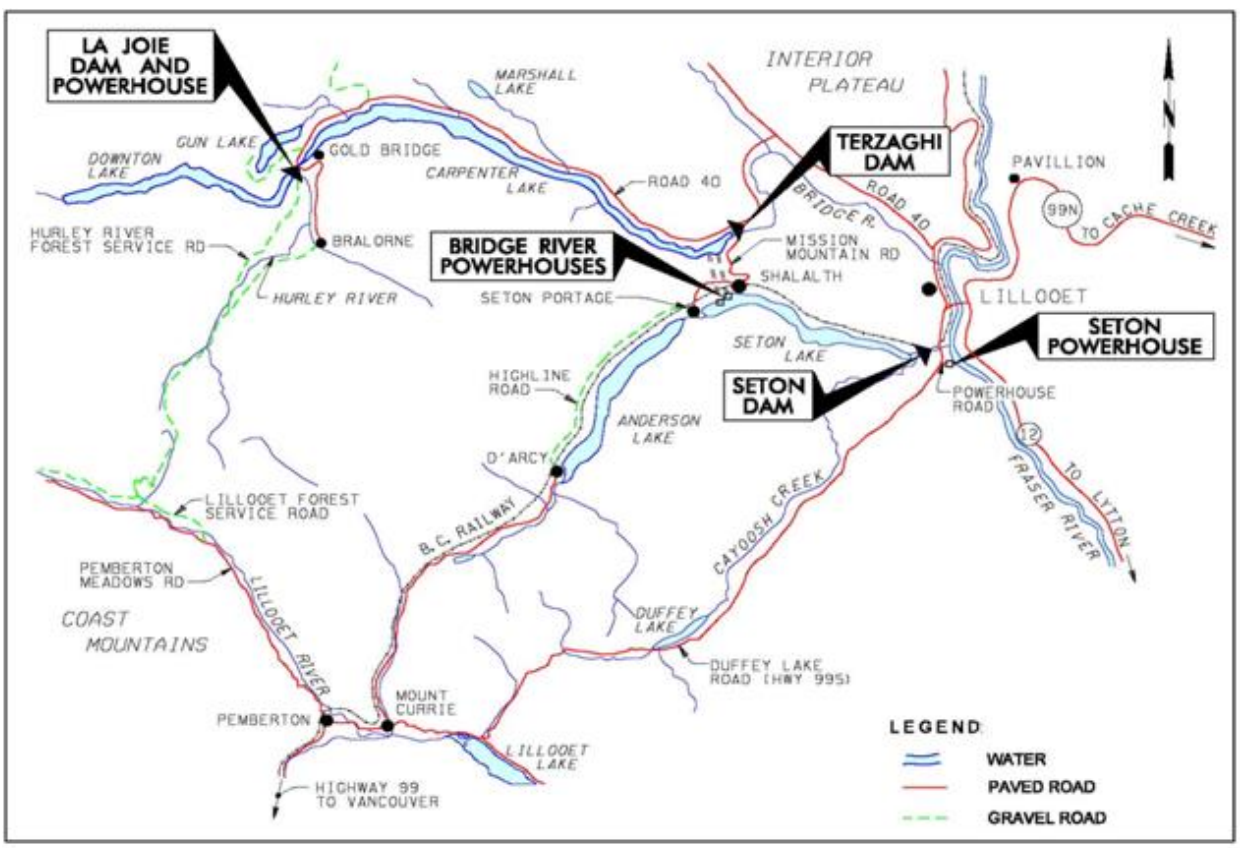

Figure 1.1. Location of BC Hydro facilities in the Bridge/Seton watersheds.

1.2 Monitoring Summary

To assess smolt entrainment rates though the powerhouse from 2006 to 2019, a fish trap was installed downstream of Seton Dam. Sockeye Salmon smolts marked with immersion dye were released above the trap but below Seton Dam to determine trap efficiency, permitting expansion of trap catch to the abundance of smolts migrating down Seton River (Levy et al. 2008; Sneep et al. 2012; Harrower et al. 2019, Lingard et al. 2020). In some years, smolts were marked with a second colour of dye and released upstream of Seton Dam to determine the proportion of fish migrating through the powerhouse.

Synthesis of data collected between 2006 and 2019 revealed that the approach used presented substantial challenges for addressing the three management questions. Three key pieces of data have primarily addressed management questions:

1) Hourly and daily catch as a proportion of the total annual catch estimates the proportion of fish that migrate between 20:00 and 02:00 April 20 to May 20 (MQ1);
2) When marked fish were released above the dam (2008, 2011, 2012 and 2019) the proportion of fish migrating through either the powerhouse or dam could be estimated (MQ2);
3) Hourly and daily catch were used to recommend operational refinements to improve fish protection efficiency (MQ3).

Results synthesizing the dataset are available in Lingard et al. (2020). In short, both H_{1a} and H_{1b} were supported in some years, but H_{1c} was never supported. Nightly shutdowns were adequately timed to divert the 80% target (H_{1A}) through the dam between 20:00 and 02:00 April 20 to May 20 in 7 of 11 years (excluding two years that the powerhouse was not operated). In high abundance years, increasing the duration of the shutdown both seasonally and nightly would be required to meet the target. The proportion of fish captured between April 20 and May 20 met the 90% threshold in 8 of 13 years (H_{1b}) but the proportion captured between 20:00 and 02:00 varied annually and the 90% target was not met across thirteen monitoring years (H_{1c}). However, Lingard et al. (2020) highlight that these conclusions ignore potential biases associated with using raw catch data to estimate seasonal run timing and not being able to account for variable trap efficiency across discharge conditions.

Two years of data synthesis (2018 and 2019), each led by separate and independent biologists, determined the data insufficient to answer MQ2 or MQ3 (Harrower et al. 2019; Lingard et al. 2020). A major limitation of the dataset was a lack of replication in the releases of marked fish above the dam under each operational scenario. The inability to account for mortality of marked fish after release, or the amount of time from release to migration were also identified as limitations (Harrower et al. 2019, Lingard et al. 2020). Additionally, it was not possible to determine potential changes in capture efficiency with discharge given the use of non-unique marks; therefore, a single annual capture efficiency was calculated, and each day's catch was adjusted by the same amount to estimate abundance. The result was a value that simply represented raw catch data to estimate seasonal and daily run timing. Not stratifying trap efficiency estimates by time and discharge has serious implications. Trap efficiency usually decreases with increasing discharge (Bonner and Schwarz 2011; Lingard et al. 2019) and if catch data are not calibrated to reflect this, results will show less fish moving at higher discharges, not that the trap caught less of the animals present.

Management questions require an understanding of the proportion of fish moving at discrete time intervals and in response to discharge conditions, which the original experimental design did not provide. Therefore, a new study approach was recommended for the remaining two years of the project (2020 and 2021). The proposed methods included using radio telemetry to assess movements of individual tagged fish out of Seton Lake, the release of Passive Integrated Transponder (PIT) tags to evaluate how capture efficiency changes with discharge, and a Bayesian time stratified mark-recapture model to estimate Seton River smolt abundance and seasonal run timing. Following recommendations from St'at'imc Eco-Resources, BC Hydro amended the BRGMON-13 TOR; the following report details results of the 2020 field season using this modified approach.

2. Methods

2.1 Study Site

The Seton River is located at the outflow of Seton Lake and runs east 4 km into the Fraser River at the town of Lillooet, BC. Seton Dam is located approximately 0.5 km downstream of Seton Lake and diverts Seton Lake outflow into a 4 km long power canal while also regulating flows into the Seton River (Figure 1.1). The power canal flows to the Seton Generating Station or powerhouse, which then discharges the diverted water into the Fraser River.

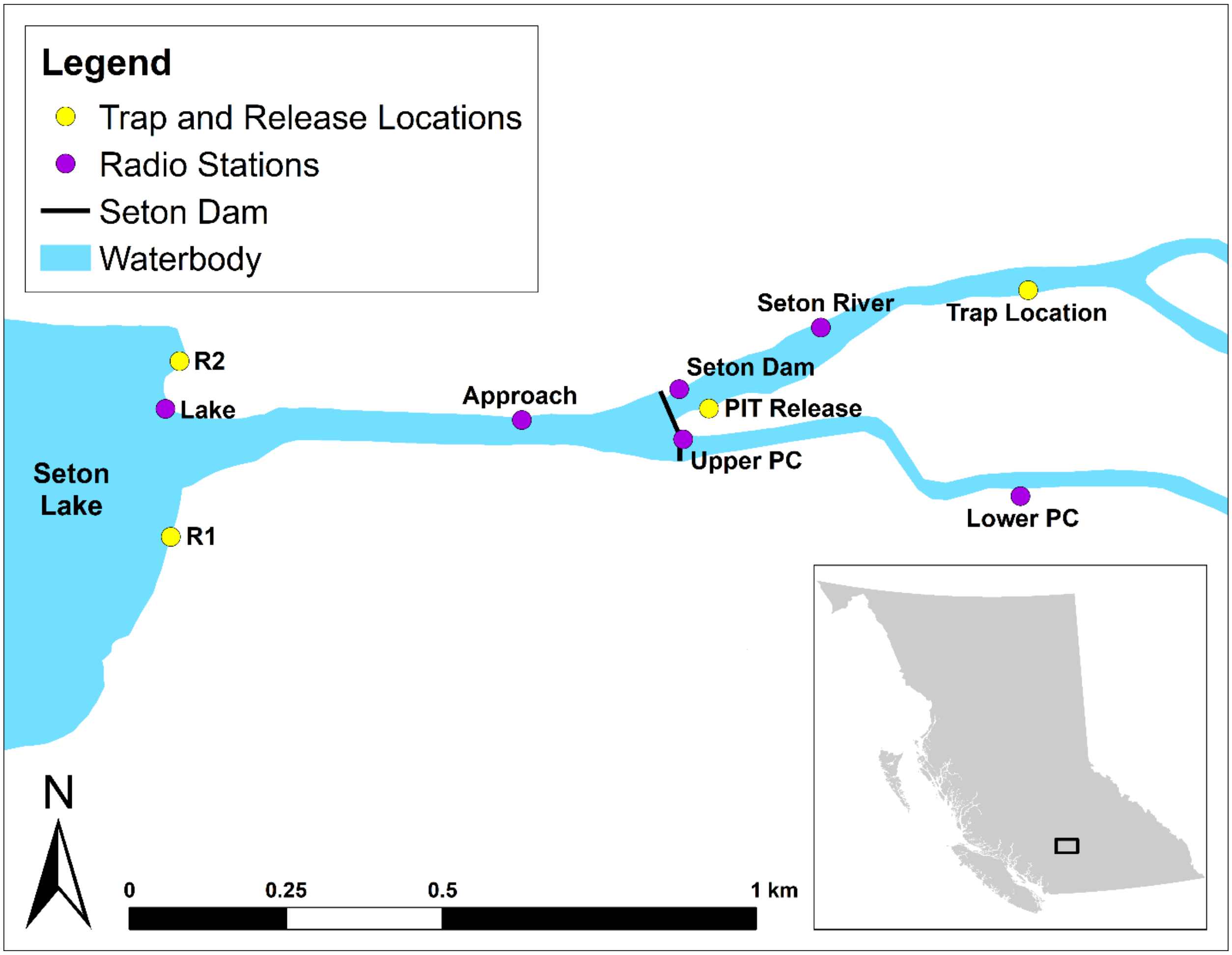

Figure 2.1. Map of BRGMON-13 study area with names of Radio stations specified. PIT-tagged fish were released at "PIT Release" and radio tagged fish at 'R1' and 'R2'.

2.2 Discharge and Powerhouse Operations

Records of hourly Seton Dam and powerhouse discharge between March 16 and June 15, 2020 were obtained from BC Hydro. Seton Dam discharge was calculated as the sum of discharge from the fish ladder, FWRG, radial gate and all five siphons. Daily average dam discharge was calculated. The total percent of hours that the powerhouse was operational during the seasonal shutdown period from April 20 and May 20 was calculated.

2.3 Smolt Capture and Tagging

Either an Incline Plane Trap (IPT) or eight-foot diameter Rotary Screw Trap (RST) was installed in the Seton River approximately 500 m downstream of the Seton Dam (Figure 2.1). Although previously an RST was used exclusively, an IPT was installed on April 15 because there was uncertainty if the RST would spin at the low flows. The IPT was replaced by an RST on April 29 because the IPT was not catching fish. The RST was successfully operated until June 3. Traps were checked and cleaned every 1 to 3 hours; crews of three fisheries technicians worked in two 10-hour shifts: 10:00 to 20:00 and 20:00 to 06:00. Captured fish were identified to species, measured, counted, and released downstream of the trap unless they were retained for tagging. A sub-sample of Sockeye Salmon smolts were also measured for fork length and weight.

A sub-sample of the daily catch of Sockeye Salmon smolts were implanted with 12 mm half-duplex PIT tags (0.1 g in air and 2.12 mm diameter; Oregon RFID) and released upstream of the RST below the dam. Recaptures were used to estimate trap efficiency and abundance of fish migrating via Seton Dam through mark-recapture modeling. PIT tagging occurred in the morning between 08:00 and 12:00. Fish were brought to shore for PIT tagging in batches of 10 to 15. All fish were anesthetized with 0.5 mL of a 1:10 clove oil- ethanol solution diluted in 4 L of river water creating approximately 20 mg/L of eugenol, the active compound in clove oil. The anesthetic bath was continuously aerated and refreshed after every batch of fish, ensuring water temperatures remained within 2°C of the Seton River. PIT tags were inserted into the coelom using a 12-gauge needle 2-3 mm off the linea alba near the tip of the pelvic fin (Leidtke et al. 2012). Following PIT tagging, fish were returned to holding boxes for recovery until transport and release, which occurred between 18:00 and 19:30 daily. Transport occurred following the guidelines in Leidtke et al. (2012). A 252 L insulated tank aerated with compressed oxygen gas was filled with river water immediately prior to transport. Oxygen levels were maintained at between 12.0 and 13.5 mg/L to match river conditions. The release location was approximately 400 m upstream of the trap and immediately below Seton Dam (Figure 2). Release groups ranged from 40 to 150 fish.

A sub-sample of the daily catch of fish were also surgically implanted with radio tags that actively transmit a unique identifier picked up by deployed receivers, allowing for passive collection of movement data. Radio tagging occurred opportunistically as staff, catch size, and fish condition permitted throughout the season. The tags (NFT-2; 0.3 g in air and 9.6 x 3 x 5 mm LOTEK Wireless) transmitted every 3.5 seconds and had an estimated tag life of 33 days. A strict protocol was followed for the surgical implantation of radio tags to minimize stress and mortality. A minimum fish weight of 5.0 grams was required to achieve a maximum tag burden of 6% (Collins et al. 2013). An anesthetic bath was prepared with 1.0 mL of 1:10 clove oil-ethanol solution diluted in 4 L of river water (approximately 40 mg/L eugenol). Fish were brought to the tagging station in groups of three and held in an aerated covered bucket. Fish were anesthetized individually. Upon reaching stage III anesthesia (Summerfelt and Smith 1990), fish were placed supine on a v-shaped cradle padded with rubber and their gills continuously irrigated with river water. Maintenance anesthesia was not provided during surgery. A 1-cm incision was made 2 mm off the linea alba posterior to the tip of the pectoral fin and anterior to the insertion of the pelvic fin. A second smaller puncture incision was made with the tip of the scalpel approximately 2 mm posterior to the pelvic fin insertion. A hollow feeding tube with a rounded tip was inserted from the posterior incision and guided to the larger incision to facilitate feeding of the tag antenna through the body cavity. A single uninterrupted surgical knot of 5-0 Monocryl closed the anterior incision. The puncture incision did not require a suture.

Following surgery fish were recovered from anesthesia in aerated buckets and then in holding boxes for up to 48 hours. The original protocol was to hold tagged fish for a 24-hour recovery period; however, the time between capture and release was increased as the season progressed in response to increasing signs of physiological stress and mortality. Holding fish following tag implantation to allow recovery from acute handling stress can improve post tagging survival in both juvenile and adult salmon (Liedtke et al. 2012). On several occasions > 50% of a release group did not survive. In this case, remaining fish were held an additional 24 hours and released with the following day's radio tagged fish to create a larger release group. All radio tagged smolts were transported as detailed for PIT tagged fish to either R1 on the eastern shore of Seton Lake adjacent to the approach channel or R2, a small bay along the western shore of Seton Lake adjacent to the approach channel (Figure 2.1). Both release locations had large boulders to serve as cover for recently released fish while they acclimatized to the lake. Fish were released at the two sites on alternating days.

2.4 Abundance and Run Timing

A modified Petersen mark-recapture model was used to generate abundance estimates for Sockeye Salmon smolts in the Seton River using the daily catch data and recaptures of PIT-tagged fish. In traditional Petersen methods, data pooling between sampling events (strata) is often required. Pooling strata assumes homogeneity in capture probabilities, which is often violated due to varying river discharge and capture effort. Given heterogenous capture probabilities, pooled Petersen estimators can substantially underestimate uncertainty in abundance estimates. Therefore, to account for heterogeneity in capture probability a Bayesian Time-Stratified Spline Model (BTSPAS) was used. The BTSPAS model, a modified Petersen method, estimates weekly abundance using splines to model the general shape of the run and allows for sharing information on catchability among strata when data are sparse (Bonner and Schwarz 2011).

To align as closely as possible with the shutdown time and evaluate the proportion of population migrating during the seasonal window of nightly shutdowns, data were pooled into ten, five-day strata ending on the following dates: April 19, April 24, April 29, May 4, May 9, May 14, May 19, May 24, May 29, June 3.

2.5 Radio Telemetry

2.5.1 Receiver Network and Testing

Seven radio receivers were installed to detect movement of radio-tagged fish from release in Seton Lake, through either Seton Dam or the powerhouse and into the Fraser River (Figure 2.1, Table 2.1). Two types of radio receivers were deployed; SRX 400 receivers (LOTEK Wireless) were used at the Lower Power Canal (PC) and Seton River locations, while all other locations had Orion receivers (Sigma Eight). Orion receivers can scan all frequencies simultaneously whereas SRX400 receivers switched between frequencies every seven seconds, approximately double the tag burst rate. Tags were distributed across three frequencies. Each receiver had a single Yagi antenna oriented perpendicular to the waterway.

Receivers were activated on April 30, 2020 and operated until June 18, 2020. Our abilities to range test the receivers were limited due to tight timelines between equipment procurement and study initiation, lack of access, and a lack of personnel given COVID-19 restrictions. The Seton Dam, Seton River and Upper PC stations underwent range testing upon deployment. The objective of range testing at these stations was to ensure that there was no overlap in detection area among stations (i.e., between the Seton River and Seton Dam and between Seton Dam and the Upper PC) and that the Seton Dam or Upper PC stations did not detect tags above the dam. Without a watercraft available for range testing, results were based on data that could be obtained from a test tag deployed from various points along the shore. We recognize that the limitations of range testing limit confidence in the resulting data. If telemetry is pursued in the future, we recommend a dedicated effort to range testing all receivers, and ideally at various flow scenarios.

Table 2.1. Name, location, and purpose of radio receivers deployed under BRGMON-13.

Receiver	Location	Purpose
Seton Lake	Seton Lake at entrance to the approach channel	Detect fish in Seton Lake once they have left release locations.
Approach Channel	In the approach channel approximately 500 m downstream of Seton Lake	Detect fish as they move through the approach channel and enter forebay.
Seton Dam	Immediately downstream of Seton Dam on the left bank of Seton River	Detect fish as they pass Seton Dam.
Seton River	Approximately 200 m downstream of Seton Dam	Detect fish that have passed Seton Dam as the move down Seton River.
Upper PC	At the upstream entrance to the power canal.	Detect fish that are in the power canal, approaching the powerhouse.
Lower PC	In power canal, approximately 300 m downstream of Upper PC receiver	Detect fish that are in the power canal, approaching the powerhouse. Confirm direction of movement in power canal.
Fraser River	Approximately 1.2 km downstream of powerhouse outflow in the Fraser River.	Detect fish upon entry to Fraser River. Installed for a concurrent Fraser River research program.

2.5.2 Holding Studies

Two holding studies were conducted to investigate tagging-induced mortality. Sockeye Salmon smolts were implanted with deactivated radio tags according to the previously described methods. In the first study, 10 tagged fish were held for seven days and in the second, 15 tagged and 15 untagged control fish were held together for seven days. Holding boxes (122 liters) were dark, covered, and submerged in the river with adequate perforations to allow gas exchange. Three holding boxes were available and no more than 20 fish were held in each box. Holding boxes were checked once daily to assess mortality.

2.5.3 Detection Histories

The Seton Dam is a noisy environment. This creates interference with radio telemetry stations and can affect data quality. Raw data had many false detections and erroneous codes and needed extensive filtering to produce logical detection histories. After removing detections that are known to be false (e.g., tag codes not released), additional filtering was required to remove false positives that created illogical detection histories. For example, it was common for detections to occur on many receivers simultaneously. Different filtering thresholds were applied to Sigma Eight receivers, which can scan several frequencies simultaneous, than Lotek receivers, which cannot. Filtering mostly relied on the duration between detections of a given code at a given station (i.e., lag). False positives were common on the Fraser River receiver, which required an additional filter than all other stations. All receivers, except the Lower PC, also had a high incidence of interference and detections had to be further filtered based on the power of detection (a tag in closer proximity will be detected with a great power and is more likely a true positive). While filtering was required to produce a useable dataset, each filter applied also increased the probability of removing true positives. We caution that the filtering conducted exceeded what would normally be required of a radio telemetry dataset, which inherently limits our confidence in the resulting conclusions. Filtering followed the steps outlined in Appendix A.

A detection history was built for each fish to determine passage route, and a criterion of rules were established to classify migration route as one of seven possibilities: Confirmed Seton River, Suspected Seton River, Confirmed Entrained, Confirmed Power Canal, Suspected Power Canal, Mortality, and Undetermined (Figure 2.2). These classifications can be used to determine a range of proportions migrating via each route. Fish last detected on the Seton Dam or Seton River receivers were assumed to have migrated through the dam. Fish last detected on the Upper PC or Lower PC receivers were classified as migrating via the power canal, but fish can only be classified as entrained through the powerhouse if they were subsequently detected on the Fraser River receivers. Fish that were only detected in Seton Lake and the Approach Channel were assumed to have remained above the dam and were classified as mortalities; these fish did not contribute to the assessments of routing proportions and entrainment.

Data were too sparse to calculate specific detection efficiencies for each receiver. However, efficiency seems to have been low, particularly for receivers in the Seton River and lower power canal. Some fish missed by the Seton River and Lower PC receivers were later detected on the Fraser River receiver. Additionally, the Seton Dam receiver was intended to only detect fish immediately below the dam and the Upper PC receiver only fish within the power canal. However, fish were commonly detected on both the Seton Dam and Upper PC receivers in the unfiltered dataset. Filtering generally removed these “illogical” detection histories, but their presence suggests the array did not function as intended.

2.5.4 Timing of Movements

Methods typically used for analyzing telemetry data (e.g., Generalized Linear Models, Time-To-Event analysis; Nygnist et al. 2017) were not appropriate for this dataset given small sample sizes and poor data quality. For fish that passage route could be classified, the first detection at either the Seton Dam or Upper PC was selected as the estimated time of migrated through either structure. Any fish missed by either the Seton Dam or Upper PC receivers were excluded. These data can be compared to raw capture data to better understand the timing of movements both nightly and seasonally. Detection histories were also compared to dam and powerhouse discharge data to determine conditions at the time of passage and address management questions regarding how releases from Seton Dam may affect routing proportions. The ratio of dam to powerhouse discharge was calculated for each fish at the time of passage.

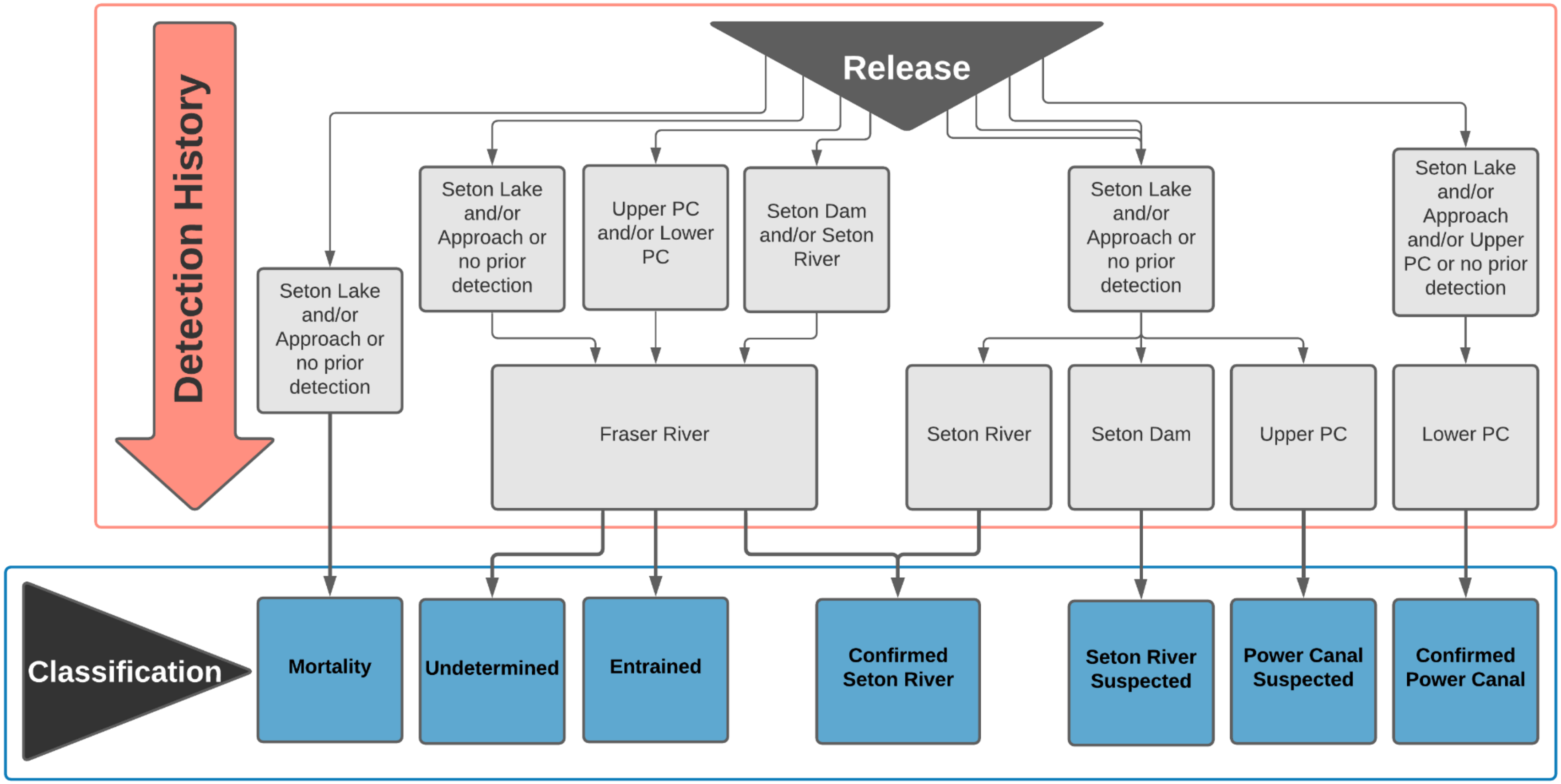

Figure 2.2 Overview of the criterion of rules used to classify migration route of tagged Sockeye Salmon smolts based on detection histories.

2.6 Entrainment and Mortality

Detection data were used to observe entrainment events. The known entrainment rate is the percentage of fish classified as migrating via the powerhouse, as confirmed by detection on the Fraser River receiver following detection in the power canal (Entrained). Fish last detected on the Lower PC receiver (Confirmed Power Canal) can also reasonably be assumed to have been entrained. Including fish last detected on the Upper PC receiver (Power Canal Suspected) provides a maximum estimate of entrainment. Throughout this monitoring program, annual mortality has been estimated by multiplying the percentage of fish migrating through the powerhouse and dam by the mortality rates presented in Andrew and Green (1958): 17% for the powerhouse and 2% for the dam. Summing the two values provided an estimate of total mortality, which was compared to total mortality calculated annually since 2008. The authors of this report do not support this approach as a meaningful way to calculate mortality given the many assumptions and uncertainties. Contrary to previous years, where only one mortality estimate was produced based on a single value of routing proportions, we used the range of route classifications (Figure 2.2) to produce a range of mortality estimates that better represent data quality and certainty in results. Four mortality estimates were produced based on routing proportion classifications: Minimum, Suspected, Probable, and Confirmed. Minimum mortality assumes the Seton River to be the preferred route; only those fish confirmed to have been entrained (Entrained) and those confirmed to have selected the power canal route (Confirmed Power Canal) were assumed to have migrated through the powerhouse (all others migrated via the dam into the Seton River). Suspected mortality follows the routing proportion classifications as detailed above and in Figure 2.2. Probable mortality follows the same routing proportion classifications as in Figure 2.2 but omits all fish with suspected routes (includes Entrained, Confirmed Power Canal, and Confirmed Seton River). Confirmed mortality uses only those fish for which final passage route could be confirmed (i.e., Entrained and Confirmed Seton River fish that were last detected in the Fraser or Seton Rivers). Sample sizes for routing proportions are provided in Results Table 3.7.

2.7 Injury Assessments

As the field season progressed, mortality during holding (both pre- and post-tagging) increased and fish condition decreased. In response to this unexpected observation, assessments of visually detectable injuries began on May 15 and were conducted until the last day of trapping as catches permitted for a total of 15 days. Injuries recorded included: eye trauma, scale loss, bleeding, body scarring, and damage to opercula and fins. Fish were selected for injury assessments randomly, and prior to any tagging. Samples of 41 to 51 fish were anesthetized and visually assessed for injuries daily. Injury classification followed methods adapted from Cook et al. (2018) (Table 2.2). Following assessment, fish were recovered in buckets until swimming freely and released downstream of the trap.

This semi-quantitative and systematic method of injury assessment allowed for detection of changes to fish condition over time. However, because injury monitoring did not begin until May 15, no formal analyses were conducted. Except for scale loss, injury observations were reported as either as present or absent; for example, although ‘Fin Damage’ has six categories of severity (Table 2.2), data were reported as if fins were damaged or not. Full data resolution could be used for comparative analyses if injury monitoring continues.

Table 2.2. Injury assessment criteria for Sockeye Salmon smolts (adapted from Cook et al. 2018).

Injury	Measure	Description
Alive	0, 1	If the fish was responsive (1) or not (0)
Scale Loss	%	Percentage of body missing scales; in increments of 10.
Torn Operculum	0, 1	0 = operculum intact, 1 = part of operculum missing
Red Eye	0–3	Hemorrhages observed in the eyes; 0 = none; 1 = small red spot in eye. 2 = half the eye is red. 3 = one eye is completely red, 4 = both eyes are partially red, 5 = both eyes are completely red
Pop Eye	0–2	Distension of eyes; 0 = no distention, 1 = one eye distended, 2 = both eyes distended
Vent Bleed	0, 1	Turn fish over apply gentle pressure to stomach to determine if red fluids are draining from the vent: 0 = no bleeding, 1 = bleeding.
Fin Damage	0–6	A count of the number of fins not including adipose that are damaged in any way
Fin Severity	0–2	Categorize most damaged fin; 0 = no damage; 1 = minor nicks and splits, 2 = parts of fin missing

3. Results

All mean values are presented with standard deviation (SD).

3.1 Discharge and Powerhouse Operations

In 2020, the powerhouse was shut down for 30-hour periods from April 20 to May 20. While operational, the powerhouse discharge was approximately 120 m^3/s (Figure 3.1). Percent operation time over the seasonal shutdown period was 36%, which approximates the average operational time among all monitoring years (Table 3.1). In previous years, the powerhouse was typically shut down from 20:00 to 02:00 daily (operated between 02:00 and 20:00) from April 20 to May 20 or was shut down completely during the entirely of the seasonal period (Table 3.1, Appendix B).

Discharge from Seton Dam during the Sockeye Salmon smolt migration window generally followed the WUP target hydrograph (described in BC Hydro 2011a) and did not exceed the target maximum of 60 m^3/s (Figure 3.2). During the shutdown period from April 20 to May 19, total dam discharge varied from 28 to 33 m^3/s. After the shutdown period from May 20 to June 15, total dam discharge was 35 to 47 m^3/s. Most of the water was released through Siphon 4 during the study period beginning April 20 with a small proportion released from the fish ladder (approximately 10% with stable discharge of 1 m^3/s) and the FWRG (10-35%; Figure 3.2). Discharge through the FWRG ranged from 1 to 13 m^3/s over three distinct periods. Initially from March 15 to April 15, FWRG discharge was held at approximately 13 m^3/s. On April 15 through to May 27, discharge was dropped to 1 m^3/s followed by gradual increases back to 13 m^3/s while total dam discharge was also being increased. On May 27 and for the remainder of the study period, FWRG discharge was dropped and held at 1 m^3/s. Discharge through all other dam structures were negligible until May 27 when overall discharge from Seton Dam was increased with the additional water released through Siphon 1 (Figure 3.2).

Table 3.1 Percent operation time of the Seton Generating Station or powerhouse during the seasonal shutdown window from April 20 to May 20 each year. Previous years' data from Lingard et al. (2020). There was no monitoring in 2016.

Annual Operation Time (%)	
2006	45
2007	52
2008	82
2009	34
2010	21
2011	57
2012	3
2013	47
2014	0
2015	55
2016	NA
2017	0
2018	44
2019	6
2020	36
Average	34.4

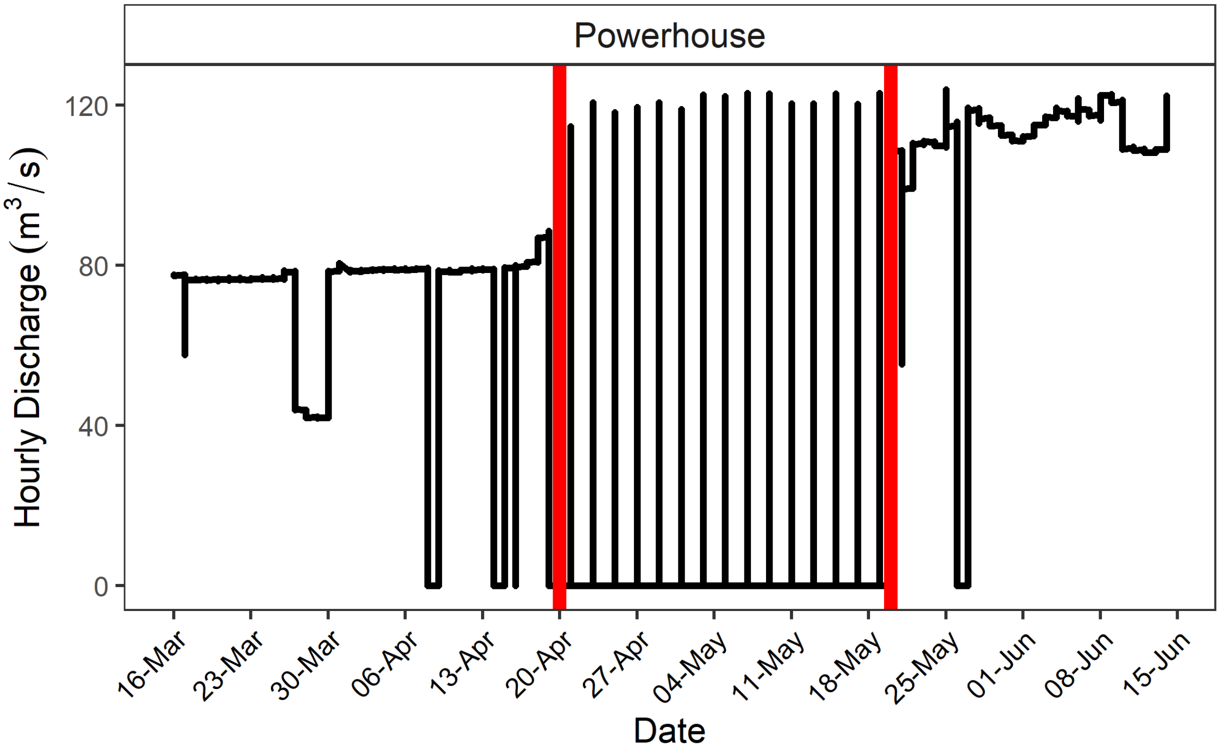

Figure 3.1 Hourly discharge through Seton Generating Station or powerhouse from March 15 to June 15, 2020. The red lines denote the start and end of the seasonal shutdown period (April 20 to May 20), during which the powerhouse was shut down for 30-hour periods.

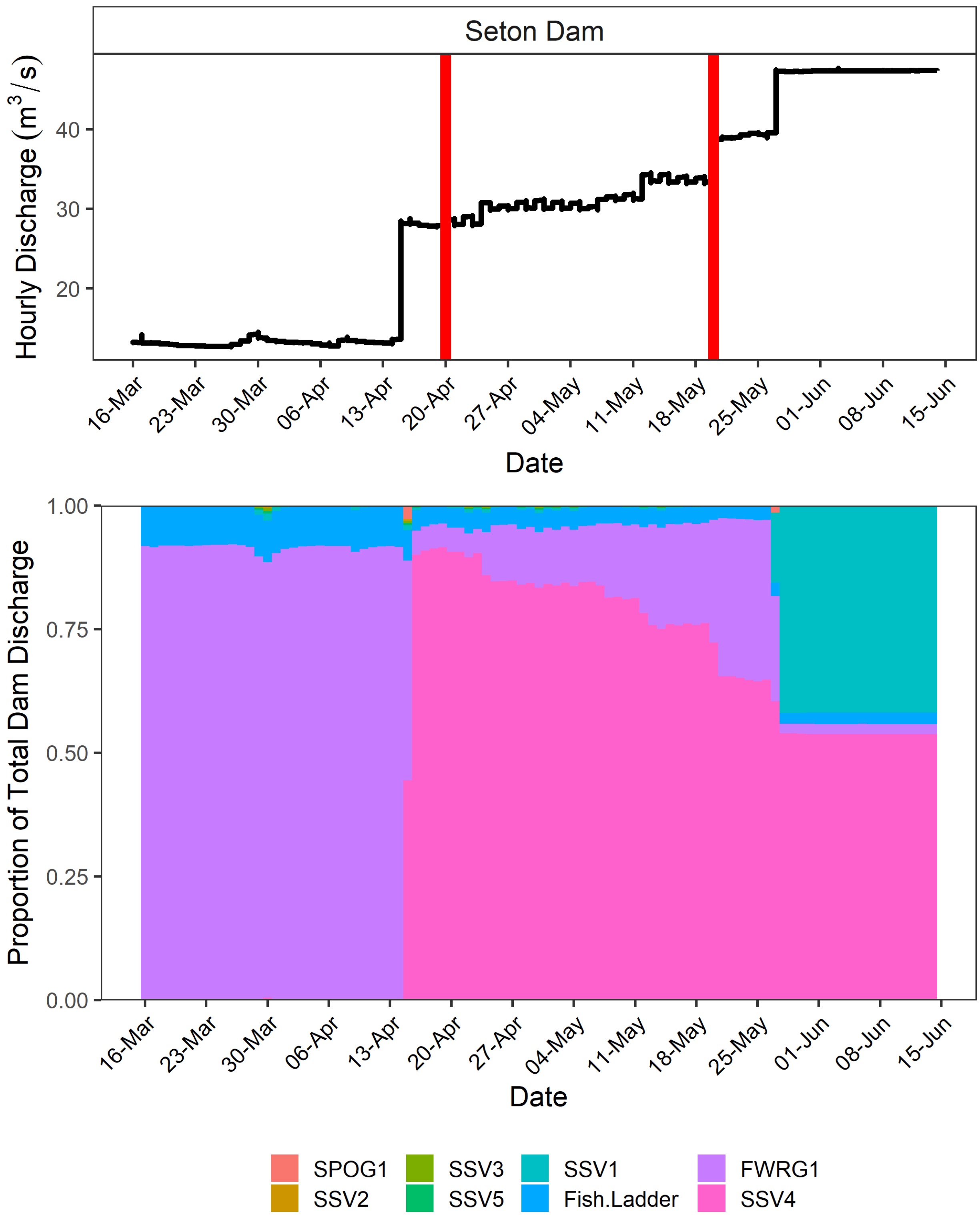

Figure 3.2 Hourly discharge through the Seton Dam with the seasonal shut down period (April 20 to May 20) denoted in red lines (top panel), and the proportion of total dam discharge released from each conveyance structure (bottom panel) during the spring of 2020. SSV1 through SSV5 are siphons, SPOG1 is the spill way operating gate, and FWRG1 is the fish water release gate.

3.2 Smolt Capture

The IPT and RST operated for a combined 49 days in 2020. Average fork length of smolts captured in 2020 was 88 mm (SD 0.34, n = 1112), which was the second smallest cohort since size recorded during the monitoring program (Figure 3.3).

The total Sockeye Salmon smolt catch between April 15 and June 3, 2020 was 33,657. Raw catch data is best used to describe hourly trends in fish movement. Between 20:00 and 02:00 from April 20 to May 20, 43% of the total catch was obtained, which was less than in most previous years (Table 3.2). Hourly catch as a proportion of the total catch indicates that 62% of smolts migrated between shutdown hours 20:00 to 02:00. Overall, most fish (78%) migrated between the hours of 21:00 and 05:00 (Figure 3.4).

Table 3.2 Percent of the total Sockeye Salmon smolt catch obtained between 20:00 and 02:00, April 20 and May 20 during each monitoring year. Data prior to 2020 from Lingard et al. (2020). There was no monitoring in 2016.

% Catch Obtained Annually During Shutdown Period	
2008	45
2009	68
2010	70
2011	77
2012	36
2013	71
2014	70
2015	71
2016	NA
2017	83
2018	69
2019	80
2020	43

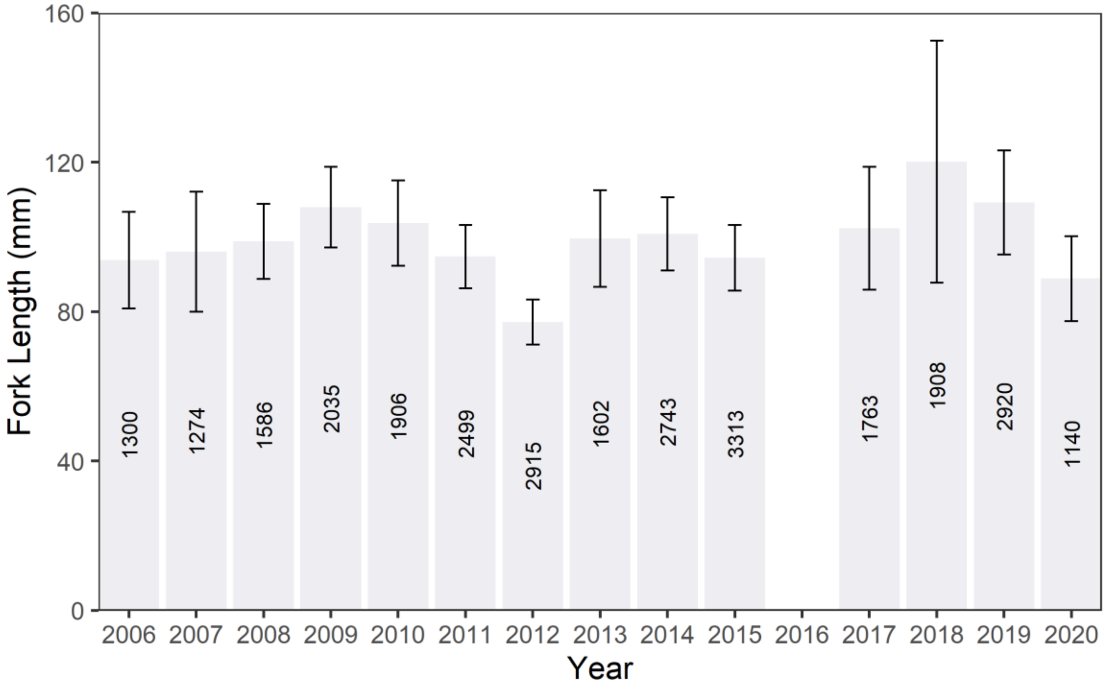

Figure 3.3 Mean fork length and standard deviation of Sockeye Salmon smolts captured annually in the Seton River. Sample size displayed in the middle of each bar. There was no monitoring in 2016.

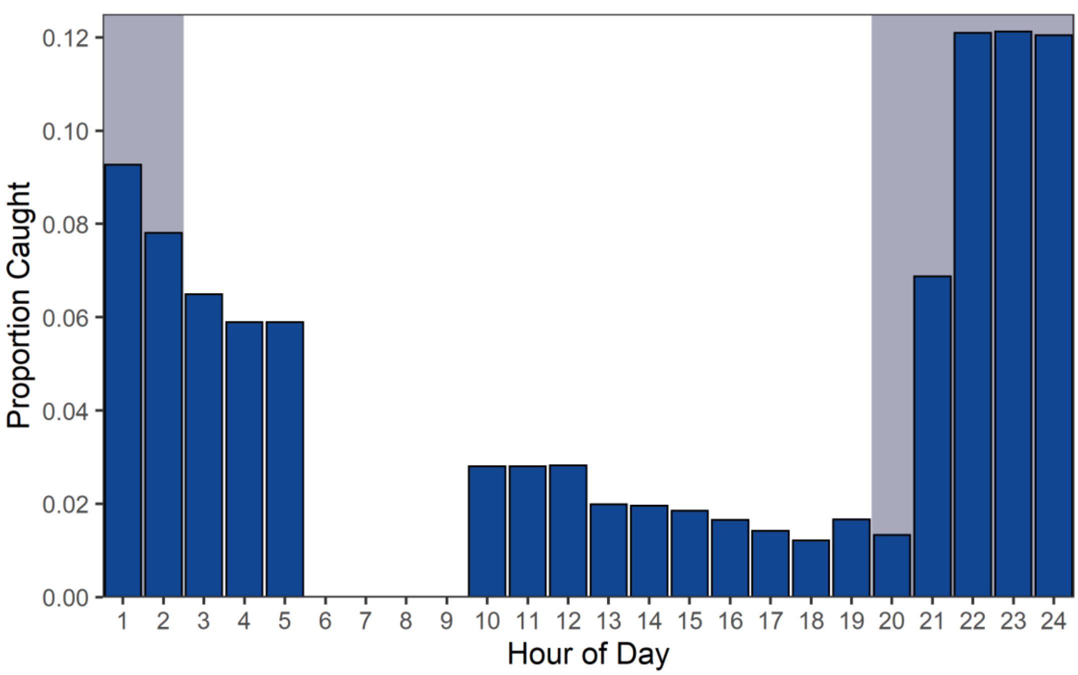

Figure 3.4 Hourly catch as a proportion of the total annual Sockeye Salmon smolt catch in 2020. The trap was not fished 06:00 to 10:00 daily. The timing of the nightly shutdown period is shaded.

3.3 Abundance and Run Timing

Recaptures of PIT-tagged smolts permitted estimation of abundance across date strata. From the 3,388 PIT-tagged smolts released, 126 were recaptured (recapture rate of 3.7%). The recapture rate varied from 1% to 9% among strata. There appeared to be no trends between recapture rate and discharge, but no statistical analyses were conducted (Table 3.3)

The BTSPAS model estimated that 996,442 (SD 115,934) Sockeye Salmon smolts migrated through Seton Dam and down the Seton River in 2020. Being more robust than raw catch data, BTSPAS estimates across strata are best used to describe seasonal changes in run timing through the Seton River. Of the total population, 387,664 Sockeye Salmon smolts migrated between April 20 and May 19 and 608,777 smolt migrated after May 20 (Figure 3.5). Therefore, 39% of smolts migrated during the seasonal shutdown window. Less than 0.01% of fish migrated prior to April 20. Across strata, the peak of abundance occurred on May 25, after the shutdown period (Figure 3.5).

Table 3.3 Summary of data used to estimate Sockeye Salmon smolt abundance by the Bayesian Time-Stratified Spline Model (BTSPAS) model, and the mean hourly dam discharge within each date strata.

Date Strata Ended	Marked Fish (n)	Recaptured Fish (n)	Unmarked Fish (n)	Recapture Rate (%)	Mean Hourly Discharge (m^3/s)
April 19	0	0	2	NA	26.7
April 24	28	2	51	7.1	28.5
April 29	198	1	311	0.5	30.2
May 4	639	12	3571	1.9	30.4
May 9	372	19	1111	5.1	30.7
May 14	545	32	9789	5.9	32.6
May 19	567	14	3522	2.5	33.5
May 24	400	13	9773	3.3	38.4
May 29	404	12	5000	3.0	43.2
June 3	235	21	527	8.9	47.4

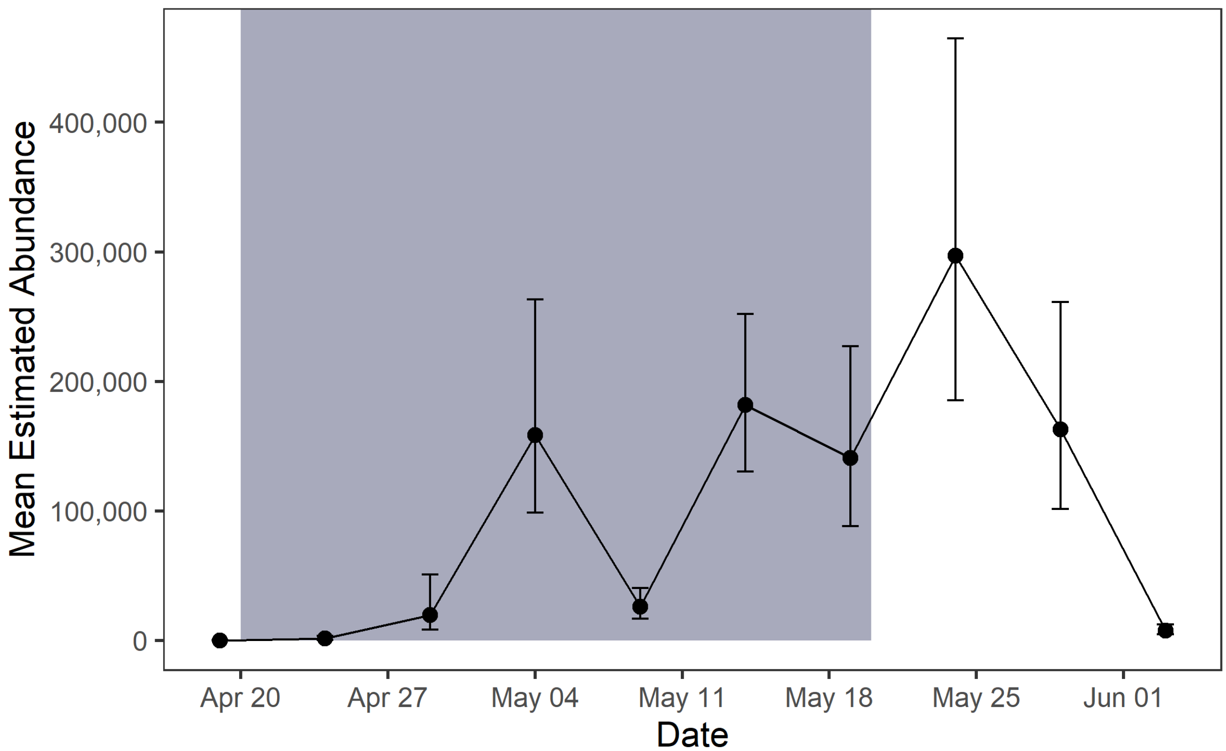

Figure 3.5 Run timing of Sockeye Salmon smolts through the Seton Dam in 2020, as indicated by the mean estimated smolt abundance by 5-day strata as produced by the Bayesian Time-Stratified Spline Model (BTSPAS) model. Error bars denote 97.5% confidence intervals. Shading indicates the seasonal shutdown window from April 20 to May 20, during which the Seton Generating Station or powerhouse is shut down for intermittent periods.

3.4 Radio Telemetry

Of the 201 radio tags applied, 117 were released [n = 93 before May 15 (within shutdown period) and n = 24 after May 23 (outside of shutdown period)]; the remaining tagged fish did not survive (n = 71) or lost tags (n = 13) prior to release (Table 3.4). Surgeries occurred according to protocol. Anesthesia and surgery times were typically 2-3 minutes and 1.5-3 minutes, respectively. Tag burden ranged from 1.4% to 8.1%. Most fish had tag burdens below our 6% threshold, but 12% (n = 25) were above. Mortalities had marginally higher tag burdens (4.7 ± 1.1%) than surviving fish (4.5 ± 1.3%), but the difference was not statistically significant (t-test; $t = 0.9_{df = 157.2}$, $p = 0.4$). Pre-release mortality was variable among release groups (0-73%; Table 3.4).

Table 3.4 Details of radio-tagging surgeries by release group of Seton River Sockeye Salmon smolts. Means are presented for each release group with standard deviation, inclusive of mortalities.

Tagging Date	Release Date	n Tagged	n Released	Pre-release Mortality (%)	% Tag Burden	Fork Length (mm)	Water Temp. (°C)
Apr-30	May-01	21	20	5	4.8 ± 1.1	97 ± 6	6.7
May-05	May-06	20	16	20	6.6 ± 1.1	86 ± 4	7.0
May-07	May-08	26	17	31	4.1 ± 0.6	100 ± 5	7.1
May-08	May-09	16	16	0	5 ± 5	95 ± 6	7.0
May-09	May-11	15	4	73	4.9 ± 0.9	93 ± 5	5.3
May-10	May-11	33	15	55	4.2 ± 0.9	98 ± 8	5.2
May-13	May-14	16	5	69		93 ± 6	6.1
May-22	May-24	5	4	20	3.9 ± 1.4	103 ± 19	9.7
May-23	May-24	11	10	9	3.8 ± 0.5	100 ± 7	10.3
May-24	May-26	13	2*	33	3.8 ± 0.9	102 ± 8	10.4
May-25	May-26	15	3*	50	4.4 ± 0.9	97 ± 7	10.0
May-26	May-27	10	5	50	3.6 ± 0.6	105 ± 9	10.0

* During the May 26 release, tags from 13 fish became entangled around an aeration hose and tags were removed (n = 6 and n = 7 from tagging on May 24 and 25, respectively). The loss of these tags was an anomaly and fish are excluded from mortality calculations.

3.4.1 Holding Studies

Two seven day holding studies were completed to evaluate survival and tag retention. In the first, one tagged fish died within 24 hours and another on Day 7. In the second study three weeks later, six tagged fish died within 24 hours and three during the next 24 hours; one untagged fish died. Fish characteristics were similar between fish tagged for holding studies and fish tagged for release (Table 3.5). Surgeries followed the same protocols, with similar induction and tagging times (data not shown).

Table 3.5 Results of two seven-day holding studies to assess tagging-induced mortality in Seton River Sockeye Salmon smolts. Means are shown ± standard deviation for the cohort. Untagged controls were randomly selected and not measured.

Start Date	Group	Total	Mortalities	Mortality (%)	Tag Burden (%)	Fork Length (mm)	Water Temp. (°C)
Apr-27	Tagged	10	2	20	4.2 ± 0.7	101 ± 6	5.1
May-13	Tagged	15	9	60	4.4 ± 0.6	97 ± 4	6.1
May-13	Untagged Controls	15	1	7	NA	NA	6.1

3.4.2 Routing Proportions

Of the 117 fish released, 67 were detected, from which migration route classifications were made for 38 (Figure 3.6). We could confirm entrainment for four fish (Entrained), another four fish went as far as the lower power canal (Confirmed Power Canal, entrainment probable), and one fish migrated via the Seton River (Confirmed Seton River). All other detection histories resulted in "suspected" route classifications (Suspected Seton River n = 9; Suspected Power Canal n = 20). Migration route was unclear for four fish (Undetermined). Detected fish that remained above the dam (n = 25) in addition to those not detected (n = 50) were assumed to be mortalities (Figure 3.6). Post-release mortality ranged from 40 to 80% among release groups and was 64% overall (Table 3.6); this is in addition to the 71 tagged smolts that did not survive to release for a total mortality of 146 fish (Figure 3.6).

Routing proportions and entrainment rates depend on our confidence in these classifications and confidence in the detection data. We could only confirm route of passage with downstream detection data for five fish: four were entrained and one migrated via the Seton River (Figure 3.6). Using just fish with confirmed migration routes, confirmed entrainment was 80% (Table 3.7). This data has the most certainty but defining routing proportions with such a limited sample size is misleading. In an additive manner, assuming fish detected as far downstream as the lower power canal (Confirmed Power Canal) were entrained but missed by the Fraser River receiver results in a probable entrainment rate of 89% (Table 3.7). Considering data from all 38 fish, including all suspected classifications and assuming fish suspected of migrating via the power canal were entrained, gives a suspected entrainment rate of 74% (Table 3.7). However, fish that were classified as Suspected Power Canal were last detected on the Upper PC receiver, and so it could be equally assumed that these fish only temporarily moved into the power canal entrance but ultimately migrated via the Seton Dam and into the Seton River. Following these assumptions, produces a minimum entrainment rate of 21% (Table 3.7). Therefore, entrainment could range from 21% to 89%. Routing proportions did not seem to vary among release groups, though sample sizes were small (Table 3.6).

Table 3.6 Summary of total assumed mortality by release group of Sockeye Salmon smolts released with radio tags in the Seton River above Seton Dam. Assumed mortality includes both fish that remained above the dam and those that were not detected. Passage route totals for the power canal (PC) and Seton River via the dam (Seton) including all fish suspected of migrating via each route.

Date	Released (n)	Not Detected (n)	Remained Above (n)	Assumed Mortality (%)	Passage Route (n)		
					Entrained	PC	Seton
May-01	20	4	9	65	0	5	2
May-06	16	2	7	56	0	4	1
May-08	17	8	2	59	0	3	2
May-09	16	10	2	75	1	2	0
May-11	19	12	1	68	2	3	1
May-14	5	2	0	40	0	1	1
May-24	14	5	3	57	0	5	1
May-26	5	4	0	80	1	0	0
May-27	5	3	0	60	0	1	2
TOTAL	117	50	25	64	4	24	10

Table 3.7 Routing proportions according to various scenarios that were classified based on detection data of radio-tagged Sockeye Salmon smolts. Note that fish classified as Suspected Power Canal were last detected on the Upper Power Canal receiver and could have migrated via the Seton Dam (into the Seton River) rather than completely moving through the power canal.

Scenario	Classification Criteria	Routing		n
		Seton River	Entrained	
Confirmed	Only Confirmed Seton River and Entrained fish	20%	80%	5
Probable	Added Confirmed Power Canal fish as entrained	11%	89%	9
	Added all suspected fish with:			
Suspected	Suspected Seton River as Seton River, Suspected Power Canal as entrained	26%	74%	38
Minimum	Suspected Seton River as Seton River, Suspected Power Canal as Seton River	79%	21%	38

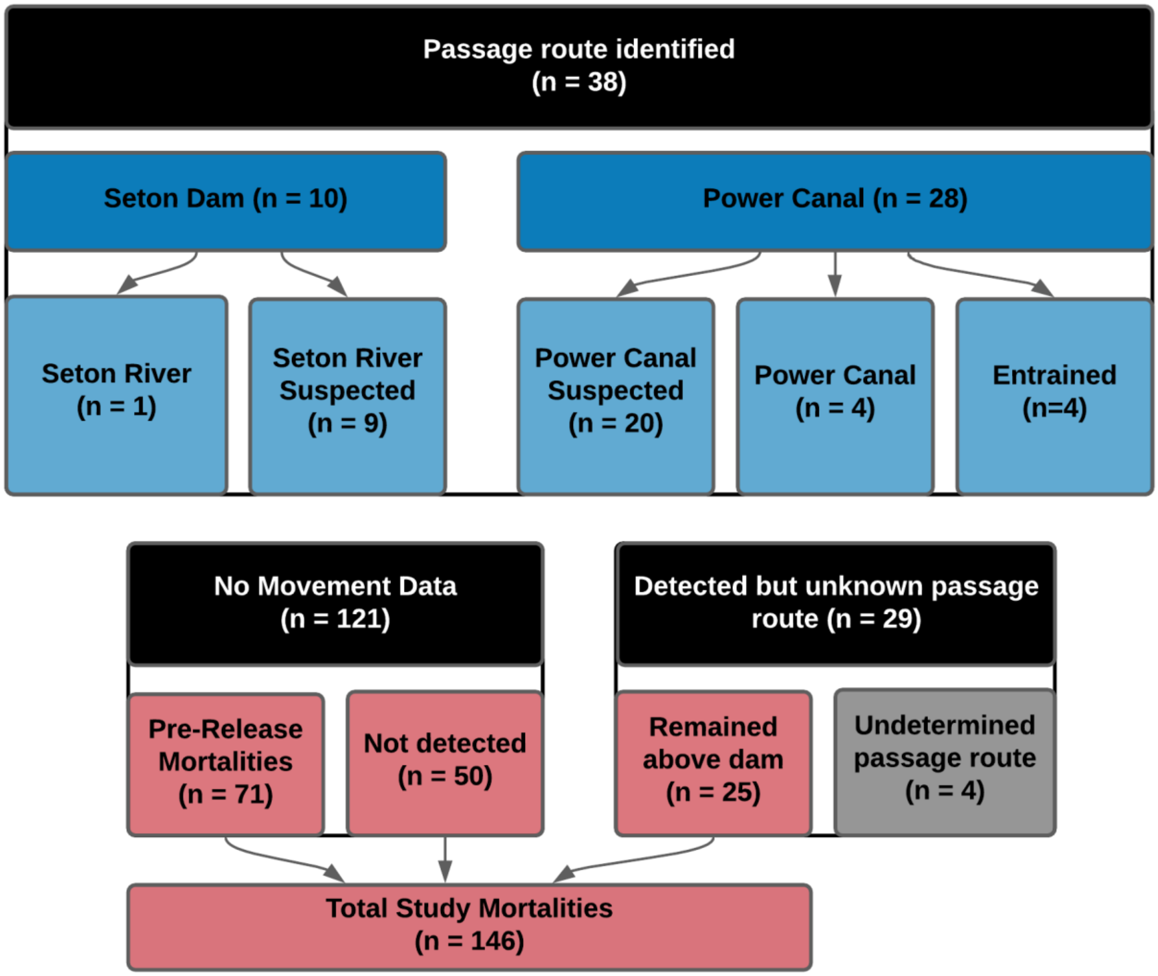

Figure 3.6 Numbers of radio-tagged Seton River Sockeye Salmon smolts migrating via each passage route based on detection histories according to rules established a priori. Post-release mortalities include fish not detected below the dam, in addition to those that were never detected.

3.4.3 Detection Histories

Time to first detection from release among the 67 detected fish varied considerably. While some fish were first detected in under five minutes on the Approach and Seton Lake receivers, others were not detected for over 20 days (on Approach and Upper PC receivers; maximum = 37 days). Variability in time to first detection did not appear driven by release date (data not shown). Once downstream movement began, most fish were only detected within the system for less than 12 hours (mean detection time = 3.5 ± 9.1 days, median = 7.2 hours). Entrained fish were detected for a mean of 2.2 hours (Table 3.8, Figure 3.7) and fish confirmed to have migrated into the Power Canal for a mean of 24.8 hours (Table 3.8, Figure 3.8). The one fish confirmed to have migrated via the Seton River was in the system for 25.9 hours (Table 3.8, Figure 3.9). The greatest variability in total time detected was among fish with "suspected" migration paths (Table 3.8), where detection histories show increased movement among stations (Appendix C). Several fish were detected for multiple weeks, including one fish was detected for nearly 40 days (See Fish 56 in Appendix C); it is possible this fish, and other detected for long periods, died or dropped their tag.

Table 3.8 Total time radio-tagged Sockeye Salmon smolts were detected within the system (inclusive of all stations). Means with standard deviation (SD) are presented along with medians, given low sample sizes (n). Where durations were extended, an estimate in days (d) is also presented. Those with undetermined passage routes are not included, nor are those with a single detection point remaining following filtering.

Route		Total Time Detected (Hours)				n
		Mean ± SD	Median	Min	Max	
Seton River	Confirmed	25.9				1
	Suspected	199.2 ± 395.5	0.4	0.02	953.5 (40 d)	9
Power Canal	Entrained	2.2 ± 1.3	1.7	1.3	4.2	4
	Confirmed	25.8 ± 2.2	24.8	24.4	29.1	4
	Suspected	138 ± 212.4	0.4	0.002	647.8 (35 d)	18
Mortality		36.8 ± 173.7	0.2	0.001	852.3 (27 d)	24

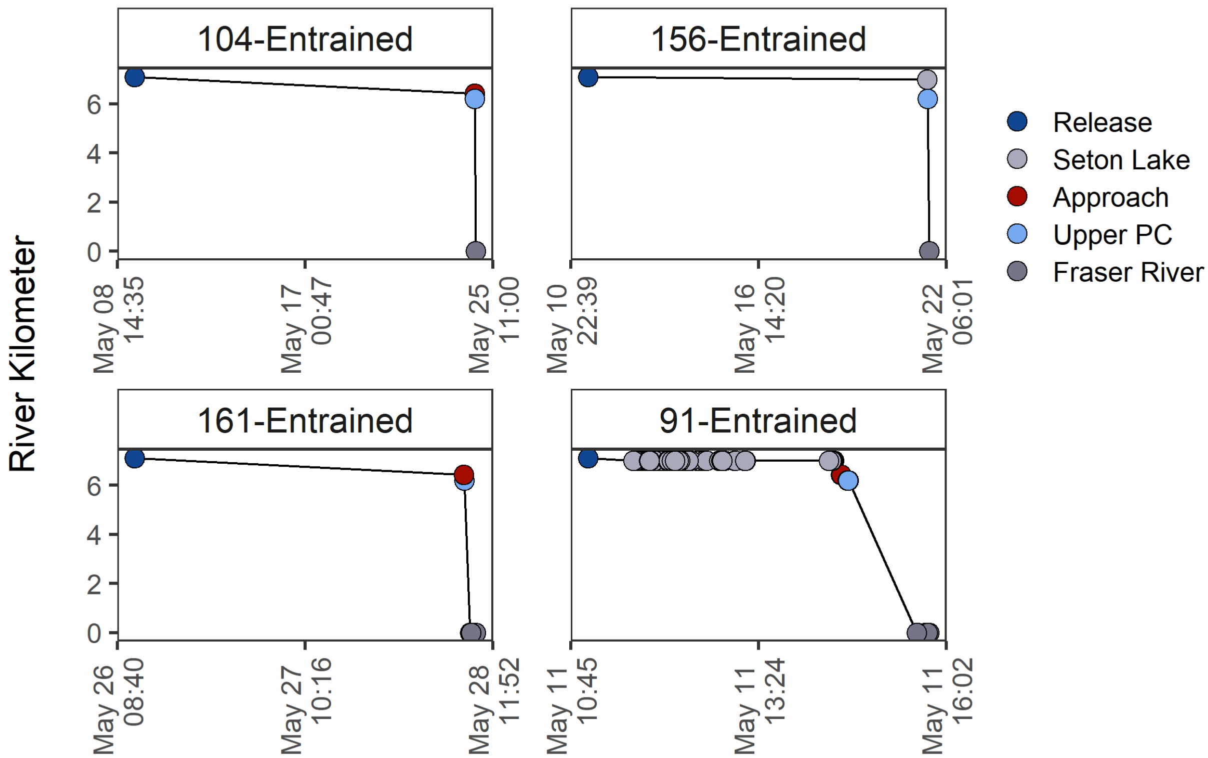

Figure 3.7 Detection histories of radio tagged Sockeye Salmon smolts confirmed to have been entrained through the Seton Generating Station, as indicated by detection within the power canal followed by detection within the Fraser River. River kilometers are calculated from the most downstream station (Fraser River, rkm 0).

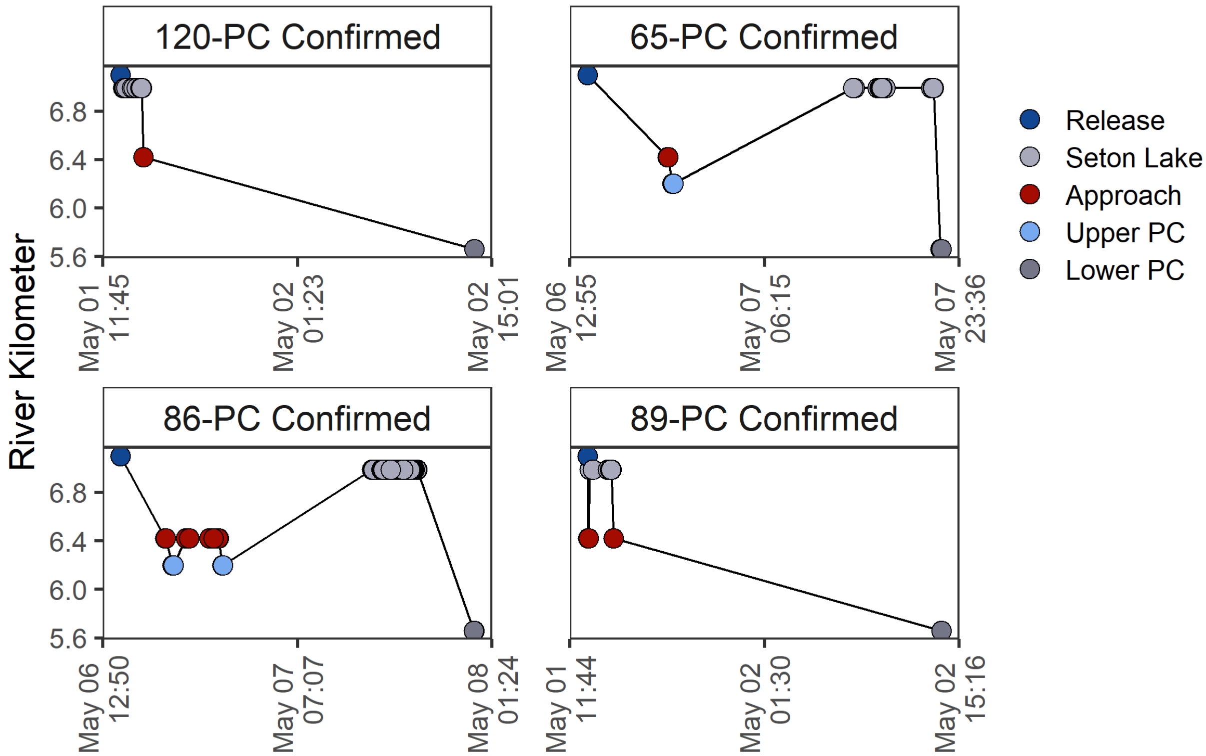

Figure 3.8 Detection histories of radio tagged Sockeye Salmon smolts confirmed to have entering the Power Canal and were likely entrained through the Seton Generating Station. These fish were detected in the Lower Power Canal but without subsequent detection in the Fraser River to confirm entrainment. River kilometers are calculated from the most downstream station (Fraser River, rkm 0).

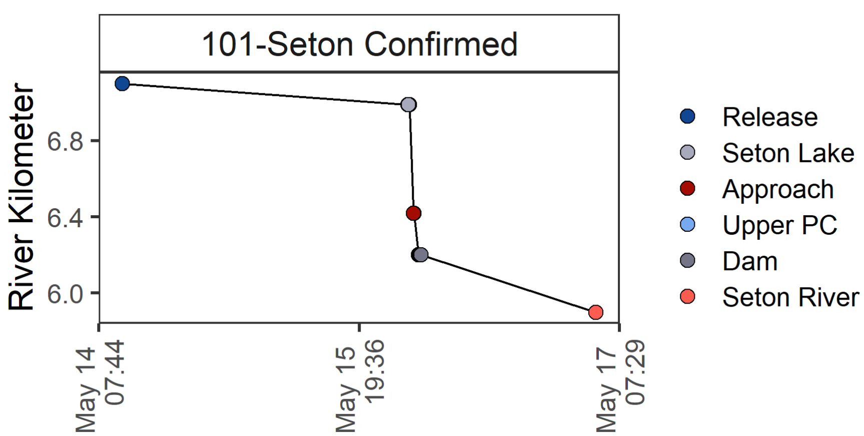

Figure 3.9 Detection history of the one radio tagged Sockeye Salmon smolt confirmed to have migrated via the Seton River, as indicated by detection in the Seton River downstream of the Seton Dam. River kilometers are calculated from the most downstream station (Fraser River, rkm 0).

3.4.4 Timing of Movements

Of the 38 smolts for which passage route could be identified, 28 were released during the seasonal shutdown period (April 20 to May 20) and 10 after. However, 12 of those released during the seasonal shutdown period were not detected downstream of Seton Lake and Approach receivers until after May 20. Unlike shown by raw capture data, timing of passage among radio-tagged Sockeye Salmon into the power canal or Seton Dam revealed most movement occurred during daylight hours (Figure 3.10).

Observing the number of radio-tagged fish suspected of migrating through each structure at different ratios of Seton Dam to powerhouse discharge may reveal patterns in route preference or entrainment rate. Observing flow ratios is informative because it reveals the distribution of flows across each route. When the powerhouse was operational, flows through that structure were relatively consistent (Figure 3.1); therefore, the ratio can be interpreted as increasing with the total flow through Seton Dam. A ratio of one indicates all discharge was through the Seton Dam, which occurred when the powerhouse was shut down. It is notable that when the powerhouse was shut down (ratio = 1.0), more fish were suspected of migrating via the power canal (n = 5) than through the Seton Dam (n = 3; Figure 3.11). While the powerhouse was operational (ratios < 1.0), most fish were detected on power canal receivers when ratios were between 0.35 and 0.40 (n = 15 of 19; dam discharges of 39 – 47 m^3/s) and via Seton Dam at ratios of 0.25 and 0.27 (n = 4 of 7; dam discharges of 30 – 33 m^3/s). However, these differences are small, sample sizes limited, and exact timing of passage uncertain. The ratios of hourly Seton Dam to powerhouse discharge that occurred most during the period of fish movement were 0.39 to 0.44 (62% of observations; data not shown).

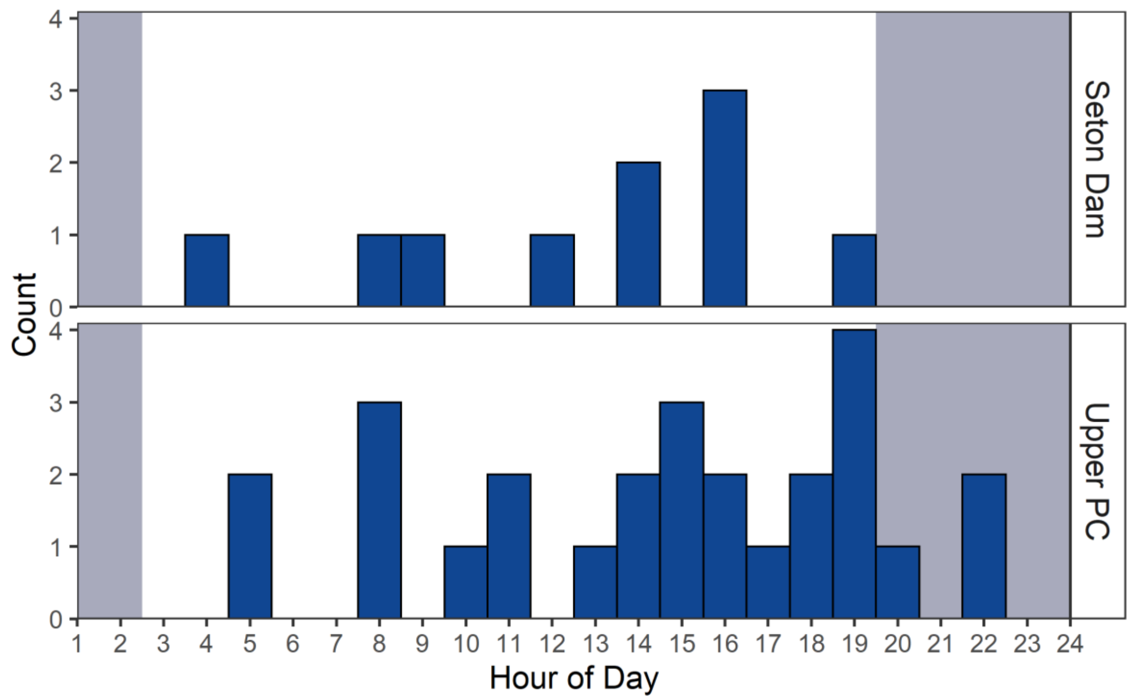

Figure 3.10 Timing of movement among radio tagged Sockeye smolts from released in Seton Lake and migrated via either the Seton Dam or into the power canal. Timing of movement was determined as the first detection on receivers within either the upper power canal or below the Seton Dam for fish migrating via those routes.

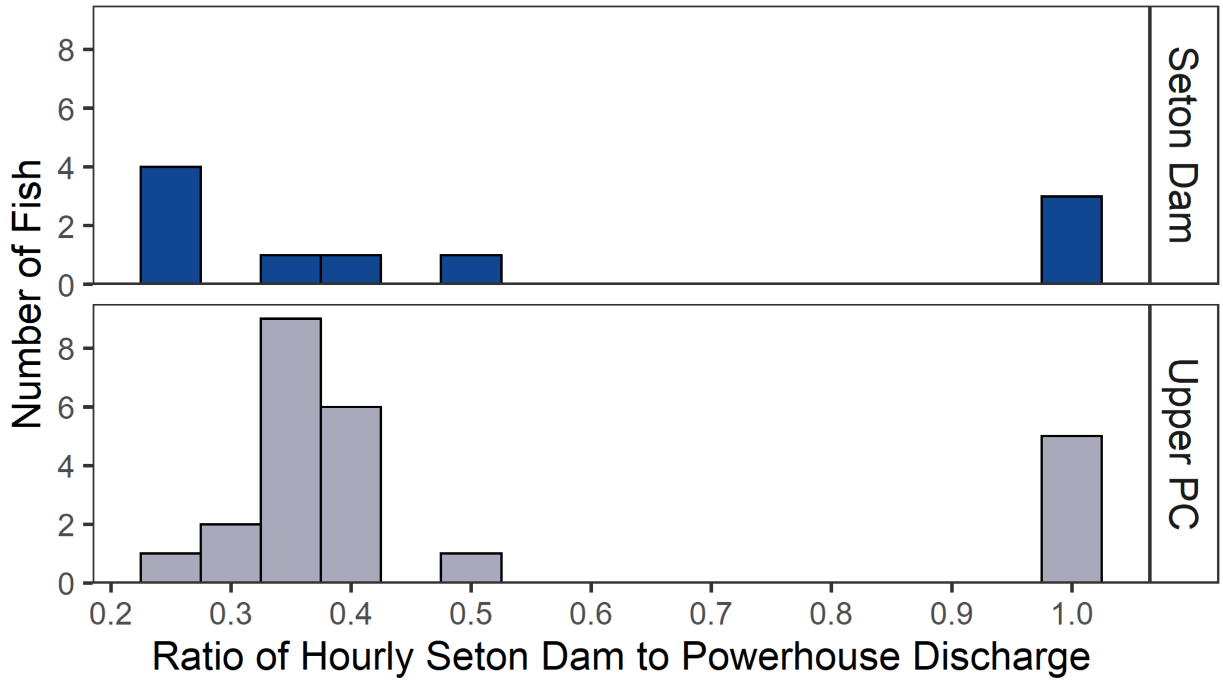

Figure 3.11 Number of radio-tagged Sockeye Salmon smolts migrating into the Powel Canal (PC) or Seton River among varying discharge conditions. Discharge condition on the x-axis shows the binned ratio of Seton Dam to powerhouse discharge, where 1.0 indicates all discharge was through the Seton Dam (occurred during powerhouse shutdowns). Timing of movement is defined as the first detection on either the Seton Dam or Upper PC receivers, for fish migrating via those routes.

3.5 Entrainment and Mortality

Among fish for which passage route could be classified, detection data indicated that entrainment rate could range from 21% to 89% (Table 3.7). These entrainment rates are based on the detected data classifications described in 3.4.2 Routing Proportions and produce mortality rates classified as Minimum, Suspected, Probable, and Confirmed. Estimated abundance from the BTSPAS model for fish migrating via the Seton Dam and into the Seton River was 996,442 smolts (see 3.3 Abundance and Run Timing). Applying the range of the proportion of smolts estimated to have been entrained, total population size could range from 1,262,160 to 8,967,978 smolts (Table 3.9). It should be noted that the sample size was < 10 for two of the classification scenarios (Probable and Confirmed) and so values should be interpreted with caution. The total estimated population size for three of the classification scenarios (i.e., Minimum, Suspected, Confirmed) were in line with the range of previous years' values (Table 3.10), while the greatest estimate under the Probable scenario was nearly double that of the past maximum. Applying the fixed mortality estimates of 17% for powerhouse migrants and 2% for dam migrants to the four routing proportion scenarios results in mortality estimates ranging from 5% to 15%, greater than those recorded in most other monitoring years (Figure 3.12). As previously stated, the fixed mortality rates applied here have a number of assumptions and uncertainties (see 2.6 Entrainment and Mortality, as well as Mortality Estimates in 4 Discussion). While the authors do not support this approach as a meaningful way to calculate mortality, these data are the results of established methods for BRGMON-13 and are presented for comparison with past monitoring.

Table 3.9 Estimated population size and mortality of Sockeye Salmon smolts migrating through the Seton Dam (into the Seton River) and through the Seton Generating Station (powerhouse) across various scenarios using classifications from radio telemetry data. Results are estimated from the proportion of fish entrained and the population estimate from a BTSPAS model for Sockeye Salmon migrating via the Seton River, rounded to the nearest 100 fish. Fixed mortality rates are 2% for dam migrants and 17% for powerhouse migrants. Sample size is the number of radio-tagged fish in the routing proportion scenario.

Scenario	n	Entrainment (%)	Population Size			Total Mortality	Mortality (%)
			Seton River	Powerhouse	Total		
Minimum	38	21	996,442	265,700	1,262,200	65,100	5.2
Suspected	38	74	996,442	2,790,000	3,786,500	494,200	13.1
Probable	9	89	996,442	7,971,500	8,968,000	1,375,100	15.3
Confirmed	5	80	996,442	3,985,800	4,982,200	697,500	14.0

Table 3.10 Estimated population size and mortality of Sockeye Salmon smolts migrating through the Seton Dam (into the Seton River) and through the power canal to the Seton Generating Station (powerhouse) from previous years of the BGRMON-13 project (values from analysis data tables of Lingard et al. 2020). Population sizes were rounded to the nearest 100 fish. Routing proportions were estimated using mark-recapture methods (rather than radio telemetry) with some variation in methods among years (see Harrower et al. 2019 for an overview of methods from 2008 to 2018, and see Levy et al. 2008, Sneep et al. 2012, Harrower et al. 2019, Lingard et al. 2020 for detailed methods). Fixed mortality rates were consistent with 2% for dam migrants and 17% for powerhouse migrants. In 2014 and 2017, the powerhouse was no operational, hence 0 values. No monitoring was conducted in 2016.

Year	Entrainment (%)	Population Size			Total Mortality	Mortality (%)
		Seton River	Powerhouse	Total		
2006	45	606,900	515,100[a]	1,133,500[a]	99,938	8.8
2007	43	874,000	658,900[a]	1,549,700[a]	129,824	8.4
2008	76	115,500	409,000	534,600	72,050	13.5
2009	13	271,700	38,100	304,000	11,788	3.9
2010	14	360,900	49,400	403,900	15,481	3.8
2011	8	2,958,800	1,657,300	4,836,500	345,332	7.1
2012	8	2,453,800	1,680,900	4,889,900	349,939	7.2
2013	52	239,200	260,500	491,000	48,902	10.0
2014	0	838,900	0	873,300	17,466	2.0
2015	39	1,506,600	688,000	1,759,000	138,375	7.9
2016	-	-	-	-	-	-
2017	0	1,556,300	0	1,785,200	35,703	2.0
2018	44	223,000	278,400	520,700	52,179	10.0
2019	2	781,100	17,300	798,300	18,563	2.3

a: estimate based on "shutdown" sampling numbers only, as operational catches were not consistent in these years

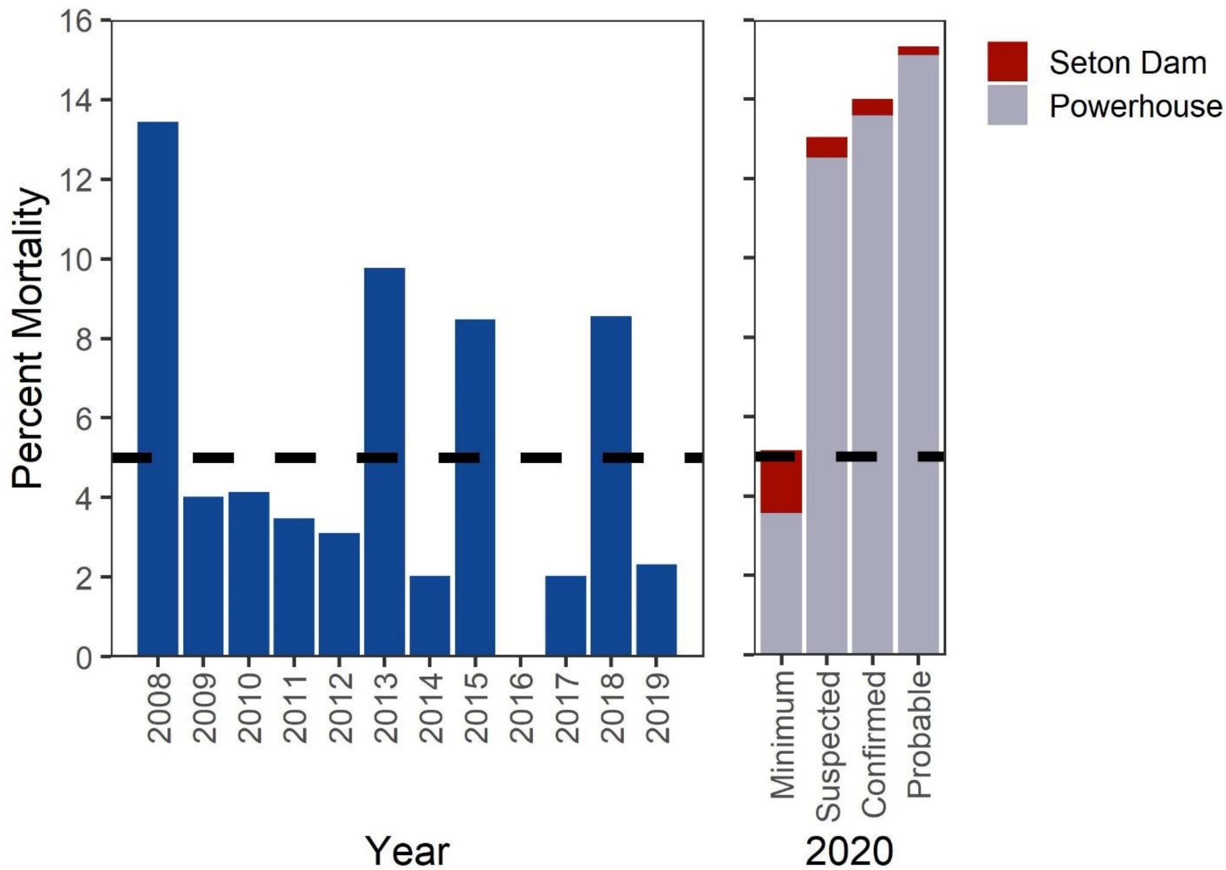

Figure 3.12. Annual Sockeye Salmon smolt mortality estimates at the Seton hydroelectric power facility as a percentage of the total smolt population. The horizontal dashed line indicates the 5% smolt mortality target outlined in the Settlement Agreement (2011). Previous years' estimates combine mortality from both the dam and powerhouse (left). For 2020, four mortality estimates are shown corresponding to the various estimates of entrained smolts from radio telemetry data (right).

3.6 Injury Assessments

A total of 744 fish were assessed for injuries between May 15 and June 3; of these, 58% (n = 430) showed external injuries that met the predetermined injury assessment criteria. The most common injury was scale loss (53.6%), which increased in both severity and prevalence throughout the injury monitoring period (Figure 3.13). Other injuries were less common (Table 3.11). Multiple injuries were present in 13% (n = 96) of fish assessed and barotrauma-related injuries (bleeding vent, red eye, pop eye, missing eyes) were observed in 5% of fish (n = 39). Prevalence of barotrauma-related injuries did not increase through the injury monitoring period (Figure 3.14). Numbers of injuries recorded among severity category for each injury type and assessments of changes to prevalence with week are shown in Appendix D.

Table 3.11 Percent of total sample (n = 744) of Sockeye Salmon smolts that migrated through the Seton Dam with each type of injury assessed. All severity categories are combined.

Category	Injury	% of Sample
Non-barotrauma Related Injuries	Scale Loss	53.6
	Fin Damage	5.9
	Body Scarring	3.8
	Torn Operculum	1.2
Barotrauma Related Injuries	Red Eye	3.5
	Pop Eye	1.3
	Bleeding Vent	0.9
	Missing Eyes	0.4

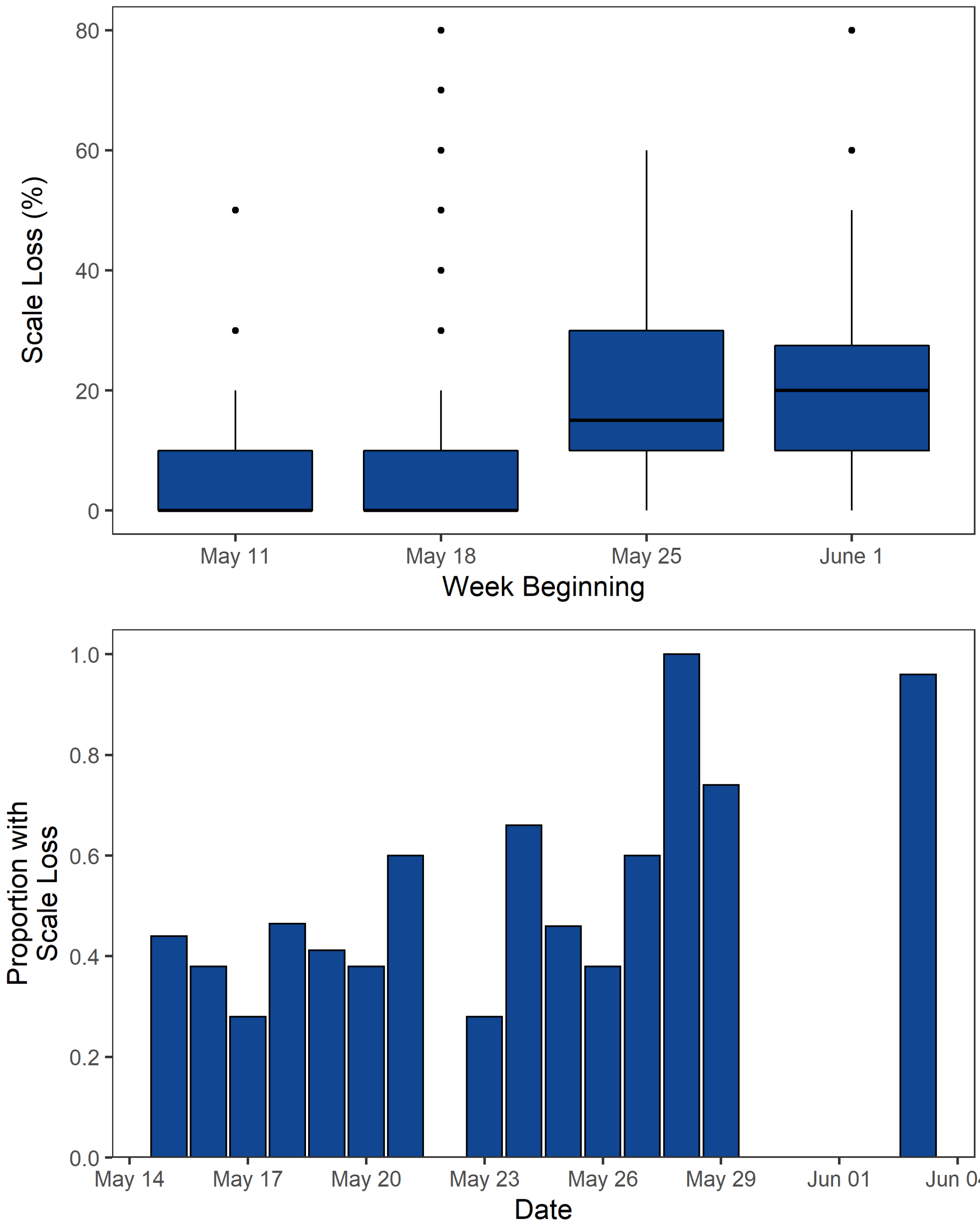

Figure 3.13 Severity of scale loss (recorded as percent of body surface missing scales) assessed in Sockeye Salmon smolts that migrated though the Seton Dam and were captured in a downstream rotary screw trap (top). Prevalence of scale loss, the proportion of the sample with scale loss present (all severities combined), is shown for each assessment day (bottom).

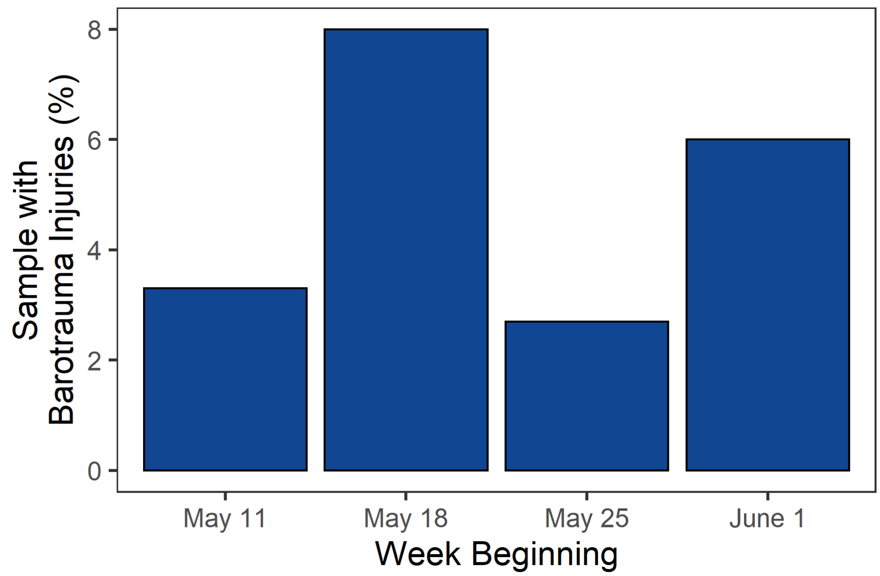

Figure 3.14. Prevalence of barotrauma-related injuries, inclusive of missing eyes, pop eye, red eye, and bleeding vents, among Sockeye Salmon smolts that passed the Seton Dam and were captured in a downstream rotary screw trap.

4. Discussion

New methods were introduced in 2020 to better understand of the migration behaviour of Seton River Sockeye Salmon smolts and obtain more robust estimates of abundance and run timing using a Bayesian time stratified mark-recapture model. All Sockeye Salmon were captured below the dam. Abundance and run timing were determined through the recapture of PIT tagged fish released in the Seton River below the dam and radio-tagged fish were released within Seton Lake to assess migration behaviour through the entire Seton Hydro-Electric Facility. An injury monitoring program was also introduced mid-season given high mortality and observation of barotrauma-related injuries.

The methods used in 2020 were better suited for addressing BRGMON-13 management questions than those used in previous years. There were nonetheless limitations and opportunities for improvement in future years. An inability to extensively range test receivers prior to deployment unfortunately led to uncertain detection data. In addition, poor fish condition that deteriorated through the season limited our sample sizes, and therefore influenced our ability to reach conclusions. These observations also raised concerns regarding the effects of dam passage, previously thought as a protection strategy, on migrating Sockeye Salmon smolts. Results are discussed in the context of each management question, along with discussions of mortality, injury, and suggestions for further refining the monitoring approach.

Management Question 1: What proportion of total Sockeye Salmon outmigrants from Seton Lake will pass through Seton Dam when the powerhouse is shutdown each night (20:00 – 02:00) between April 20 and May 20?

Addressing this management question is difficult given that powerhouse operations in 2020 did not align with those described. Instead of 6-hour nightly shutdowns (20:00 to 02:00), the powerhouse was shut down for 30 hours (20:00 Day 1 to 02:00 Day 3) every other day from April 20 to May 20. This new strategy resulted in the powerhouse being operated 36% of time between April 20 and May 20, still within the normal range relative to previous years. All sources of data, including movement derived from radio telemetry, raw capture data, and run timing determined from the stratified population estimate, indicated that in 2020 a substantial proportion of fish moved outside of the typical shutdown hours (20:00 to 02:00) and after May 20.

There are three hypotheses associated with management question 1. The first is that nightly powerhouse shutdowns (accompanied by an > 25 m^3/s dam release) conducted 20:00 to 02:00 between April 20 and May 20 will result in > 80% of the Sockeye Salmon smolts being diverted to Seton River from Seton Lake. This hypothesis can neither be supported nor rejected given the change in operations. We are cautious in presenting a definitive routing proportion value given uncertainties surrounding radio telemetry data. For example, it is possible that the receivers in the power canal had better detection efficiency (and, therefore, were more likely to detect more fish). It is also possible that the receiver in the upper power canal was able to detect fish in the forebay, or that fish moved between the upper power canal and the forebay prior to migrating via the dam and into the Seton River (and being missed by those receivers). The weight of evidence nonetheless suggests that more fish migrated via the power canal than Seton Dam and the target was not met; 74% of fish were last detected within the power canal and thus were suspected to migrate via that route.

BTSPAS results inform $H_{2A,}$ that > 90% of smolts migrate between April 20 and May 20, while raw capture data is best applied to H_{3A}, that > 90% of smolts leave Seton Lake between 20:00 and 02:00. We reject both hypotheses; only 43% of catch was obtained during the seasonal and nightly shutdown period in 2020. Seasonally, stratified estimation of abundance from the BTSPAS model determined that 39% of smolts migrated between April 20 and May 19, with peak abundance occurring between May 25 and 29. The percentage falls substantially short of the threshold detailed in $H_{2A.}$ The 90% target has been met in eight of the twelve monitoring years (Lingard et al. 2020). With respect to $H_{3A,}$ though more fish were captured during shutdown hours than not, the percentage (67%) did not meet the stated target. Across monitoring years, the percentage of smolts captured during nightly shutdown hours has ranged from 38 to 83% (Lingard et al. 2020). That is, the 90% target has never been met. Catch data from previous years was summarized by Lingard et al. (2020), who detailed how management hypothesis targets have not been met in multiple years.

The 2020 results present multiple lines of evidence that operating the dam within the WUP target discharge range of 19 to 36 m^3/s without exceeding 60 m^3/s (actual discharge was between 28 and 47 m^3/s through the entire smolt migration period) and implementing alternating 30-hour shutdowns between April 20 and May 20 did not divert the target 80% of smolts through the dam. Results are also supported by data collected from 2006 to 2019, as reported in Lingard et al. (2020). Collectively, the 14 years of monitoring suggest that powerhouse shutdowns could be adjusted to better reflect migration timing and meet the targets outlined in the hypotheses. In years of high smolt abundance, and particularly years of high Portage Creek abundance, increasing the duration of the shutdown both seasonally and nightly would be required to meet the given target.

Management Question 2: How is the proportion of Sockeye Salmon outmigrants leaving during shutdowns affected by total release from the Seton Dam and the configuration of dam discharge facilities used to release water?

With high post-release mortality and uncertain detection histories, the available sample of radio-tagged fish that successfully migrated makes comparing migration characteristics among operational conditions difficult. Additionally, consistent discharge configurations throughout the seasonal shutdown period resulted in few discrete operations to compare; Siphon 4 discharged most water and total dam discharge remained between 30 and 40 m^3/s during the seasonal shutdown period. We did determine the timing of passage at different ratios of Seton Dam to powerhouse discharges throughout the monitoring period for qualitative comparisons, but data were deemed insufficient to also consider the configuration of dam discharge facilities. Any comparisons should be interpreted cautiously given uncertainties regarding the exact timing of passage, and low sample sizes of fish with confirmed migration routes. The first detection on either the Upper PC or Seton Dam receivers were selected as the time of passage for fish migrating via those routes, but it is possible that these receivers were able to detect fish in the forebay.

When the power canal is operational, most fish migrated into the power canal at dam discharges of 39 – 47 m^3/s but among those migrating via Seton Dam, most did so at dam discharges of 30 – 33 m^3/s. These results may suggest that when the powerhouse is operational, higher dam discharges could detract fish from migrating through the dam and instead attract fish to the power canal. Again, we caution that there are many uncertainties surrounding these comparisons.

Although there remains substantial uncertainty regarding how migration characteristics during shutdowns are affected by Seton Dam releases and/or the configuration of dam discharge facilities, radio telemetry results do show that powerhouse shutdowns may not be as successful at diverting fish away from the power canal as previously thought. The most certain finding from available migration timing data is that most fish migrated via the power canal and when the powerhouse was operational. Even when the powerhouse was not operational, more fish migrated via the power canal than the Seton Dam. Salmon smolts are typically surface flow oriented during downstream migration and avoid areas of accelerating water (Arnekleive and Kraabol 2007; Coutant and Whitney 2000). Therefore, migrating smolts may not be attracted to the dam conveyance structures. That fish entered the power canal when there was no flow (i.e., during shutdowns) may indicate preference for the open surface flow structure of the power canal. Such conditions present the most “natural” laminar flow option. It is possible that siphons and other non-surface flow conveyance structures in the dam present velocity barriers (Enders et al. 2012; Haro et al. 1998).

It is worth considering that the question of how Seton Dam releases or the configuration of dam discharge facilities effects migration behaviour may not be the most pertinent at this time. First, substantial data gaps exist regarding whether the dam is a safer fish passage structure than the powerhouse. It is also unknown what proportion of fish migrate through each conveyance structure or the corresponding immediate and latent mortality for each structure. Also unknown is if, and to what extent, operations may delay fish migration. Barrier-induced migration delay is known to have consequences for smolt survival (Marschall et al. 2011; Nyqvist et al. 2017). Continued monitoring using a technology that can reliably assess fish behaviour, passage success and survival is needed to address these data gaps prior to investigating how discharge and dam operations may influence passage route.

Management Question 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?

Under the assumption that powerhouse shutdowns improve fish protection, shutdown timing could be adjusted to better match smolt migration timing. Most fish movement over the Seton Dam occurred between 21:00 and 5:00 and after May 20. Extending shutdown timing both hourly and seasonally would better align with migration patterns seen this year, and in most previous years (summarized in Lingard et al. 2020).

However, radio telemetry data revealed that fish entered the power canal despite shutdowns. Therefore, powerhouse shutdowns may not serve to divert fish away from the powerhouse or provide fish protection. Surface-flow oriented smolts may not be attracted to the sub-surface conveyance structures of the Seton Dam available during shutdown periods.

Additionally, while catch data has consistently shown a preference for movement during the nightly shutdown timing, the same pattern was not apparent from radio telemetry data. This divergence could be attributed to detection ranges of the Upper PC and Seton Dam receivers being larger than anticipated (i.e., detected fish in the forebay) or could be indicative of a need to better evaluate movement patterns and the potential for delay in the forebay. This discrepancy between the catch data and radio detection data highlights the importance of using technologies that can monitor individual fish behaviour to develop mitigation strategies.

In past reports, we suggested that extending the nightly shutdowns would increase fish protection. These new data suggest it may be more valuable to further investigate smolt movement behaviour, routing proportions, and passage survival among the available migration routes before altering shutdown timing.

Injuries and Potential Causes

In response to observations of injuries among captured fish that worsened as the season progressed and high mortality among tagged fish, a standardized injury evaluation protocol was adopted on May 15. Physical injury was observed on 58% of assessed fish. Scale loss was the most common injury, the severity and prevalence of which increased over the study period. Scale loss can result from a multitude of factors, including predation, disease, turbulence, barotrauma, gas bubble disease (GBD), or even stress (Brown et al. 2014; Weitkamp and Katz 1980). Increases in the severity and prevalence of scale loss did correspond with increases in Seton

Dam discharge, though we cannot confirm a cause-and-effect relationship given the potential for condition to generally decrease through the season, regardless of discharge conditions. Seton Dam discharge increased from ~34 to 39 m^3/s on May 20 and to 47 m^3/s on May 27. In future analyses, the prevalence and severity of all injuries should be directly compared to changes in Seton Dam discharge.

Some of the less common injuries observed such as fin damage, body scaring, and eye hemorrhaging (red eye) can be caused by abrasion or turbulence (Deng et al. 2010). Eye hemorrhages, missing eyes, distension (pop-eye) and internal bleeding (as indicated by bleeding vents) can also be signs of barotrauma caused by pressure changes (Brown et al. 2014) or GBD resulting from high total gas pressure below dams (Weitkamp and Katz 1980). Though the percentages of barotrauma-related injuries were low (2.7 to 8% of the sample in each week), outward signs of barotrauma may be slow to develop following dam passage (Brown et al. 2014). Additionally, not all signs of barotrauma are visually detectable. In a review of GBD in salmonids, Weitkamp and Katz (1980) found that only a small portion (< 5%) of fish afflicted with GBD show outwards signs of trauma. Similar rates of internal injury not visibly apparent can occur in fish suffering from barotrauma (Brown et al. 2014). Finally, there appears to be species-specific variability in susceptibility to barotrauma (Brown et al. 2014) and data for Sockeye Salmon are sparse.

Although barotrauma-related injuries did not increase in severity linearly through the monitoring period with increases in discharge as seen with scale loss, the types of injuries observed have been studied extensively in juvenile salmonids following dam passage and are clearly associated with barotrauma (Brown et al. 2012; Brown et al. 2014; Richmond et al. 2014). It is concerning that these types of injuries are being observed at moderate discharges that are within the WUP target hydrograph (~ 30 to 50 m^3/s). It has not been uncommon for the Seton Dam discharges to exceed the WUP target hydrograph (e.g., from 2017-2019; Lingard et al. 2019), and it will likely be exceeded again in the future given upstream water management needs (BC Hydro, personal communication).

Injury data had not been collected for Sockeye Salmon smolts migrating via the Seton River since initial assessments by Andrew and Green (1958), who recorded similar injuries to those herein (but did not assess scale loss or fin damage). In Andrew and Green (1958), alive and dead fish were caught within a few meters of the outflow of either a siphon or the FRWG. Injury prevalence and severity varied by conveyance structure. Fish that survived passing through the siphon had similar rates of eye hemorrhage (1.7%) and torn opercula (1.7%) whereas fish passing through the FRWG experienced higher rates of eye hemorrhage (3.6%) but lower rates of torn opercula (0.4%) than those passing through the siphon. Too few dead fish were captured to compare injuries between passage routes (n = 24 FWRG; n = 5 siphons). The authors hypothesized the main cause of injury through the FWRG was barotrauma, whereas abrasion on concrete was likely the main cause of injury for fish passing through siphons. Dam discharge was not specified, but it was likely low as trapping using nets below the dam was possible.

Ultimately, Andrew and Green (1958) suggested that immediate mortality and injuries were low, except for when fish pass through the FWRG in the open position (estimated 10% mortality). This conclusion led to the recommendation of the 'down' position for the sluice gate to reduce injury, which BC Hydro implements annually during the smolt migration period. No additional research was completed to assess if this mitigation measure reduced smolt injury or mortality. More injury was observed in 2020 than in the initial 1958 investigation, but methodological differences preclude direct comparisons. In Andrew and Green (1958), study fish were captured immediately below the dam and in 2020 study fish were captured ~500 m downstream of the dam. It is nevertheless interesting that the occurrence of eye hemorrhage and internal bleeding (i.e., vent bleed) observed in 2020 was similar to that observed among fish passing through the FWRG in the open position in Andrew and Green (1958).

Continued standardized injury monitoring may provide a valuable tool for future comparative assessments of fish condition. The frequency of observed injuries in 2020 combined with low survival of radio tagged fish in this study indicate Sockeye Salmon smolts were in poor condition after dam passage and may experience low rates of migration success to their marine destinations. Further investigations of injury and survival following passage through various structures is needed to inform the best practices for operations at the Seton Dam and powerhouse during the Sockeye Salmon smolt migration period.

Mortality Estimates

Injury observations characteristic of dam passage trauma suggest mortality may be higher than previously thought. The suggestion by Andrew and Green (1958) that operating the FWRG in the 'down' position reduces mortality requires testing. Additionally, there are no data on the proportion of fish migrating through conveyance structures under different operational conditions, or knowledge of how variable discharge through each structure may influence mortality. Despite these data gaps, a consistent 2% mortality rate has been applied to all Seton Dam passage scenarios for the past nine years (Sneep et al. 2012; Harrower et al. 2019; Lingard et al. 2020). It is unclear where the estimated 2% dam mortality, reported in the TOR for BRGMON-13, was obtained when Andrew and Green (1958) estimated mean mortality to be 1.2% for passage through siphons and 7.0% through the FWRG and no discharge was specified. It is likely that increasing discharge would cause more mortality as pressure and shear forces increase (Neitzel et al. 2004).

Considering the available evidence and the extent of knowledge gaps, it is probable that both immediate and latent mortality following passage at the Seton Hydro-Electric Facility have been underestimated to date. Mortality estimates presented under BRGMON-13 to date should, therefore, be interpreted cautiously. The mortality estimates presented here have no associated error (i.e., confidence intervals) nor do they take total discharge or discharge configuration into account. Total mortality (i.e., combined powerhouse and dam mortality) for 2020 was calculated to potentially range from 5 to 15%, depending on the routing proportion classifications used. It is worth noting that each classification had a relatively small sample size, which creates uncertainty as to the representation of true routing proportions. Further investigation is recommended with some alternative methods explored below.

Challenges and Future Directions

The new approach adopted in 2020 was better designed to address management questions, but some findings were surprising and challenged conclusions from previous years. Given divergent findings and some substantial limitations of the available data, we strongly recommend additional years of monitoring and further refining the experimental design to target specific knowledge gaps.

Radio telemetry was introduced in 2020. Sockeye Salmon were captured below the dam, radio-tagged, and released above the dam to determine route of passage. We were unable to release all purchased tags due to high pre- and post-tagging mortality; captured smolts were very sensitive to handling and had visually apparent physical trauma and injuries. Even with tagged fish in apparent good condition upon release, 64% of radio-tagged fish were assumed to have died following release into Seton Lake (were never detected or remained above the dam). To reduce potential biases associated with enduring a tagging procedure following dam passage and having to pass Seton Dam twice, we suggest capturing and tagging naïve fish in Seton Lake.

Detection data did provide insight into routes of passage despite limited sample sizes. However, poor detection efficiency among some receivers meant a conservative approach was taken to assign passage route. Poor detection efficiency of a radio telemetry array is common in noisy environments such as hydropower facilities. We have greater knowledge of how to improve both detection efficiency, and the detection range of each receiver if radio telemetry were to be used again. In 2020 testing was impeded by complex and dangerous conditions around the dam and restrictions on staffing resulting from COVID-19. Improvements to array performance would increase resolution of movement data and may permit the use of statistical models to describe movement rather than qualitative comparisons.

We recommend exploring new technologies in future years that may better address knowledge gaps. For example, acoustic telemetry has several advantages over radio telemetry that could benefit that monitoring program. For one, because acoustic tags do not have antennas, the surgery is less invasive than for radio tags that require a second incision and extracting the antenna through the body cavity. Any means to reduce stress associated with tagging would benefit data quality, especially because Sockeye Salmon smolts are less resilient to handling stress than other salmon species. A further benefit of acoustic systems is that they are less susceptible to noise, meaning data quality (e.g., false detection rate) is less likely to be impacted in noisy environments such as hydropower facilities. Conversely, acoustic receivers must be deployed underwater, which would be logistically difficult around the dam and powerhouse. Price is also limitation, with both tags and receivers being approximately twice the price relative to radio technology. Therefore, although radio telemetry provided a cost-effective means to understand Sockeye Salmon smolt movement in 2020, using acoustic telemetry would add to this dataset and improve data quality. Either telemetry system would be complimented by deploying a Sensor Fish, a small autonomous device that provides the hydrological and pressure forces fish experience passing through various structures (Deng et al. 2014).

Moving forward, we strongly recommend testing assumptions made during the development of the WUP regarding how many fish migrate through each conveyance structure in the dam, whether the FWRG is less dangerous for fish in the ‘down’ position, and how mortality and injury fluctuate with discharge. These assumptions were used to develop the fixed mortality rates for passage via Seton Dam and the powerhouse, have formed the basis for the management questions and hypotheses, and guided the use of nightly shutdowns as the preferred mitigation tool. Data collected in 2020 indicate some of these assumptions are likely incorrect and that passing both the Seton Dam and the powerhouse may result in significant impacts to fish health. The injury monitoring conducted is the first such assessment since the Andrew and Green (1958) research, 62 years ago, and results were concerning. While the Andrew and Green (1958) study was robust in its time, there have been significant technological and scientific advancements that have increased our understanding of fish condition and the survival implications for fish migrating past barriers. It would be negligent to not continue injury monitoring and we recommend expanding on these efforts (e.g., with the use of Sensor Fish). It is unknown definitively what caused the observed injuries. Incorporating blood chemistry and a dissection protocol with tissue sampling would facilitate testing for internal signs of GBD and barotrauma (Weitkamp and Katz 1980; Brown et al. 2014). Incorporating Sensor Fish into the study may also identify where, how, and under what conditions injuries are occurring (Deng et al. 2017). Finally, monitoring of total gas pressure, the factor that causes GBD, through the dam and powerhouse should also be implemented regularly if it is not already.

Overall, the 2020 data provided a valuable understanding of how operations at the Seton Hydro-electric Facility influence routing proportions and smolt migration success. We recommend further investigations into injuries and migration behaviour to better inform mitigation measures and reduce mortality in Sockeye Salmon smolts.

5. References

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Appendix A: Radio Telemetry Filtering

Table A 1 Details of filtering of detection data conducted to produce logical and defensible detection histories for tagged fish.

Step	Filter	No. Detections Removed
1	Remove tag codes that do not match released tags	351,230
2	Remove consecutive detections at each station for which lag was < 3 s (minimum burst rate) and > 7 s (Sigma Eight receivers) or < 3 s and > 30 s (Lotek receivers)	59,037
3	Application of power filter on receivers with high interference	328,537
4	Retained detections on Fraser River receiver only if multiple detections occurred within 2 minutes.	23

Appendix B: Discharge Among Monitoring Years

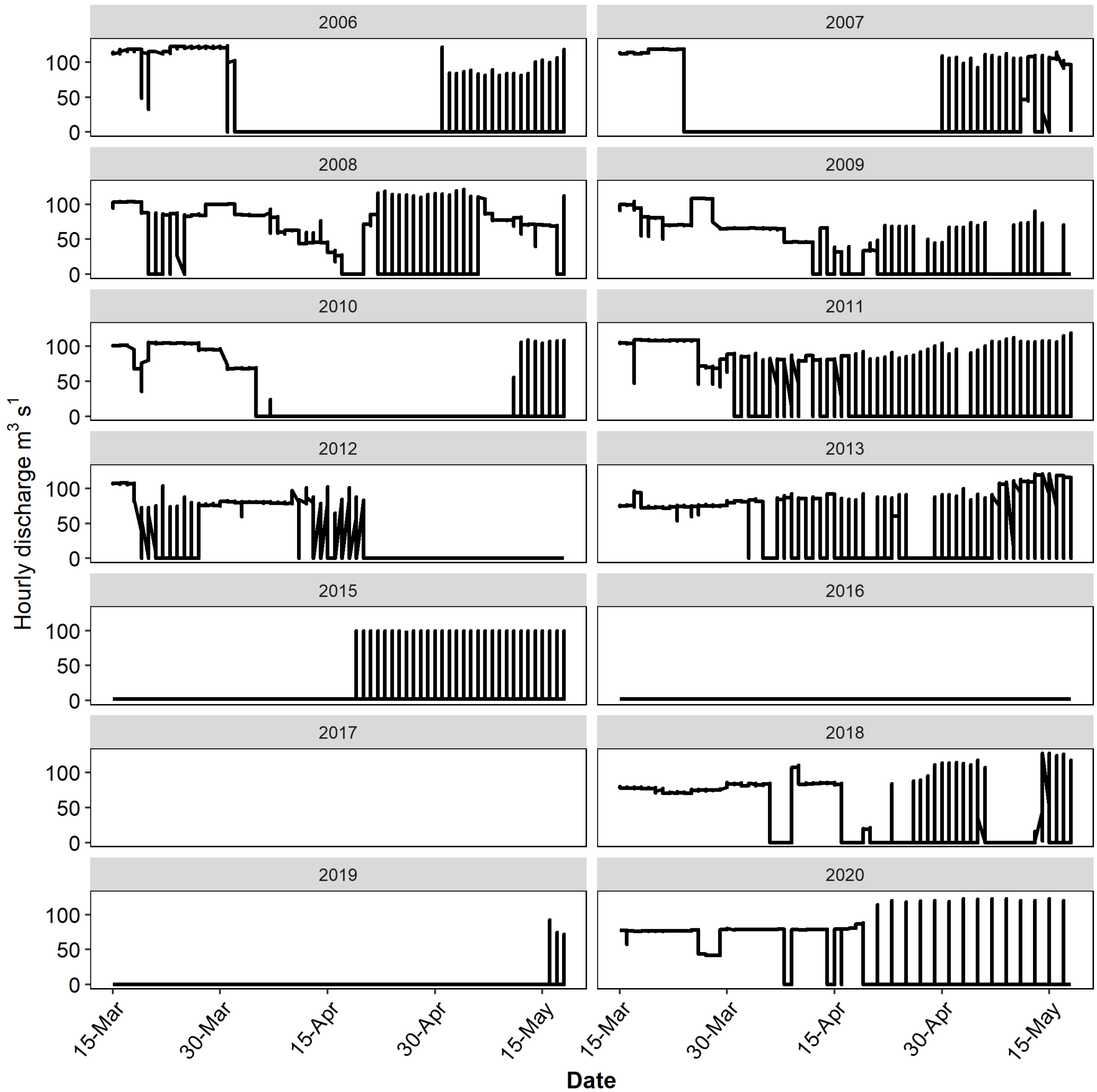

Figure B 1 Hourly turbine discharge at the Seton powerhouse from 2006 to 2020.

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Appendix C: Additional Detection Histories

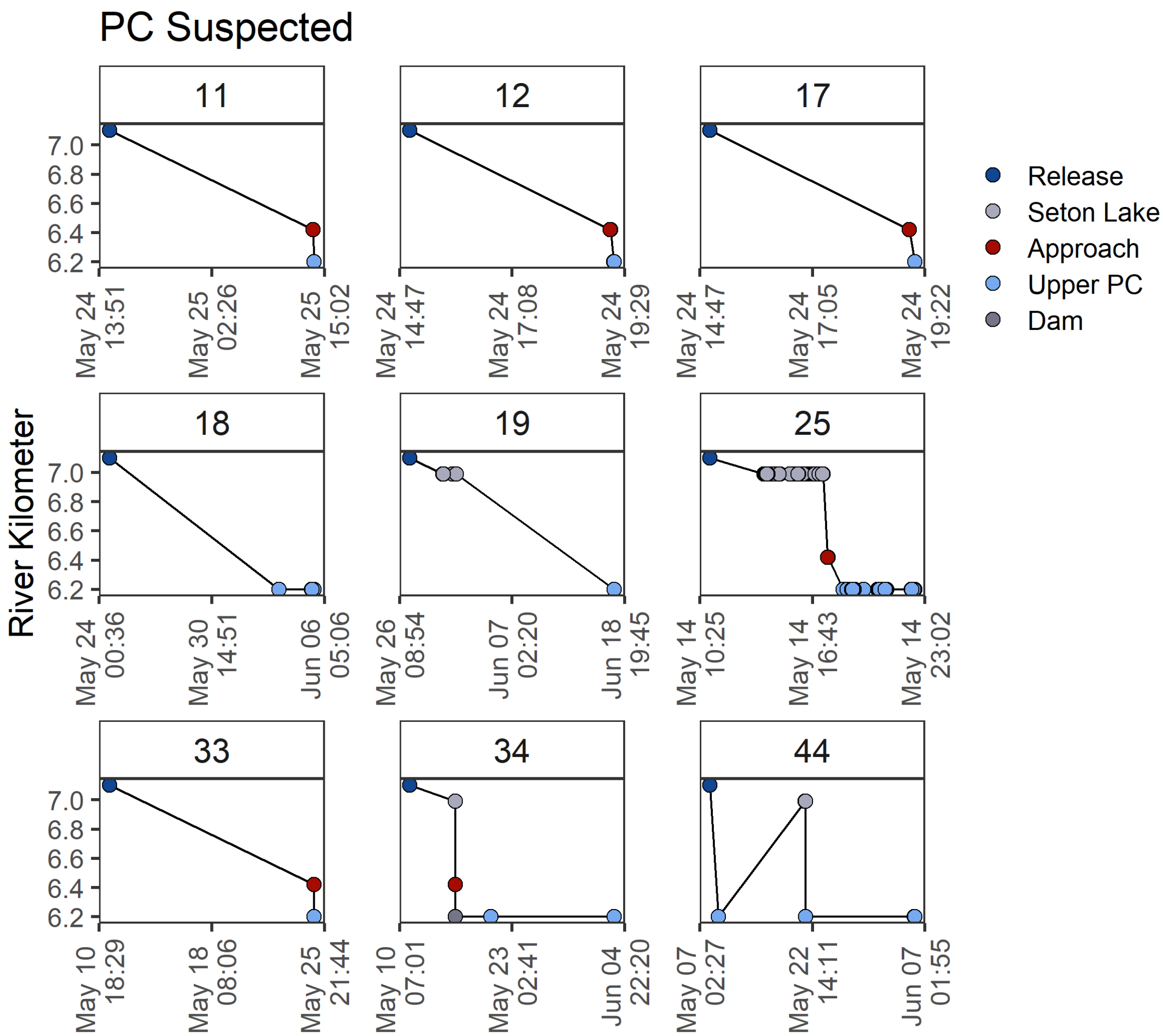

Figure C 1 Detection histories of radio tagged Sockeye Salmon smolts suspected to have migrated via the power canal (PC). River kilometers are calculated from the most downstream station (Fraser River, rkm 0).

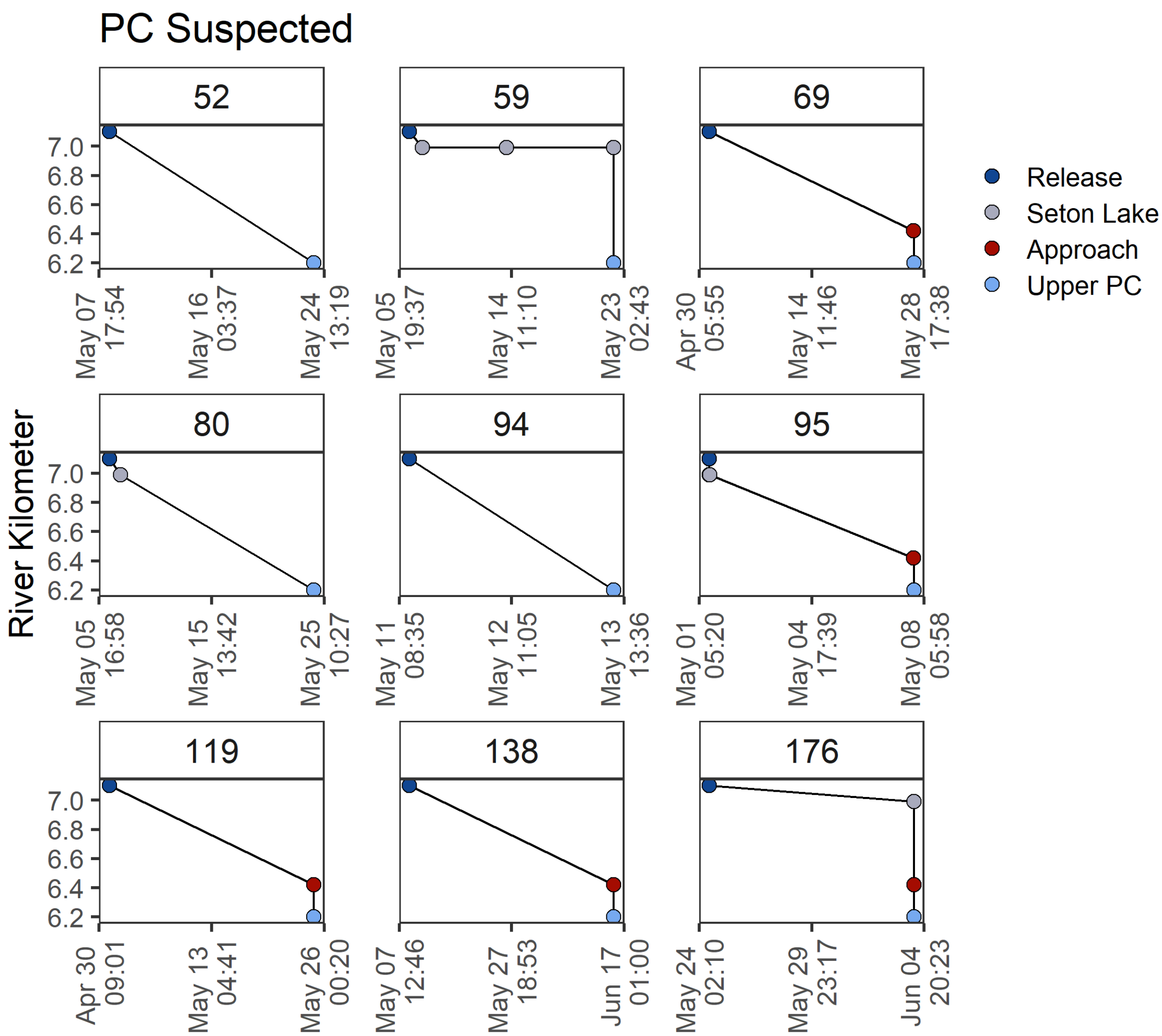

Figure C 2 Detection histories of radio tagged Sockeye Salmon smolts suspected to have migrated via the power canal (PC). River kilometers are calculated from the most downstream station (Fraser River, rkm 0).

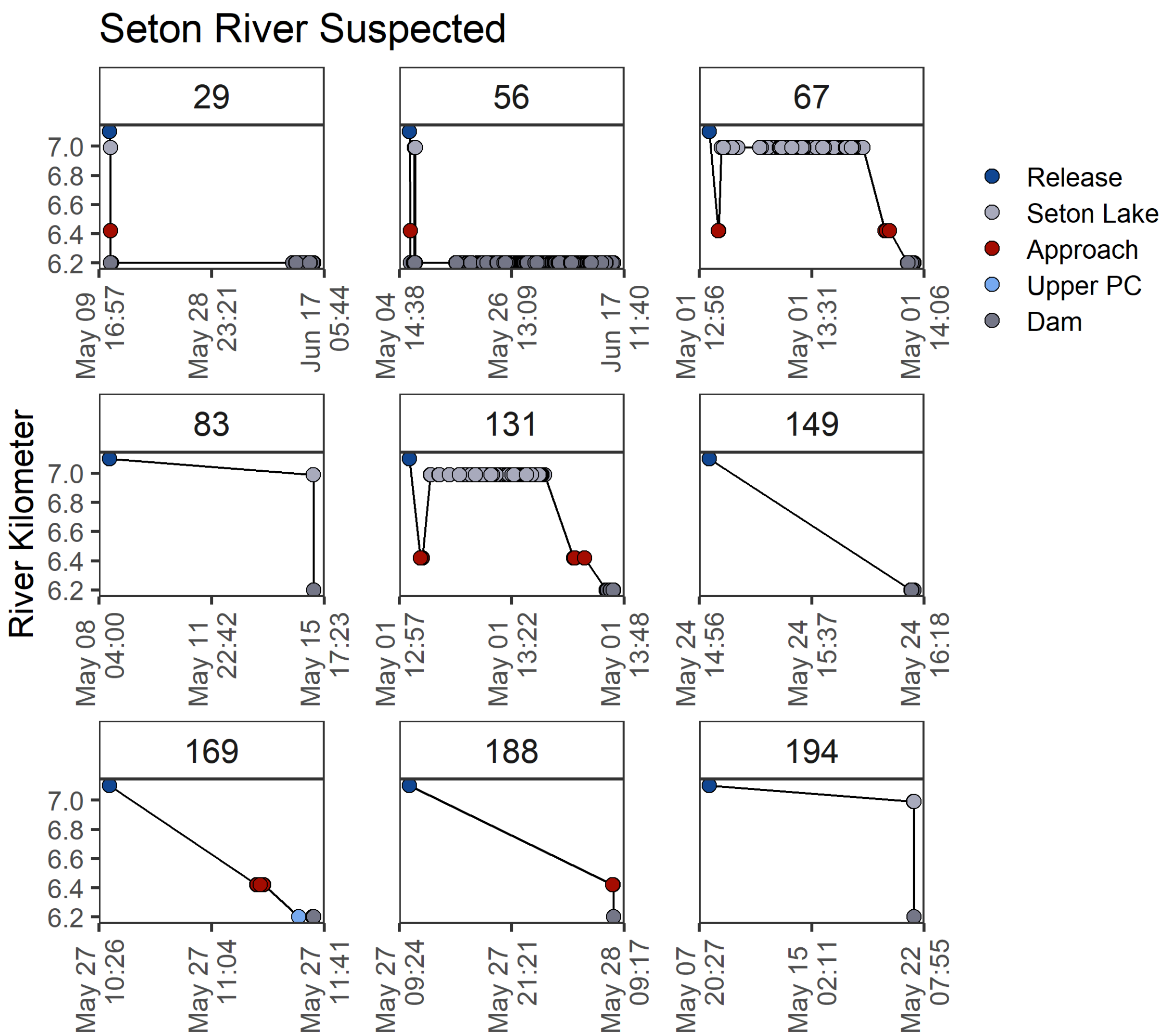

Figure C 3 Detection histories of radio tagged Sockeye Salmon smolts suspected to have migrated via the Seton River. River kilometers are calculated from the most downstream station (Fraser River, rkm 0).

Appendix D: Injury Data

Table D 1 Types of injuries recorded among Sockeye Salmon captured in the Seton River below the Seton Dam.

	Injury	Score	Total
Barotrauma Related Injuries	Missing Eyes	0	741
		1	3
	Pop Eye	0	734
		1	9
		2	1
	Red Eye	0	718
		1	22
		2	3
		3	1
	Bleeding Vent	0	737
		1	7
Non-Barotrauma Related Injuries	Body Scarring	0	716
		1	27
		2	1
	Fin Damage	0	700
		1	41
		2	3
	Fin Severity	0	700
		1	43
		2	1
	Torn Operculum	0	735
		1	9
	Scale Loss	0	345
		10	232
		20	84
		30	39
		40	26
		50	8
		60	5
		70	3
		80	2

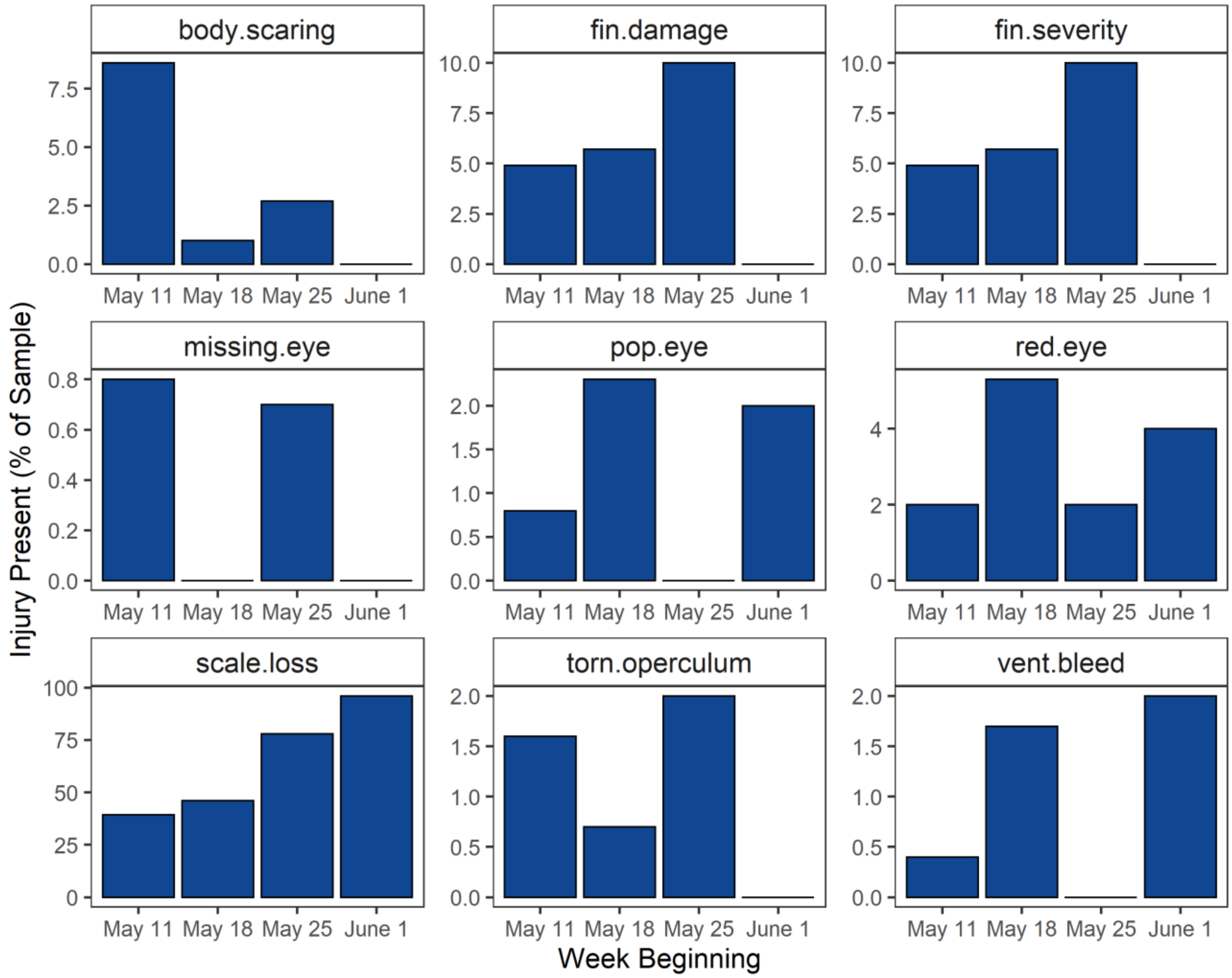

Figure D 1 Prevalence of each injury type for each assessment week.