Fishway passage, water diversion and warming temperatures: Factors limiting successful spawning migration of Seton-Anderson watershed sockeye salmon.

Final Report for the Bridge Coastal Restoration Program, Project 07.BRG01

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Executive summary

• Adults from two populations of sockeye salmon return to the Seton-Anderson watershed to reproduce. They must pass a powerhouse outflow, a dam and a fishway en route to spawning areas. Previous research suggests that mortality may be relatively high in this section of the migration route. These populations have shown significant decline in spawning abundance in recent years and are being considered for listing as threatened or endangered by the IUCN.

• The objectives of our 2007 research were to quantify mortality along the migratory route in the Seton-Anderson watershed, evaluate fishway passage efficiency, assess the impact of the fishway on migration success and identify needs for management experiments and future research.

• We used telemetry to track migrations and determine fish fate, and related the results to environmental conditions encountered (e.g. discharge, temperatures) and physiological condition (stress or maturation levels measured from non-lethal biopsy). Eighty-seven Gates Creek sockeye salmon were captured by dip net from the Seton Dam Fishway, non-lethally biopsied, tagged with a telemetry transmitter and released either upstream or downstream of the dam.

• Blood plasma cortisol, lactate, glucose, and ion concentrations were similar to values from the literature for healthy migrating sockeye salmon suggesting that fish were not physiologically stressed or exhausted after fishway ascent. Successful migrants were not physiologically different from failed migrants, and physiological condition was not strongly correlated with migration behaviour. These results suggest that sockeye released downstream of the dam were in good condition to re-ascend the fishway and that failure was probably not related to physiological stress or physical exhaustion.

• Total loss of migrating sockeye between releases sites downstream of the dam and spawning grounds was exceptionally high (52%). Over half of this loss (32%) occurred in the 4.4 km reach between the Fraser River and the top of the fishway. The remaining mortality (20%) occurred between the outlet of Seton Lake and spawning grounds.

• Of fish released downstream of the dam, 71% of 17 males and 40% of 38 females reached spawning grounds, suggesting that females suffer higher mortality than males. These findings have serious implications for conservation since spawning success of a population depends largely on females.

• Five sockeye that fell back from the Seton dam or lower Seton River were detected in the powerhouse tailrace on this Fraser River. This suggests that the tailrace may attract and delay sockeye even under the current Seton River dilution guidelines aimed at reducing this problem. The cause of tailrace attraction is unknown but it may involve attraction to homestream water, alternate route seeking behaviour by fallbacks, or utilization of a thermal refuge.

• Twenty percent of fish failed to pass the dam and fishway. We believe this failure rate is a conservative estimate because our subjects had prior experience in entering the fishway. Failure at the fishway was related to locating the entrance (i.e. attraction) and not ascent of the fishway itself. These findings were consistent with our previous study of fishway passage at the Seton dam in 2005 (Pon et al. 2006).

• Pooling results from 2005 and 2007 revealed that fishway attraction efficiency varied with spill discharge from the dam (range: 11 to 60 m^3/s). Attraction was the lowest (40%) and average delay (± SE) the longest (44.2 ± 20.9 hrs) during the highest discharge level of 60 m^3/s although sample size was small (n=5 fish). However, when considering all discharge levels studied, there was not a simple relationship between discharge levels and levels of attraction. This was also recognized by Pon (2008).

• Of fish that passed the dam and entered Seton and Anderson lakes, total in-lake mortality was 33% for fish released at the powerhouse tailrace and 19% for fish released in the lower Seton River, compared to only 7% of fish released upstream of the dam. The cause of in-lake mortality is not clear but it was probably not associated with stress or energetic costs incurred re-ascending the fishway. At least one tagged sockeye was captured by fisheries and it is possible that other fish that disappeared in the lakes were also harvested.

• Temperature loggers recovered from tagged sockeye and fixed stations indicated that fish generally did not encounter extremely stressful temperatures. Temperatures in the Seton River were cool (12-15 ^{o}C), and sockeye did not delay in cooler waters in Cayoosh Creek (11-12 ^{o}C), but could have utilized the powerhouse tailrace as a thermal refuge. Temperature exposure in Anderson Lake was highly variable and many sockeye utilized cool water refugia in the hypolimnion.

• Temporary blockage or obstruction in the fishway could have serious consequences for populations of migrating adult sockeye. We found that a small number of tagged sockeye fell back downstream when the upstream exit of the fishway was blocked during sampling and these fish generally did not re-ascend. Therefore, we recommend that the fishway is monitored and maintained frequently (daily) during the migration season so that blockages are cleared immediately. Furthermore, any new modifications to the fishway, such as fish enumeration devices, should be carefully evaluated in terms of their effects on passage (see also Pon et al., 2006)

• More research is needed to quantify delay, and ramifications of delay, when sockeye initially encounter the powerhouse tailrace on the Fraser River. This should involve a re-assessment of the 'dilution level' issue in terms of tailrace attraction, and examine the role of the tailrace as a thermal refuge. We cannot suggest management actions aimed at reducing tailrace attraction based on results of the present study.

• When possible, managers should strive to minimize relatively high discharge levels ($\geq 60\ m^3/s$) in the Seton River in order to facilitate sockeye passage. Management experiments which involve manipulating spill discharge in the Seton River are needed to better define the relationship between discharge level and passage success.

• Based on the combined results from our 2005 and 2007 studies, we conclude that failure to ascend the dam was primarily associated with locating the fishway entrance and not with passage of the fishway itself. Hydraulic conditions near the dam face vary widely with changes in discharge and this will affect orientation cues for salmon. As was recently suggested by Pon (2008), management experiments are needed which alter hydraulic conditions in the tailrace of Seton dam at a given discharge level (via different locales of water release from the various sluices), and assess delay and fishway attraction. Studies should also examine whether there is a threshold level of delay that causes salmon to fallback or seek alternate routes, reducing the probability of successful migration.

• Our estimate of passage failure at the fishway should be considered an underestimate. Future studies should sample fish that are "fishway-naïve" by catching sockeye in the lower Seton River. We attempted this with tangle and dip nets in 2007 but fish numbers were too low for these techniques to be effective and all indications are that these sockeye runs will not be large in the near future so this sampling problem will persist. We recommend using a fish weir with trap boxes in the lower Seton River, to be installed and operated during sockeye spawning migrations, during years when fish need to be captured for telemetry or biosampling to assess fishway performance and migration mortality.

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Introduction

Dams and other infrastructure built for hydroelectric power generation can act as a barrier to the migrations of fish, with serious consequences at both population and ecosystem levels (Sheer and Steel, 2006; Nilsson et al., 2005). Fishways can provide a route of passage around or over an obstruction and are an important tool used to re-connect habitats fragmented by dams. However, previous research has shown that fishway efficiency can be poor, and these facilities continue to impede migrations and contribute to declining fish populations (Williams et al., 2005). Consequently, there is a need to monitor and evaluate fishway performance after construction (Odeh, 1999).

The Seton Dam Fishway in South Western British Columbia was built in 1956 to restore connectivity in the Seton-Anderson watershed, an area affected by the Bridge Hydroelectric Complex. The system includes an inter-basin diversion into Anderson Lake, a diversion dam and fishway on the lower Seton River, and a penstock and powerhouse outflow into the Fraser River. The watershed supports populations of bull trout, rainbow trout, white sturgeon, mountain whitefish and several species of anadromous Pacific salmon (BC Hydro, 2000). Our research efforts focused passage of sockeye salmon through the Seton-Anderson watershed, including the Seton Dam Fishway.

Two populations of sockeye salmon (*Oncorhynchus nerka*), the Gates Creek and Portage Creek stocks, spawn upstream of Seton Dam and both have had declining spawning escapements in recent cycles (Gates and Portage ranked “critically endangered” and “vulnerable”, respectively; Salmonid Specialist draft report for the IUCN – Pete Rand, Wild Salmon Center, Portland, Oregon, pers. comm.). Along their migration route through the Seton-Anderson watershed, these two populations pass several locations that may slow, impede, or otherwise cause physiological stress to migrants. First, sockeye must pass a powerhouse tailrace that discharges homestream

Seton Lake water into the Fraser River 500 m downstream of the confluence of the Seton River. Telemetry research by the International Pacific Salmon Fisheries Commission (IPSFC) conducted 25-30 yrs ago (summarized in Fretwell, 1989) indicated that Gates and Portage sockeye often stopped their upstream migration at, and were injured in, the tailrace - their success rate in departing the tailrace, entering the Seton River, and reaching the dam ranged considerably depending on the Seton River water quality (the Seton River is an engineered mixture of Seton Lake water and Cayoosh Creek water) with higher Cayoosh Creek dilution levels resulting in higher migration failure. Even at the IPFSC recommended (and BC Hydro adopted) dilution levels of 20% and 10% during the Gates and Portage migrations, respectively, migration mortality rates of ~ 10% and 30% for these stocks respectively, occurred in the IPFSC studies.

Once sockeye enter the Seton River, they must travel 5 km to and ascend the Seton Dam Fishway, then migrate through Seton Lake (and Anderson Lake for Gates sockeye, ~ 50 km) to spawning grounds. In 2005 our research group conducted a detailed pilot study using physiological telemetry to assess the migration success of Gates and Portage sockeye through the fishway and surrounding area (Pon et al., 2006). We tagged Gates fish captured in the fishway and transplanted them a short distance downstream in the Seton River and found that 25% of these were unable to re-locate the fishway entrance - presumably this is a conservative estimate of how the population on a whole would respond because we did not tag fish that were not able to initially locate the entrance.

To make matters worse for Gates and Portage migrants, water temperatures in the Fraser River and its main tributaries have been increasing over the past 40 years with a > 1.5^{o}C increase in average summer temperatures, recent years exhibiting record high levels, and all climate models indicating even warmer peak temperatures in near future years (Patterson et al., 2007). Gates fish now typically encounter Fraser temperatures exceeding 18-19 ^{o}C, levels that are extremely stressful and prolonged exposure causes disease and migration mortality (Crossin et al., 2008; Young et al., 2006). Many Portage fish are migrating upstream 3-6 weeks earlier than normal (as are many other Late-run Fraser stocks; Cooke et al., 2004) exposing them to high temperatures like Gates sockeye. Ironically, the tailrace confluence may inadvertently provide a 'cool-water' refuge for Gates and Portage sockeye. However, fish which seek refuge here are delaying their migrations and delays of only a few days can lead to premature senescence and subsequent enroute mortality in Fraser sockeye (Hinch et al., 2006). During our study in 2005 we observed large groups of fish aggregating at the powerhouse tailrace but their stock composition, duration of migration delay, and fate were unknown (Pon et al., 2006).

In summary, a substantial portion of Gates and Portage sockeye are likely dieing between the powerhouse tailrace on the Fraser and spawning grounds, a relatively small part of their total migration route. In particular, previous research suggests that the powerhouse tailrace and the Seton Dam Fishway are two locales that may hinder sockeye migration. However, further research is needed to estimate delay and mortality at these locations, and to assess the impacts of hydroelectric facilities on sockeye migration success. Studies identifying locations and mechanisms of migration failure are necessary to suggest operation and design modifications that would improve fish passage and lessen the footprint impact of the dam. This report presents the findings of our study in 2007 examining sockeye migration through the Seton-Anderson watershed, including the Seton Dam Fishway.

Our basic approach was to use telemetry to track migrations and determine fish fate, and relate the results to environmental conditions encountered (e.g. discharge, temperatures) and physiological condition (stress or maturation levels measured from non-lethal biopsy). The first objective was to quantify mortality for different sections of the migratory route between the powerhouse tailrace on the Fraser River and spawning grounds at Gates Creek. Second, since the fishway may be the largest limiting factor for fish migrations, a detailed evaluation of passage efficiency, attraction, rates of passage and delay was conducted. The third objective was to experimentally assess the impact of the fishway and other sections of the migration route on migration behavior and fate. This objective was accomplished by transporting and releasing fish up- or down-stream, and comparing fate and rates of mortality between fish released upstream of the fishway and those released at sites downstream of hydroelectric facilities. Our last objective was to provide recommendations for management options and experiments, and directions for future research.

Study goals and objectives

1) Quantify mortality for different sections of the migratory route between the powerhouse tailrace on the Fraser River and spawning grounds.
2) Evaluate fish passage at the Seton Dam Fishway by quantifying attraction efficiency, passage efficiency, rates of passage and delay.
3) Experimentally assess the impact of the fishway and other sections of the migratory route on migration behavior and fate.
4) Overview a need for management experiments and future research.

Methods

Study fish

To assess sockeye migration through the Seton-Anderson watershed, we used fish from the Gates Creek population exclusively in 2007. In that year, the run size for Portage Creek sockeye was very small, and this stock co-migrated with a large run of pink salmon that would have made it difficult to catch sufficient numbers of Portage fish. In addition, since we have better estimates of mortality for Gates than Portage fish in 2005, a focus on Gates fish also allowed us to make better inter-annual comparisons of results. Since the migration route is shared, our results should also be applicable to Portage Creek fish. Gates sockeye are part of the summer run stock complex and most of the population spawns in an artificial spawning channel approximately 1 km upstream of the mouth of Gates Creek. A smaller number of fish spawn in the Creek itself either downstream or upstream of the channel.

Study area and hydroelectric facilities

We tracked sockeye between the powerhouse tailrace on the Fraser River, near Lillooet, BC, and spawning areas at Gates Creek, near D'Arcy, BC (Figure 1). Specifically we tracked fish along the following route: the Fraser River between the powerhouse tailrace and the confluence of the Seton River (1.2 km), the lower Seton River from the mouth to the Seton River dam (4.4 km), Seton Dam Fishway, Seton Lake, Portage Creek (a 6km long tributary connecting Anderson and Seton Lakes), Anderson Lake, Gates Creek, from the mouth to spawning channel in D'Arcy, BC (Figures 2 and 3). The Seton Dam is a diversion dam spanning the Seton River and is located 760 m downstream from Seton Lake (Figure 3). The dam is 7.6 m in height and consists of a radial gate spillway, five siphon spillways, a fish water sluice and a vertical-slot fishway (Figure 4). A canal extends from the diversion dam 3.8 km to a powerhouse located on the Fraser River downstream of the confluence of the Seton and Fraser Rivers. The downstream end of the canal feeds into a 5.5 m diameter penstock that runs an additional 113 m to a single 58, 500 horsepower turbine located within the powerhouse. Operational flow is provided in part from water diverted from Cayoosh Creek, which is routed through a 490 m tunnel from a dam on Cayoosh Creek to Seton Lake. Cayoosh Creek water not diverted to Seton Lake enters Seton River 1.3 km downstream of the Seton Dam. Additional water for the powerhouse is diverted from the Bridge River watershed, located adjacent to the Seton basin, into Seton Lake. There are two artificial spawning channels on the lower Seton River that were built to compensate for the pink salmon spawning habitat lost at the outlet of Seton Lake when the dam was built. These channels have helped restore the pink salmon population but are not used for spawning by sockeye, coho, Chinook or resident trout species (BC Hydro, 2000). Additional information regarding hydroelectric facilities in the area can be found in Andrew and Geen (1958).

Seton Dam Fishway

The Seton Dam Fishway is a vertical slot type fishway, consisting of a baffled concrete channel extending a total distance of 107 m. It consists of 32 pools and makes two 180^{o} turns (Figure 5). At each pool, the fishway ascends 0.23 m in elevation, for a total elevation gain of 7.4 m. This equates to an overall grade of 6.9%. Typical pools found between vertical baffles within the fishway channel measure 2.4 m in width by 3 m in length. Vertical slot fishways are designed to create complex flow patterns that improve the dissipation of energy within each pool (Clay, 1995). These complex flows include low velocities and reverse flows, creating areas of refuge for fish to use during fishway ascent. Water passes among pools via vertical slots measuring 41 cm in width, with maximum flow velocities of approximately 1.3 m^3/s. Water depth within the fishway is approximately 1.5 m, and because the vertical slot extends to the bottom of the fishway channel, fish may pass between pools at any chosen depth. The two pools found at points where the fishway makes a 180^{o} turn are roughly twice the length of regular pools and are characterized by a greater availability of low velocity refuge areas.

The entrance to the fishway is located on the dam face of the river right side of the channel (Figure 5). Fish are attracted to the entrance of the fishway by flows released through the six siphon valves. The siphon valve located closest to the fishway is positioned slightly lower than the other siphons in order to create flows that attract fish as close as possible to the entrance. This ‘fish-water sluice’ provides further attraction flow via water discharged through a gated opening submerged adjacent to the fishway entrance.

Fish capture, transport and recovery period

All study fish were captured by dip-net from the top pool of the Seton Dam Fishway while using a removable screen gate to block the upstream exit. Although the original protocol was to collect fish in the Seton River downstream of the dam by tangle net, abundance of Gates sockeye was unexpectedly low (early-summer run size was less than 25% of pre-season forecast) and it was not possible to capture adequate numbers in the proposed location.

Capture and transport of sockeye can cause certain blood metabolite and hormone levels to be elevated (Kubokawa et al., 1999). Because one of our objectives was to relate initial physiology to ultimate fate, and some fish would be released at the capture locale whereas others would be transported then released, we needed to evaluate and control for the effects of transportation. We held most of our fish for a 5-hour in-river recovery period after capture, but before biopsy sampling, and release. During this holding period the metabolite levels should have returned to near baseline (Portz, 2006; Milligan et al., 2000). An additional 20 sockeye were biopsy sampled, tagged and released without a recovery period to compare initial physiology of fish which were held to those not held.

After capture from the fishway, sockeye were transferred to an aluminum transport tank (approximately 1 m x 1 m x 1.5 m) that was filled with fresh river water and continuously aerated with 12-inch air diffuser (Sweetwater®, Aquatic Eco-systems Inc., Apopka, FL, USA). Fish were then transported by truck to one of the release sites (see below) where they were held for recovery, then tagged, biopsied and released. A 4 m x 8 m x 4 m enclosure consisting of an aluminum tubing frame, vinyl sides and bottom, and nylon mesh ends was used to hold fish during the recovery period. The enclosure was placed in the river at the release site such that a steady current passed through it, requiring the fish to swim slowly against the current to maintain position but without becoming exhausted. A maximum of 12 fish were transported in the tank and then recovered in the enclosure at one time. After recovery, biopsy, and tagging fish were released in one of three locations (Figure 3): 1) Powerhouse tailrace on the Fraser River (hereafter 'tailrace'; n=33), 2) lower Seton River at Cayoosh Creek confluence (hereafter 'Cayoosh'; n=27), 3) Seton Lake near outflow (n=8). The 20 fish released without a recovery period were released directly upstream of the dam into Seton River after processing.

Fish handling and sampling

For tagging and sampling, fish were placed in a V-shaped trough filled with water. The trough was lined with foam, contained an integrated measuring tape and was supplied with fresh river water from a hose directed towards the mouth of the fish. The trough was angled slightly so that the water was deep enough to cover the entire head of the fish while leaving the caudal peduncle only partially submerged. The capture and tagging team consisted of at least three individuals. Members of our research team at the University of British Columbia pioneered a novel technique for linking individual physiological status with behaviour and fate. We have used this approach extensively for assessing the migration biology of sockeye salmon (Crossin et al., 2008 Cooke et al., 2006; Pon et al., 2006; Young et al., 2006) and have shown that these handling and sampling approaches have no negative effects on salmon migration behaviour, survival or spawning (Cooke et al., 2005). The approach is summarized below.

Tagging and physiological biopsy

First, fish were restrained in the trough. One individual held the head of the fish with one hand, gently covering the eyes and keeping the head down, and held the caudal peduncle with the second hand, restraining the tail. When the fish was restrained, a second individual who performed tagging and sampling stood at the end of the trough and gripped the caudal peduncle with one hand. At this point, the first individual moved their hand slightly anterior on the caudal peduncle to provide room for the hand of the blood sampler but while still assisting with restraining the tail. Using their other hand, the sampler aligned a Vacutainer syringe (1.5", 21 gauge) with the caudal hemal arch and when the fish was still, plunged the syringe into the caudal vessel. Detailed descriptions and diagrams of caudal sampling blood from fish can be found in Houston (1990). The Vacutainer (3 ml) was then activated, usually resulting in the immediate collection of blood. On some occasions, the fish would move, bending the needle or terminating the vacuum, or blood did not immediately begin to enter the vacutainer. If subtle adjustments to the position of the syringe did not remedy the problem, the blood sampler then used a new, pre-rigged vacutainer and syringe. If the blood was not drawn within 1 minute, blood sampling was abandoned, but tagging and release proceeded. The restrainer maintained their grip on the caudal peduncle and applied light pressure to the puncture site to facilitate clotting.

Next, a small tissue sample was removed from the adipose fin using a hole punch and stored in ethanol for later DNA analysis. The fork length of the fish was recorded to the nearest 5 mm. A microwave energy meter was used to assess somatic lipid concentrations (Distell Fish Fatmeter model 692, Distell Inc., West Lothian, Scotland, UK; see Crossin and Hinch, 2005). This hand-held device houses a microwave oscillator that emits a low powered wave (frequency, 2 GHz, 2000 MHz; power 2 mW) that interacts with water in the somatic tissues. Drawing from the strong, inverse relationship between the water and lipid content in fish tissues, microwave sensors convert water concentration to estimates of lipid concentration. The energy meter requires that the fish be held slightly out of water, straight and generally relaxed. The probe of the energy meter was placed on the left side of the fish in two locations to obtain measurements of the energetic status. Data collected from sockeye by the energy meter were converted to estimates of gross somatic energy (GSE) density following relationships described in Crossin and Hinch (2005). Next, sockeye were marked with an external tag (FT-4 Cinch-up, Floy Tag Inc., Seattle, WA) attached through the dorsal musculature immediately anterior to the dorsal fin using a hollow needle. The external tag permitted visual identification of study sockeye on spawning grounds, or if they were caught by fisheries.

The final step of the biosampling and tagging process involved the insertion of an acoustic telemetry transmitter in the stomach using a plastic tag applicator (Ramstad and Woody, 2003). Transmitters were V16-1H-R64K coded pingers from Vemco Inc. (Shad Bay, NS) that were 54 mm in length, 16 mm in diameter and weighed 20 g in air and 9 g in water. All transmitters were activated the day before deployment and tested to ensure that they were functioning properly before insertion. After tagging fish were released directly into the water at the release site and upon release all fish swam away strongly.

Thermal logging and discharge data

Small archival temperature loggers were fastened to all telemetry transmitters with a non-toxic adhesive before transmitter insertion. Temperature loggers were iButton Thermochrons (model DS1921Z, Dallas Semiconductor Maxim, Sunnyvale, CA, USA) that were the same diameter as transmitters, and when attached increased the length of the transmitter by 4 mm. Loggers were set to record temperature once every hour (± 0.1^{o}C) and provided detailed records of temperatures experienced by sockeye during migration. However, since the loggers store data internally, temperature profiles were only obtained for fish recovered on spawning grounds or returned from fisheries. Thermal loggers were also attached to each telemetry receiver to provide a record of lake, river and fishway water temperatures. Daily records of the discharge from Seton dam and Cayoosh Creek, and the ratio of Seton Lake to Cayoosh Creek water in the Seton River downstream of Cayoosh Creek were obtained from BC Hydro.

Tracking and telemetry receiver array

After release individual fish movements were tracked via a fixed array of telemetry receivers deployed along the migratory route. These receivers (model VR2, Vemco Inc., Shad Bay, NS) were deployed under water and logged transmitter signals (individual code, time and date) for each fish while it was within a given receiver's detection zone. Receivers were placed in strategic locations along the migratory route such that fish were detected at various checkpoints as they moved through the watershed. In total, 17 receivers were deployed between the power house tailrace and Gates Creek spawning channel (Table 1), including one at the tailrace, two in the lower Seton River, two immediately downstream of the dam, and four in each of Seton and Anderson Lakes (Figures 6 and 7). In addition three receivers were deployed inside the fishway. One receiver was placed in pool 3 to detect entrance into the fishway and a second receiver was placed near the halfway point in pool 17, where the channel makes a 180^{o} turn (Figure 5). The third receiver was placed in the top pool of the fishway (pool 32) to detect fish that successfully ascended the entire fishway (Figure 5). These three receivers were strategically located in pools that would allow us to discern entry and ascent and that would also maximize detection rates (i.e. large pools where fish spent time resting). To detect fish when they reached the bottom of the dam (but prior to fishway entry), one receiver was positioned at the downstream end of the radial gate spill channel and a second receiver was positioned ~80 m downstream from the dam in a deep pool. These two receivers were considered redundant to each other, so that a fish detected on either one of these receivers was known to have reached the area below the dam. Telemetry receivers in the lakes were either suspended in the water column using sandbags, rope and subsurface buoys or fixed to structures (e.g. docks, deadheads). Receivers in the river were fixed to the substrate using rebar and cinder blocks.

Physiological analysis

Stock identity (i.e. Gates Creek population) was confirmed for all study fish using DNA analyses conducted at the Pacific Biological Station in Nanaimo, BC (Beacham et al., 1995, 2004). Blood plasma samples were analyzed for ion (Na^+, K^+, Cl^-), lactate, and glucose concentrations, and for total osmolality. After centrifugation in the field, plasma samples were immediately placed in liquid nitrogen, and then transferred to storage at -80^{o}C for subsequent analysis in the laboratory. Plasma lactate and glucose concentrations were measured using YSI 2300 STAT Plus glucose and lactate analyzer (YSI Inc., Yellow Springs, OH, USA). Plasma chloride concentrations were measured in duplicate using a model 4425000 digital chloridometer (Haake Buchler Instruments, Saddle Brook, NJ, USA). Concentrations of plasma sodium and potassium ions were measured using a model 510 Turner flame photometer (Palo Alto, CA, USA). Plasma osmolality was measured using a model 5500 vapour pressure meter (Vapro, Wescor, Logan, UT, USA). Detailed description of all assays presented here including inter-assay variability and quality control criteria are provided in Farrell et al. (2001).

Data Analysis

Data from telemetry receivers were downloaded and detection efficiencies for each of the receivers were calculated using the method of Jolly (1982) as described in Welch (2007). For detection efficiencies at receivers that were positioned at fish release sites (receivers 1 and 3), fish that were released at a particular site were not counted for efficiencies at that receiver, since sockeye often moved upstream immediately after release before they could be detected. Therefore, because no fish were released downstream of the tailrace, there is no detection efficiency for receiver 1. As calculating detection efficiency for a given receiver requires that there is an upstream receiver, efficiency could not be calculated for the receiver near spawning grounds (#17).

Individual migration fates and travel times for different sections of the migratory route were calculated. Individuals were categorized as successful migrants if they reached receiver 17, the inflow of Anderson Lake. This location was used as a proxy for the spawning grounds since a receiver in Gates Creek or the spawning channel would have poor detection efficiency, and spawning areas are a very short distance upstream from the Anderson Lake inflow. Individuals were categorized as failed migrants if the transmitter (and presumably the fish) stopped moving upstream before reaching receiver 17 and was either continuously detected on a receiver or moved downstream out of the detection zone and did not return. Travel times for different reaches were calculated by the difference between the first detection at the upstream end of a reach and the last detection at the downstream end of a reach.

Analysis of variance (ANOVA) was used to compare energetic status, size, physiological variables and continuous measures of fish behavior (e.g. fishway ascent time) between sexes and treatments. Relationships between physiological variables and continuous measures of fish behavior were assessed using Pearson's correlation. Chi-square tests were used to compare survival among groups of fish (i.e. sexes, recovery treatments and release locations) if all groups had at least five individuals. Otherwise Fisher's exact test was used to compare survival. For all analyses, variables that did not meet model assumptions were $\log_{10}$-transformed to reduce heteroscedascity and better meet normality. A confidence level of 0.05 was used but Bonferonni corrections were made when there were multiple comparisons.

Results

Eighty-eight sockeye were caught and tagged between the 15th and 24th of August, 2007. All telemetry receivers were successfully recovered in late September and October. Tagging date, release location and fate of all fish is provided in Table 2. In total, there were 33 fish released into the powerhouse tailrace, 27 fish released into the lower Seton River at Cayoosh Creek, 8 fish released into Seton Lake near the mouth, and 20 fish released upstream of the dam without a recovery period. DNA analysis indicated that one fish released at Cayoosh Creek that left the Seton system and was never detected was a stray from the Chilko stock, so this fish eliminated from all analyses.

During analysis on the telemetry data, we observed that a few fish ascended the fishway and arrived at the top of pool during times when we were capturing and tagging fish. Since a gate was used to block the upstream exit of the fishway during these times, these recently tagged fish were unable to exit the fishway. Three of these fish (two released at Cayoosh and one released at the tailrace) descended and exited the fishway and were not subsequently detected in the fishway. These fish were not used in analyses of ultimate fish fate. However, data from these fish were used for analyses concerning behaviour prior to their encounter with the gate at the top of the fishway (i.e. travel from release to dam, fishway attraction and passage).

Detection efficiencies for each of the telemetry receivers in the array are presented in Table 1. Detection efficiency was 100% for all stations in Seton and Anderson lakes whereas efficiencies in the river environment were lower, ranging from 48% to 98%. Because the two receivers in the lower Seton River (#2 and 3) did not have good detection efficiencies, it was not possible to definitively distinguish between fish released at the powerhouse tailrace that failed to enter the Seton River and those that entered the Seton River but failed to reach the dam. Together, the two receivers immediately below the dam (#4 and 5) had an efficiency of 95%, indicating a good ability to detect fish that reached the dam. Receivers in the fishway had efficiencies of 100%, 74% and 91% for the stations at the top, middle, and bottom, respectively. Thus, the ability to detect fish that entered the fishway was quite high (91%) and if the bottom and middle fishway receivers were used together (redundantly) to detect fishway entrance, efficiency improved to 95%. Therefore, we had excellent ability to quantify mortality of fish prior to reaching the Seton Dam Fishway, in ascending the Seton Dam Fishway, and in reaching spawning grounds.

Physiological and energetic assessments

Exploratory multivariate analyses indicated that males and females differed with respect to our physiological measures; therefore, sex was included as a factor in statistical models. Table 3 shows mean values of length, energy and physiological variables for male and female sockeye that were held for a recovery period prior to sampling and release (hereafter 'recovered') and for sockeye sampled and released immediately after capture ('control'). Two-way ANOVA models showed significant differences after Bonferonni correction (all *P*-values < 0.005) between recovered and control fish for the variables testosterone, glucose, K^+, and length (Table 4). Males and females differed in terms of cortisol, testosterone, glucose, Na^+, K^+, and GSE after Bonferonni correction (all *P*-values < 0.005), and the interaction between treatment and sex was significant for the variables glucose and K^+ (both *P*-values < 0.005; two-way ANOVA; Table 4). The sex-specific hormone estradiol was not different between recovered and control females (one-way ANOVA, p=0.43). There were no significant differences in energy, length or physiological variables between successful migrants and en-route mortalities (Table 5).

Objective 1 - Quantify mortality for different sections of the migratory route

Table 6 summarizes the fate of sockeye from the four release sites. In Table 7, the same data are used to show the percentage of tagged sockeye within each section of the migratory route that failed. Some fish released at the two sites downstream of the dam failed in the lower Seton or Fraser River before reaching the dam and fishway. After release 13% of tailrace fish and 15% of Cayoosh fish were never detected at, and are assumed to never have reached the area downstream of the dam. In fact, two fish released at the tailrace and one released at Cayoosh were never detected anywhere in the system, and, since all tags were known to be functioning properly, are presumed to have moved back into the Fraser River.

Interestingly, five fish released at Cayoosh were detected downstream at the powerhouse tailrace on the Fraser River. Of these, three later moved upstream and passed the fishway and one moved to the tailrace shortly after release and was detected there on several subsequent days but never again in the Seton system. The fifth fish (#30, Table 2) initially moved upstream after release, and was detected on four consecutive days below the dam, before moving downstream to the powerhouse tailrace where it was last detected.

Fish released at Cayoosh Creek or the powerhouse tailrace had similar rates of failure at the fishway. Of the fish released at the tailrace, 17% of the total released, or 18% of those that reached the bottom of the dam, failed to pass the fishway. Of the fish released at Cayoosh, 19% of all fish released, or 22% those that reached the bottom of the dam, failed to pass the fishway. A more detailed assessment of fishway attraction and passage is provided in the results for Objective 2.

Once upstream of the dam, all of the fish released at Cayoosh proceeded through Seton Lake and into Anderson Lake, except for one fish that passed through Seton Lake but was captured by fisheries in Portage Creek. However, 19% of fish that were released at the tailrace and passed the dam (or 10% of total tailrace release group) stopped their migrations at, and were last detected in Seton Lake. Of the fish that entered Anderson Lake, 18% of tailrace fish and 19% of Cayoosh fish never reached the final receiver at the Anderson Lake inflow and were therefore not successful migrants. These proportions represented 13% and 12% of the total tailrace and Cayoosh releases, respectively.

Overall, mortality in different sections of the migration route was similar between fish released at the two sites downstream of the dam. Therefore, fish from these two release sites were pooled to compare migration failure in the system. The percent of fish that failed within each section was 14% from the release site to the dam, 20% at the dam/fishway, 11% in Seton Lake and 18% in Anderson Lake (Table 7). The total loss of migrating sockeye between release sites downstream of the dam and spawning grounds was 52%. Over half of this loss (32%) occurred in the 4.4 km reach between the Fraser River and the top of the fishway. The remaining sockeye mortality (20%) occurred between the outlet of Seton Lake and spawning grounds.

During their migration through the lower Seton River, some sockeye were delayed at the lower artificial spawning channel (Figure 3). One sockeye tagged and released at Cayoosh Creek, as well as several untagged sockeye were observed in the channel, most often at the upstream end where the channel forms a dead end. Sockeye appeared to be actively seeking upstream passage at the dead end. Between two and eight sockeye were observed every day the channel was checked (eight days total) between August 21st and September 4th. The amount of time spent by individual sockeye in the spawning channel is unknown. However, anecdotally, the tagged sockeye was not present in the channel the day after it was first observed but one untagged sockeye identified by morphology (i.e. scars and pattern of fungus infection) remained in the channel at least two days. No sockeye carcasses were ever observed in the channel.

Archival temperature loggers were recovered from 24 sockeye on spawning grounds and from one sockeye captured by fisheries in Portage Creek. Temperature exposure during migration to spawning grounds is compared among all 25 fish in Table 8, and individual temperature profiles are presented in Appendix 1. Although temperature in the Fraser River (~16-17^{o}C) was slightly warmer than the Seton River (~12-16^{o}C; Figure 8), sockeye released into the tailrace were not often detected in temperatures above 16^{o}C, suggesting that they did not remain in the Fraser River long enough for hourly temperature sampling to detect these warmer waters. Sockeye typically experienced temperatures between 12 ^{o}C and 15 ^{o}C in Seton River. The data logger in Cayoosh Creek indicated that temperatures there were cooler (11-12 ^{o}C) than Seton River (Figure 8), but sockeye apparently did not enter these cooler waters. Temperatures experienced while in Seton Lake were also typically between 12 ^{o}C and 15 ^{o}C. The warmest temperature encountered by sockeye ranged from 17-20 ^{o}C and corresponded to migration through Portage Creek. However, the amount of time spent in Portage Creek was in most cases less than 24 hours (mean=12.7 hrs, SE=1.0, n=60, maximum=31 hrs). Temperature exposure was most variable while sockeye were in Anderson Lake. Most sockeye experienced temperatures cooler than 10^{o}C and some individuals recorded temperatures near 5^{o}C. However, many fish were also frequently detected in waters between 12 ^{o}C and 17 ^{o}C while in Anderson Lake. Dilution of Seton River by Cayoosh Creek water was between 2% and 6 % during the study period (Table 9).

Objective 2 - Evaluate fish passage at the Seton Dam Fishway

The efficiency of fishways can be divided into two components, attraction efficiency, the proportion of individuals that are able to locate the entrance to the fishway, and passage efficiency, the proportion of individuals that are able to ascend and exit the top of the fishway once they have initially entered. Fifty-one tagged sockeye (fish released at Cayoosh and tailrace were pooled for this objective) are known to have reached the Seton Dam. Since 44 of these located and entered the fishway, the attraction efficiency was 86%. Only three of the fish that entered the fishway failed to ascend and exit the top, thus, the passage efficiency was 93%.

Migratory delay associated with locating the fishway entrance was calculated by the difference between the first detection below the dam (receiver 4 or 5) and the first detection at the bottom of the fishway (receiver 6). The average delay below the dam was 16.3 ± 3.1 hours (mean ± S.E.; n = 40) with a range of 0.49 to 92.6 hours. Once inside the fishway, fish passed quickly with a mean ascent time (difference between first detection at receiver 8 and first detection at receiver 6) of 37.8 ± 4.6 min (mean ± S.E.; range 9.8 – 140.5 min; n = 36). Neither below dam delay nor fishway ascent time differed between males and females (P=0.81 and P=0.94, respectively). Total passage efficiency, behavior and river conditions are compared between 2007 and the study in 2005 in Table 10.

There were two different spill discharges from Seton Dam during times that sockeye were released and were migrating past the fishway in 2007 (Table 9). During the highest flow (~60 m^3/s), 28 sockeye were released at sites downstream of the fishway but only five of those were detected at the dam before flows were reduced on August 20th. Of those five, two entered the fishway after relatively short delays (7.0 and 11.6 hours), one never entered at all, and two had long below-dam delays (65.5 and 92.6 hours) and did not enter until after discharge ramped down to ~35 m^3/s. The remaining 39 sockeye reached the bottom of the dam during a discharge of 35 m^3/s. In comparison, discharges from Seton Dam were much lower during the Gates sockeye migration in 2005, ranging from 11 m^3/s to 15.8 m^3/s (Pon 2008; Table 10). We pooled results from these two years and compared attraction efficiency and delay before entering the fishway during five different discharges (Figure 9). Physiological variables were not significantly correlated with below dam delay or fishway ascent times for females (Table 11). For male sockeye, Na^+ was correlated with fishway ascent time (r=0.73, P=0.011) and GSE was correlated with below dam delay (r=-0.71, P=0.010) at a confidence level of 0.05 but the correlations were not significant after Bonferonni correction.

Objective 3 - Experimentally assess the impact of the fishway and other sections of the migratory route on migration behavior and fate

Fish transported and released downstream of the fishway experienced high mortality en route to spawning grounds compared to those released upstream. Only 47% of sockeye released at the powerhouse tailrace and 50% of sockeye released into the lower Seton at Cayoosh Creek successfully reached spawning grounds. In contrast, survival to spawning grounds was high for recovered sockeye released into Seton Lake (88%) and for control fish released immediately upstream of the dam (95%). Migration success was not different between recovered and control fish released upstream of the dam (*P*=0.50) and these groups were pooled for comparisons of survival. Survival to spawning grounds for sockeye released downstream of the dam was greater for males (71% of 17 fish) than for females (40% of 38 fish; *P*=0.03). Survival in sockeye released downstream of the dam was not related to timing within the season since mortality among fish released in the early, (17-19 August; 48%, n=25), middle (20-21 August; 60%, n=15), or late (23-24 August; 46%, n=15) portion of our tagging period was not statistically different (*P*=0.71).

The proportion of fish that did not reach Seton dam (receiver 4 or 5) from the release site was very similar between fish released at the tailrace (15%) and fish released at Cayoosh (13%). For fish that passed the dam and entered Seton and Anderson lakes, total in-lake mortality was 33% for fish released at the tailrace and 19% for fish released at Cayoosh, compared to only 7% of all fish (recovered and control pooled) released upstream of the dam.

For fish released downstream of the dam that did enter the fishway, the time spent below the dam before entering was not different between tailrace and Cayoosh fish (*P*=0.60). Similarly, fishway ascent time was not different between fish released at Cayoosh and those released at the tailrace (*P*=0.94). Rates of travel through Seton Lake and Anderson Lake were not different among fish released upstream of the dam, at Cayoosh, or at the tailrace (Seton travel time, *P*=0.16; Anderson travel time, *P*=0.63). Since travel times, ascent times, and failure in different reaches along the migration route were not different between fish from the two release sites downstream of the dam, these individuals were pooled to discuss fate and behavior in the system.

Discussion

Physiology, handling and transport

Physiological sampling was used to assess the condition of migrating sockeye and to compare measures of physiological stress, maturation and energy status between fate groups and recovery treatments. Overall, measures of blood physiology were similar to 'normal' values for up-river migrating sockeye suggesting that fish were not exhausted or particularly stressed after fishway ascent. Plasma lactate levels of control and recovered fish (1.3-2.2 mmol/L for males and females; Table 3) were lower than levels previously reported for adult sockeye in the late stages of migration (e.g. 4.5 ± 0.1 mmol/L; Young et al. 2006) and much lower those of sockeye exercised to exhaustion in a swim tunnel (6.1 ± 1.2 mmol/L; Wagner et al., 2006). Compared to sockeye sampled immediately after ascent of Seton Dam Fishway in 2005 (2.5 ± 0.2 mmol/L; Pon et al., 2006) lactate was similar but slightly lower in 2007. Plasma glucose, cortisol, and ion concentrations were also similar to levels reported in the literature for sockeye during late stages of migration (Crossin et al., 2008; Young et al., 2006; Pon et al., 2006), although cortisol and glucose in females was slightly elevated.

We also compared blood physiology between recovered and control fish. It was thought that sockeye that had just swum through turbulent tailrace flows below the dam and ascended the fishway would have elevated lactate. In addition, transportation from the capture site to the release site could result in a stress response and elevated stress measures compared to control fish. Previous research has shown that rainbow trout exercised to exhaustion and recovered individually in sustained water flow had improved recovery compared to fish held in still water (Milligan et al., 2000). Hence, we predicted that recovered fish would have lower plasma lactate concentrations than control fish. We found that lactate was lower in recovered than control fish in both males and females but the difference was not statistically significant. If sockeye that had ascended Seton Dam Fishway were not anaerobically exhausted or particularly stressed, and thus did not have elevated lactate, then there would be little scope for lactate clearance and recovery.

This may explain why the difference in lactate concentrations between recovered and control fish was not significant.

There were, however, significant treatment (recovery) effects on testosterone and K^+, which were both lower in recovered fish, and on glucose, which was higher in recovered fish. The elevated glucose and depressed testosterone may have been related to confinement stress associated with transport and recovery. Corticosteroids like cortisol are known to increase in confined salmonids, which can lead to glucogenesis and increased plasma glucose (Portz, 2006; Kubokawa et al., 1999). High levels of cortisol are also associated with depressed reproductive hormone levels in sockeye (Hinch et al., 2006; Kubokawa et al., 1999). In our study, confinement stress in recovered sockeye may have caused corticosteroid response that lead to increased plasma glucose and depressed testosterone concentrations. Cortisol may not have been different at the time of sampling (5 hours after confinement) because it is a fast and transient response that can return to normal levels after 60 minutes of confinement (Portz, 2006). Females had a greater increase in glucose than males, which is consistent with previous studies where stress response was greater in females migrating through difficult reaches (Hinch et al., 2006). The difference in K^+ is somewhat difficult to interpret. Concentration of plasma K^+ was lower in recovered than control females, but higher in control males than recovered ones. Loss of ions can be a sign of chronic stress for salmon in freshwater, but here the direction of the recovery effect depended on sex (there was an interaction) and the means values of K^+ for all groups were similar to generally unstressed fish.

Overall, the recovery treatment did not seem to have a large effect on sockeye physiology. Sockeye did not have elevated exercise metabolites and were not particularly stressed after fishway ascent, and so the subsequent recovery period did not unduly influence these measures. Instead we observed a moderate stress response to confinement as indicated by elevated glucose and depressed testosterone in male and female sockeye. Although these measures were different between control and recovered fish, the values were still within the range expected for healthy sockeye in the late stages of migration and therefore not such that we would expect any differences in behavior or survivorship. Indeed, sockeye that were transported and released into Seton Lake (SL; Figure 3) had similarly low mortality rates (12%) compared to fish released upstream of the dam without transport or recovery (5%, AB; Figure 3). Furthermore, there were no strong correlations among physiological variables and migration behaviour (Table 11). The only significant relationships were between GSE and below dam delay (r = -0.7), and Na^+ and fishway ascent time (r = 0.73) for male sockeye, although the relationships were not significant after Bonferonni correction. If these relationships are real, then it is difficult to imagine why higher Na^+ would be related to faster ascent time or why sockeye with lower energy would have longer delays. One might predict that lower energy would be associated with faster migration since these individuals would be more mature and closer to spawning. Regardless, the general trend was that neither behaviour nor fate seemed to be linked to physiological condition of sockeye in our study.

Our research group has conducted previous studies in which sockeye were transported downstream of a hydraulically challenging reach (Hinch and Bratty, 2000) or from a tributary back down into the Fraser main-stem (Crossin et al., 2008). In both cases most sockeye migrated quickly back to the release site, and there was no indication that enroute losses were greater than during the initial ascent. Therefore, based on our physiological sampling, similar mortality between transported and control groups (release sites SL and AB; Figure 3), and previous research transporting and releasing sockeye at downstream locations, it seems unlikely that our handling, transportation and recovery unduly influenced subsequent migration.

Migratory behavior and fate

We quantified mortality in specific sections of the migratory route of Gates Creek sockeye between the powerhouse tailrace on the Fraser River and spawning grounds at Gates Creek. Although total en-route mortality for fish released downstream of Seton dam was high (52%), failure did not occur predominantly in any one reach. Instead, we observed failure rates between 11% and 20% in each section (Table 7).

Attraction to and delay at the powerhouse tailrace has previously been identified as a factor impeding spawning migrations of Gates Creek sockeye (Fretwell, 1989). In our study, 13% of 27 sockeye released into the powerhouse tailrace did not reach Seton dam. However, because detection efficiency was poor at the two stations closest to the mouth of the Seton (#2 and 3; Table 1), we do not know whether these fish failed to enter the Seton River, or entered the river but fell back before reaching the dam. Some sockeye may have been attracted to the outflow of homestream Seton Lake water at the tailrace and never migrated into the Seton River itself. Fretwell (1989) suggested that if dilution of the Seton River by Cayoosh Creek water was less than 20%, then Gates sockeye would not show a preference for pure Seton Lake water discharged at the tailrace. Dilution levels in 2007 were 2-6% (Table 9) and therefore less than Fretwell's (1989) proposed detection limit (20%).

It could also be that sockeye were attracted to cooler water temperatures in the powerhouse tailrace. Water temperatures in the Fraser were approximately 1-2 ^{o}C cooler than water in the powerhouse tailrace in 2007 (Figure 8). Although water temperatures in the Fraser River were not extremely high in 2007, sockeye are known to behaviorally thermoregulate by seeking out the coolest waters available (Farrell et al., in press). Hence, a small difference in temperature, such as that between the powerhouse tailrace and the Fraser River, can be important and may attract migrating sockeye. Furthermore, at times when temperatures exceed 18^{o}C in the Fraser River (i.e. earlier in the migration season or years of warmer temperatures; Patterson et al,

2007) attraction to the powerhouse tailrace as a thermal refuge is likely much greater. Based on our data, and because of poor detection efficiency by acoustic receivers in the noisy environment near the outflow, it is difficult to say how much sockeye may have used the tailrace as a thermal refuge and the issue requires further study.

To assess the impact of the powerhouse tailrace we compared the success of sockeye released into the Seton River at Cayoosh Creek and those released into the powerhouse tailrace. A similar number of fish from these groups failed to reach Seton dam from the release site (15% for Cayoosh group, 13% for tailrace group; Table 7). Interestingly, five sockeye released in the Seton River at Cayoosh were detected downstream at the powerhouse tailrace. Some of these fish were detected at the powerhouse tailrace several days after release or after failing to locate the fishway entrance. These observations suggest that tailrace attraction, particularly in combination with difficulty in locating the fishway entrance, causes delay and may contribute to migration failure for sockeye salmon, even at the recommended and adopted Cayoosh to Seton River water dilution levels (Fretwell, 1989). The fact that fish released in the lower Seton River at Cayoosh were detected at the tailrace supports the idea that homing sockeye may have a "short-term memory" for water odour (Cooper and Hasler, 1973), and may be able to recall the tailrace as an alternative route containing homestream water if they cannot pass the dam and fishway (Fretwell, 1989).

It was surprising that some fish failed in the lower Seton River before reaching Seton Dam. For sockeye that were released at Cayoosh Creek or those released at the tailrace that migrated into the Seton River, the distance to the dam is relatively short (4.4 km from the mouth of the Seton River, 1.3 km from Cayoosh) and probably not hydraulically challenging for strong swimming fish like sockeye salmon. Since Cayoosh Creek was approximately 2 ^{o}C cooler than the Seton River, it presented another potential thermal refuge. However, sockeye were not often detected on the receiver at the mouth of Cayoosh Creek, and loggers did not indicate exposure to temperatures cooler than the Seton River for most sockeye, suggesting that sockeye did not use this thermal refuge.

Previous radio-telemetry research investigating migratory delay at the tailrace also showed some failure in the lower river, even at the recommended Cayoosh:Seton dilution levels of less than 20% (Fretwell, 1989). In studies conducted between 1979 and 1982, 7% of attempts to move upstream by Gates sockeye (n=27) and 28% of attempts by Portage sockeye (n=106) did not reach the dam after release into the powerhouse tailrace. Of sockeye released into the lower Seton River in these studies, 100% of Gates sockeye (n=10) and 87% of Portage sockeye (n=54) were successful in reaching the dam. Thus, our results indicated higher failure rates for Gates sockeye, but all these studies suggest that a portion of sockeye bound for spawning grounds in the Seton-Anderson watershed fail between the powerhouse tailrace and Seton Dam and this issue may be larger than it once was.

Another locale that may affect sockeye migration in the lower Seton River and could have contributed to the mortality we observed is the lower spawning channel (Figure 3). Fretwell (1980) previously reported sockeye delaying in the Seton River at the confluence of the upper and lower spawning channels but in our study we observed sockeye that actually entered the lower channel, swam 4 km to the end, and spent an unknown amount of time searching for an upstream exit. Since no sockeye carcasses were found within the spawning channel this locale is probably not a cause of direct mortality. Sockeye that were observed at the top of the channel were likely able to move 4 km back downstream to the Seton River. However, for sockeye migrating on a fixed energy budget, a delay of a few days could contribute to premature senescence and enroute mortality. Sockeye were never observed in the upper spawning channel, although it was checked on several days during the migration period, and it is unclear why the lower channel might be more attractive to sockeye.

The highest failure rate along the migratory route (and the largest absolute number of fish that failed) occurred at the dam and fishway, suggesting that this locale may be the primary limiting factor for sockeye salmon migrations in the watershed. The fact that passage efficiency was 93% and the average time to ascend the fishway was only 38 minutes suggests that passage of the fishway itself is not difficult for migrating sockeye salmon. These findings agree with our previous study in 2005, where passage efficiency of radio-tagged sockeye was 100% and electromyogram (EMG) telemetry suggested that ascent did not require exhaustive exercise (Pon et al., 2006). In both years, most of the passage failure at the fishway had to do with locating the entrance, rather than passage itself.

Total attraction efficiency at Seton Dam Fishway was 86% in 2007 and 77% in 2005. However, there are some caveats that should be discussed when interpreting our findings concerning fishway attraction. Ideally, to measure attraction efficiency fish would be caught somewhere downstream of the dam. However in both 2005 and 2007, it was not possible to catch fish downstream from the dam and all sockeye were captured from the top of the fishway. Therefore all study sockeye had already located and ascended the fishway once. If there was a segment of the population that was never able to locate and enter the fishway, then these fish were not represented in our results and our estimate of attraction may be an overestimate. Furthermore, if sockeye were able to use memory and/or learning to locate the fishway a second time then this would also have led to an overestimate. Many fish species can learn spatial patterns and use landmarks to navigate during migration (Odling-Smee and Braithwaite, 2003) although it is not known to what degree Pacific salmon could use landmarks in the context of fishway passage. On the other hand, if initial fishway passage somehow reduced the ability of sockeye to re-locate and re-ascend, then the attraction efficiency here would be an underestimate. However, our physiological analyses indicated that sockeye that had ascended the fishway were not exhausted and did not show signs of physiological stress. The failure rate presented here is therefore probably a conservative estimate, and in fact a larger portion of migrating sockeye may be unable to enter the fishway.

The mean delay below the dam before entering the fishway was 16.3 hours but seven sockeye had delays greater than 24 hours. Although the two receivers used to detect sockeye that reached the dam had high detection efficiency (95%), these receivers were located in an acoustically noisy environment and it is likely that many fish were not detected immediately upon arrival at the dam. Therefore, our values of below dam delay are minimum estimates and many sockeye were likely delayed longer while searching for the fishway entrance.

In 2007, spill discharge from the Seton Dam was much higher than in 2005 (Table 10) providing an opportunity to evaluate passage during high flows. Although there were two distinct spill discharges during the study in 2007 (Table 9), only five sockeye reached the dam and fishway during the period of higher flow making it not possible to statistically compare efficiency and passage rates between the two flow regimes. However, data from these five sockeye suggest that locating the fishway may be more difficult at very high flows. Two of the five entered the fishway with relatively short delays (7.0 and 11.6 hours), one never entered at all, and two fish had the longest delays observed of all our fish (65 and 92 hours) and did not enter until flows were reduced by nearly half. During the period of high flows, untagged sockeye were often observed approaching the turbulent tailrace of Seton dam, and swimming rapidly to maintain position in the current before falling back into calmer waters downstream. Thus, although our sample size was small, our results suggest that approach to the fishway entrance through turbulent tailrace flows may be difficult for sockeye salmon when discharges were ≥ 60 m^3/s.

During our study at the Seton Dam, one sockeye that was not able to locate the fishway entrance was later detected downstream at the powerhouse tailrace. Others fell back from the dam and were detected in the lower Seton River before disappearing. Three of the fish that reached the top of the fishway when the upstream exit was blocked descended, exited the bottom of the fishway and never returned. In all these cases after some delay at the dam, sockeye moved downstream, were never detected in the fishway again and their eventual fate was unknown. One possible explanation for these observations is that after being delayed sockeye moved downstream to seek an alternate route to spawning grounds. One sockeye that descended and exited the fishway and one other that fell back to the tailrace later returned and ascended the fishway. However, for some Gates Creek sockeye fallback may mean dropping out of the Seton system and searching for a passage route at the powerhouse tailrace or moving up- or down-stream in the Fraser, and ultimately failing to reach spawning grounds. Migrating salmonids are known to seek alternate routes at natural obstructions or anthropogenic barriers (Lucas and Baras, 2001). However, for rapidly maturing salmon that migrate with fixed energy budgets, individuals that are unable to pass an obstruction and seek an alternate route may exhaust energy reserves and perish before reaching spawning areas. The hypothesis that sockeye are more likely to drop back from Seton Dam after a certain amount of delay while searching for a passage route (i.e. the fishway) remains to be tested and is an important question for future research.

In the two years we monitored attraction and delay at Seton Dam Fishway, discharges from the dam ranged from 11.0 m^3/s to 60 m^3/s and attraction efficiency and delay varied greatly. Attraction efficiency was lowest (40%) and delays longest (mean ± SE; 44.2 ± 20.9) during the highest discharge (60 m^3/s; Figure 9). However, there was not a clear relationship between discharge and either attraction efficiency or delay. The highest attraction efficiency (100%) but the second longest delay (19.9 ± 4.8) occurred at flows of 12.8 m^3/s. The shortest delay (7.0 ±

1.7) occurred at the lowest discharge (11.0 m^3/s) but was associated with an intermediate passage efficiency (77%). At other dams, poor attraction is often related to insufficient attraction flow, and increasing flows near the fishway entrance can improve attraction (Naughton et al., 2007; Larinier, 2002). However, at the Seton Dam all or most of the water is discharged near the fishway entrance (at lower discharges the entire flow is discharged next to the fishway as 'attraction flow') and increasing discharge did not necessarily improve attraction or reduce delay. The lack of clear relationship between discharge and fishway attraction may be due to unique flow patterns created by different discharges. We speculate that currents created by certain discharges provide better directional cues for locating the fishway than others. Migrating Pacific salmon are negatively rheotactic and orient into the current but complex or turbulent flow patterns may disrupt directional cues and cause delay (Hinch et al., 2006; Hinch and Rand 1998). Turbulence can increase the energetic costs of swimming and fish may avoid these types of flows (Enders et al., 2003; Hinch and Rand 1998). Thus, optimum attraction at the fishway may rely on a spill discharge that provides adequate attraction flows and suitable directional cues for migrating salmon. Because only a few discharges were examined in our studies and sample sizes were small for several of the flows, it is not possible to say what level of discharge results in the highest fishway attraction. Our two years of results point to the need to quantify local hydraulics and fishway attraction at a wide range of discharge levels. Future research and management experiments which examine the effects of releasing water from additional sluices (e.g. not predominantly from the fish-water sluice) are clearly needed.

Mortality occurred en route from the upstream side of the fishway to spawning grounds. The lake environment provides a wide range of water temperatures (Pon et al., 2006) and from temperature loggers we recovered, it is clear that fish do utilize thermal refugia in the hypolimnion of Anderson Lake. Recent research on Weaver Creek sockeye demonstrate that fish which encounter high temperatures during their riverine migration are more successful at surviving to reach spawning grounds if they spend significant portions of time in the hypolimnion of adjacent Harrison Lake (Farrell et al. in press). Because loggers were not recovered from fish that did not reach spawning grounds in the present study, it was not possible to compare the thermal exposure of failed and successful migrants.

For fish released downstream of the dam, 20% failed during their migration from the upstream side of the fishway to spawning grounds, whereas only 7% of fish tagged and released at the top of the fishway disappeared prior to reaching spawning grounds. This difference in mortality was probably not associated with additional stress or energetic costs incurred by the former group during re-ascent of the fishway. EMG telemetry in 2005 suggested ascent was not exceedingly difficult or energetically demanding (Pon et al., 2006), and physiological sampling after initial fishway ascent in our study did not indicate that passage caused stress. Therefore, passage through the lower Seton River and Seton Dam Fishway a second time probably did not impair the ability of sockeye to migrate through the lakes or lead to delayed mortality. We are uncertain why mortality rates in this migration segment appear to differ between these two release groups, however, it is worth noting that mortality was much higher in 2005 in this migration segment (46%) for Gates sockeye tagged and released at the top of the fishway (Pon et al. 2006).

Some of the mortality upstream of the dam in both study years can be directly attributed to food fisheries. Small First Nation's food fisheries take place in Portage Creek and in Anderson Lake (Komori, 1997). In 2005, at least 13% of mortality could be directly attributed to fisheries (e.g. tags were returned from fishers; Pon et al., 2006). In our study, only one telemetry transmitter was returned to us after capture by fisheries. However, tag return rates from fisheries are typically low and it is possible that other in-lake mortalities were due to fisheries. One sockeye (#45, categorized as Seton Lake mortality) was last detected at the inflow of Seton Lake, was presumed to have moved upstream into Portage Creek, but was never detected in Anderson

Lake. This fish may have been harvested while migrating through Portage Creek. It is also possible that some of the mortalities in Anderson Lake could have been related to fisheries but based on our telemetry data it is not possible to distinguish between the two potential fates.

Only four sockeye were classified as Seton Lake mortalities, but all these fish were released at the powerhouse tailrace (Table 7). No fish released into the Seton River at Cayoosh Creek died while in Seton Lake. Physiological data do not suggest that fish released at the tailrace were in worse condition so it is difficult say why they suffered higher mortality in Seton Lake. The four Seton Lake mortalities disappeared on different days, in different locations, and during times when fish released at Cayoosh were also migrating through the lake. Therefore, it does not appear that fish released at the tailrace suffered from greater fisheries mortality, or natural mortality related to seasonal timing. Because there were relatively small sample sizes in each release group, it could be that higher Seton Lake mortality in fish released at the tailrace was simply due to chance.

Survival to reach spawning grounds differed by gender. Of fish released downstream of the dam, females had higher mortality (61%) than males (30%). [An equal number (n=14) of males and females were released upstream of the dam but since only one male and one female failed to reach spawning grounds, it was difficult to assess a gender-effect from releases at this locale.] The reason for higher female mortality is not clear. Cortisol and glucose, two indicators of physiological stress, were higher in females than males (Table 3). However, because female adult sockeye are known to have higher levels of stress (Hinch et al., 2006; Kubokawa et al., 1999) and the levels observed in our study were not critically high, stress likely did not play a role in higher female mortality. Alternatively, survival could have been related to the size of fish, since females are smaller (Table 3; Hinch and Rand, 1998) and larger individuals have faster critical swimming speeds (Webb, 1995). EMG telemetry at Seton Dam indicated that fish rarely approached critical swimming speeds during fishway ascent but some fish did swim near critical speeds in the tailrace of the dam (Pon, 2008; Pon et al., 2006). Others have reported greater passage failure of female compared to male sockeye in years of difficult migration conditions in the Fraser River Canyon, resulting in large numbers of females being found in non-natal tributaries downstream of the canyon, and a surplus of males on natal spawning grounds (Gilhousen, 1990). The finding that females had higher en route mortality in the Seton-Anderson watershed has important implications for conservation since total spawning success of a population is governed by female success whereas a loss of males has little effect subsequent generations (Gilhousen, 1990).

In addition to quantifying mortality during different segments of the Gates Creek sockeye migration, we also studied the phenomenon of fishway delay - the amount of time it took fish after reaching the dam to enter the fishway. We found that mean delay was the greatest (average of 44 hours) when discharge was the highest but that even under lower discharges in this study and in 2005, average delay ranged among discharge levels from 7 to 20 hours (Pon et al., 2006). The consequences of migratory delay at dams are not well studied. Recent research on Chinook salmon in the Columbia River U.S.A has revealed that fish with long delays and slow passage times over multiple dams had reduced probability of reaching spawning grounds, whereas slow passage at any one dam did not affect survival (Caudill et al., 2007). Columbia River sockeye which fell back downstream did not have poorer survival to spawning grounds compared to those that did not fallback (Naughton et al., 2006). In our study, most sockeye that fell back from the dam after failing to enter or pass the fishway were not detected later in the fishway, and therefore did not reach spawning grounds. This difference in behaviour between Columbia fish and our fish may be attributable to where and why fallback occurred. In the Columbia River, fallback was attributed to flow patterns and disorienting cues in the forebay upstream of the fishway, which led fish back downstream over the dam (Naughton et al., 2006) whereas in the Seton River, fallback was related to failure to initially pass the dam. Since fallbacks in the Seton River did not usually result in later return to the fishway, long delays may lead to the seeking of alternate passage routes (e.g. Fraser River powerhouse tailrace) and thus failure to reach spawning grounds.

Recommendations

The population sizes of Gates and Portage Creek sockeye have been rapidly declining over the past 12 years and both populations are being considered for listing as threatened or endangered by the IUCN (Salmonid Specialist draft report for the IUCN – Pete Rand, Wild Salmon Center, Portland, Oregon, pers. comm.). Numerous factors are likely responsible for the decline and our results suggest that mortality of sockeye is exceptionally high during their migration through the Seton system (52% loss of sockeye between the Fraser River and spawning grounds). Our findings can be used to recommend some immediate management actions, and propose management experiments and research needs.

1) Temporary blockage or obstruction in the fishway could have serious consequences for populations of migrating adult sockeye. We found that some tagged sockeye fell back downstream when the upstream exit of the fishway was blocked during sampling and many of these fish never returned. Therefore, we recommend that the fishway is monitored and maintained frequently (daily) during the migration season so that blockages are cleared immediately. Furthermore, any new modifications to the fishway, such as fish enumeration devices, should be carefully evaluated in terms of their effects on passage (see also Pon et al., 2006).

2) More research is needed to quantify delay, and ramifications of delay, when sockeye initially encounter the powerhouse tailrace on the Fraser River. This should involve a re-assessment of the ‘dilution level’ issue in terms of tailrace attraction, and examine the role of the tailrace as a

thermal refuge. Evidence suggested that the powerhouse tailrace may have caused delay and attracted fish but sample sizes were low. We cannot suggest management actions aimed at reducing tailrace attraction based on results of the present study.

3) When possible, managers should strive to minimize relatively high discharge levels in the Seton River during adult sockeye migrations. High discharge periods (~60m^3/s) created the poorest passage success into the fishway (40%) and longest delays (average 44 hrs). At lower discharge levels (11-35 m^3/s in 2005 and 2007) there was no simple relationship between discharge, and mean attraction or delay. Management experiments which involve manipulating spill discharge in the Seton River are needed to better define the relationship between discharge level and passage success.

4) Based on the combined results from our 2005 and 2007 studies, we conclude that failure to ascend the dam was primarily associated with locating the fishway entrance and not with passage of the fishway itself. Hydraulic conditions near the dam face vary widely with changes in discharge and this will affect orientation cues for salmon. As was recently suggested by Pon (2008), management experiments which alter hydraulic conditions in the tailrace of Seton dam at a given discharge level (via different locales of water release from the various sluices), and assess delay and fishway attraction are needed. Studies should also examine whether there is a threshold level of delay that causes salmon to fallback or seek alternate routes, reducing the probability of successful migration.

5) Our estimate of passage failure at the fishway should be considered an underestimate. Future studies should sample fish that are 'fishway-naïve' by catching sockeye in the lower Seton River. We attempted this with tangle and dip nets in 2007 but fish numbers were too low for these techniques to be effective and all indications are that these sockeye runs will not be large in the

near future. We recommend using a fish weir with trap boxes in the lower Seton River, to be installed and operated during sockeye spawning migrations, during years when fish need to be captured for telemetry or biosampling assessment of fishway performance and migration mortality.

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References

Andrew, F.J. and Geen G.H. 1958. Sockeye and Pink Salmon Investigations at the Seton Creek Hydroelectric Installation. IPSFC Progress. Report No. 4. New Westminster, BC, 74p.

Beacham, T.D., Lapointe, M., Candy, J.R., Miller, K.M., Withler, R.E. 2004. DNA in action: Rapid application of DNA variation to sockeye salmon fisheries management. Conservation Genetics 5: 411-416.

Beacham, T.D. Withler, R.E., Wood, C.C. 1995. Stock identification of sockeye salmon by means of minisatellite DNA variation. North American Journal of Fisheries Management 15: 249-265.

BC Hydro, 2000. Bridge-Coastal Fish and Wildlife Restoration Program, Seton River Watershed Strategic Plan. Volume 2, Chapter 11. Burnaby, BC, 28p. Acccessed on June 24: www.bchydro.com/bcrp/about/docs/ch11_final.pdf

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

Clay, C.H. 1995. Design of fishways and fish facilities, 2nd edition. Lewis Publishers, Boca Raton, FL.

Cooke, S.J., Hinch, S.G., Crossin, G.T., Patterson, D.A., English, K.K., Shrimpton, J.M., Van Der Kraak, G., and Farrell, A.P. 2006. Physiology of individual late-run Fraser River sockeye salmon (*Oncorhynchus nerka*) sampled in the ocean correlates with fate during spawning migration. Canadian Journal of Fisheries and Aquatic Sciences 63: 1469-1480.

Cooke, S.J., Crossin, G.T., Patterson, D.A., English, K.K., Hinch, S.G., Young, J.L., Alexander, R., Healey, M.C., Van Der Kraak, G., and Farrell, A.P. 2005. Coupling non-invasive physiological assessments with telemetry to understand inter-individual variation in behaviour and survivorship of sockeye salmon: development and validation of a technique. Journal of Fish Biology 67: 1-17.

Cooke, S.J., Hinch, S.G., Farrell, A.P., Lapointe, M.F., Jones, S.R.M., Macdonald, J.S., Patterson, D.A., Healey, M.C. 2004 Abnormal migration timing and high en route mortality of sockeye salmon in the Fraser River, British Columbia. Fisheries 29: 22-33.

Cooper, J.C. and Hasler, A.D. 1973. An electrophysiological approach to salmon homing. Fisheries Research Board of Canada Technical Report 415, 44p.

Crossin, G.T., Hinch, S.G., Cooke, S.J., Welch, D.W., Lotto, A.G., Patterson, D.A., Jones, S.R.M., Leggatt, R.A., Mathes, M.T., Shrimpton, J.M., Van Der Kraak, G., and Farrell A.P. 2008. Exposure to high temperature influences the behaviour, physiology, and survival of sockeye salmon during spawning migrations. Canadian Journal of Zoology 86: 127-140.

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

Enders, E.C., Boisclair, D., Roy, A.G. 2003. The effect of turbulence on the cost of swimming for juvenile Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 60: 1149-1160.

Farrell, A.P., Hinch, S.G., Cooke, S.J., Patterson, D.A., Crossin, G.T., Lapointe, M., Mathes, M.T. Pacific salmon in hot water: applying metabolic scope models and biotemetry to predict the success of spawning migrations. Physiological and Biochemical Zoology, in press.

Farrell, A.P., Gallaugher, P.E., Fraser, J., Pike, D., Bowering, P., Hadwin A.K.M, Parkhouse, W., Routledge, R. 2001. Successful recovery of the physiological status of coho salmon on board a commercial gillnet vessel by means of a newly designed revival box. Canadian Journal of Fisheries and Aquatic Sciences 58: 1932-1946.

Fretwell, M.R. 1989. Homing behaviour of adult sockeye salmon in response to a hydroelectric diversion of homestream waters at Seton Creek. Bulletin No. XXV. International Pacific Salmon Fisheries Commission. Vancouver, BC, 38p.

Fretwell, M.R. 1980. Migration of adult sockeye at Seton Creek hydroelectric plant in 1979. International Pacific Salmon Fisheries Commission. New Westminster, BC, 55p.

Gilhousen, P. 1990. Prespawning mortalities of sockeye salmon in the Fraser River system and possible causal factors. Bulletin No. XXVI, International Pacific Salmon Fisheries Commission. Vancouver, BC, 58p.

Hinch, S.G. and Bratty, J.M. 2000. Effects of swim speed and activity pattern on success of adult sockeye salmon migration through an area of difficult passage. Transactions of the American Fisheries Society 129: 604-612.

Hinch, S.G. and Rand, P.S. 1998. Swim speeds and energy use of river migrating adult sockeye salmon: role of local environment and fish characteristics. Canadian Journal of Fisheries and Aquatic Sciences 55: 1821-1831.

Hinch, S.G., Cooke, S.J., Healey, M.C., and Farrell, A.P. 2006. Behavioural Physiology of Fish Migrations: salmon as a model approach. *In* Fish Physiology Volume 24: Behaviour and Physiology of Fish. *Edited by* Sloman K., Balshine, S., Wilson, R. Elsevier Press, New York, NY. pp. 239-295.

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

Jolly, G.M. 1982. Mark-recapture models with parameters constant in time. Biometrics 38: 301-21.

Komori, V. 1997. Strategic fisheries overview for the Bridge/Seton habitat management area. Final report for the Fraser River Action Plan, Department of Fisheries and Oceans, Vancouver, BC, 93p.

Kubokawa, K., Watanabe, T., Yoshioka, M., Iwata, M. 1999. Effects of acute stress on plasma cortisol, sex steroid hormone and glucose levels in male and female sockeye salmon during the breeding season. Aquaculture 172: 335-349.

Larinier, M. 2002. Fishways – general considerations. Bulletin Francais de la Peche et de la Pisciculture 364: 54-82.

Lucas, M.C. and Baras E. 2001. Migration of freshwater fishes. Blackwell Science Ltd., Oxford.

Milligan, C.L., Hooke, G.B., Johnson, C. 2000. Sustained swimming at low velocity following a bout of exhaustive exercise enhances metabolic recovery in rainbow trout. Journal of Experimental Biology 203: 921-926.

Naughton, G.P., Caudill, C.C., Peery C.A., Clabough, T.S., Jepson, M.A., Bjornn, T.C., Stuehrenberg, L.C. 2007. Experimental evaluation of fishway modifications on the passage behaviour of adult Chinook salmon and steelhead at the lower Granite Dam, Snake River, U.S.A. River Research and Applications 23: 99-111.

Naughton, G.P., Caudill, C.C., Keefer, M.L., Bjornn, T.C., Peery C.A., Stuehrenberg, L.C. 2006. Fallback by adult sockeye salmon at Columbia River dams. North American Journal of Fisheries Management 26: 380-390.

Nilsson, C., Reidy, C.A., Dynesius, M., Revenga, C. 2005. Fragmentation and flow regulation of the world's large river systems. Science, 308(5720): 405-408.

Odeh, M. (ed) 1999. Innovations in fish passage technology. American Fisheries Society, Bethesda, Maryland, USA.

Odling-Smee, L. and Braithwaite, V.A. 2003. The role of learning in fish orientation. Fish and Fisheries 4: 235-246.

Patterson, D.A., Macdonald, J.S., Skibo, K.M., Barnes, D.P., Guthrie, I., Hills, J. 2007. Reconstructing the summer thermal history for the lower Fraser River, 1941 to 2006, and implications for adult sockeye salmon (*Onchorhynchus nerka*) spawning migration. Canadian Technical Report of Fisheries and Aquatic Sciences 2724: iv + 43p.

Pon, L.B. 2008. The role of fish physiology, behaviour, and water discharge on the attraction and passage of adult sockeye salmon (*Onchorhynchus nerka*) at the Seton River Dam Fishway, British Columbia. Master’s Thesis, University of British Columbia, Canada.

Pon, L.B., Cooke, S.J., Hinch, S.G. 2006. Passage Efficiency and Migration Behaviour of Salmonid Fishes at the Seton Dam Fishway. Final Report for the Bridge Coastal Restoration Program, Project 05.Se.01, 105p.

Portz, D.E., Woodley, C.M., Cech Jr., J.J. 2006. Stress-associated impacts of short-term holding on fishes. Reviews in Fish Biology and Fisheries 16:125-170.

Ramstad, K. and Woody, C.A. 2003. Radio tag retention and tag related mortality in migrating sockeye salmon. North American Journal of Fisheries Management 23: 978-982.

Sheer, M.B. and Steel, E.A. 2006. Lost watersheds: Barriers, aquatic habitat connectivity, and salmon persistence in the Willamette and lower Columbia River Basins. Transactions of the America Fisheries Society 135: 1654-1669.

Wagner, G.N., Kuchel, L. J., Lotto, A., Patterson, D. A., Shrimpton, M., Hinch, S. G., Farrell, A. P. 2006. Routine and active metabolic rates of migrating, adult wild sockeye salmon (*Oncorhynchus nerka* Walbaum) in seawater and freshwater. Physiological and Biochemical Zoology 79: 10-108.

Webb, P.W. 1995. Locomotion. *In* Physiological Ecology of Pacific Salmon. *Edited by* Groot, C., Margolis, L. and Clarke, W.C. University of British Columbia Press, Vancouver, pp. 71-99.

Welch D. 2007. Final Report: Investigations to determine the cause of early entry migration behavior for adult Late-run Fraser River sockeye (Kintama Component). Report to Southern Boundary Restoration and Enhancement Fund. Pacific Salmon Commission, Vancouver, BC

Williams, J.G. Smith, S.G., Zabel, R.W., Muir, W.D., Scheuerell, M.D., Sandford, B.P., Marsh, D.M., McNatt, R.A., Achord, S. 2005. Effects of the federal Columbia River power system on salmonid populations. U.S. Dept. Commerce, NOAA Technical Memorandum NMFS-NWFSC-63, 150p.

Young, J.L., Cooke, S.J., Hinch, S.G., Crossin, G.T., Patterson, D.A., Farrell, A.P., Van Der Kraak, G., Lotto, A.G., Lister, A., Healey, M.C., English, K.K. 2006. Physiological and energetic correlates of en route mortality for abnormally early migrating adult sockeye salmon in the Thompson River, British Columbia. Canadian Journal of Fisheries and Aquatic Sciences 63: 1067-1077.

Table 1. Detection efficiencies of acoustic telemetry receivers used to track Gates Creek sockeye migrations in 2007. ID numbers correspond with receiver locations in Figures 6 and 7. Receivers 4 and 5 were considered redundant, so that fish detected at either receiver were known to have reached the dam, and hence, the receivers worked as one station with a single detection efficiency.

ID #	Approximate location	Detection efficiency
1	Powerhouse tailrace (Fraser River)	n/a
2	Seton River, ~1.3 km upstream from mouth	74%
3	Seton River at Cayoosh Creek	48%
4	Seton River, ~80 m downstream of dam	95%
5	Below dam, end of radial gate channel	
6	Fishway, bottom (Pool 3)	91%
7	Fishway, 1/2 way, (Pool 17)	75%
8	Fishway, top (Pool 32)	100%
9	Seton River, ~160 m upstream of dam	98%
10	Outflow of Seton Lake	100%
11	Seton Lake, middle	100%
12	Seton Lake, West end	100%
13	Seton Lake, inflow	100%
14	Anderson outflow	100%
15	Anderson Lake, middle	100%
16	Anderson Lake, West end	100%
17	Anderson Lake, inflow	n/a

Table 2. Summary of individual Gates Creek sockeye release dates, location and migratory fates. Release locations were above Seton dam (AB), Seton Lake (SL), Seton River at Cayoosh Creek (C) and the powerhouse tailrace on the Fraser River (T). Fate categories were successful migrant (S), in-lake mortality (L), failed to locate or pass the fishway (FW), failed in Seton or Fraser River downstream of dam (R), descended fishway because of sampling blockage by researchers (SB), and known fisheries mortality (FM).

Fish #	ID Code	Release location	Release date	Fate	Fish #	ID Code	Release location	Release date	Fate
1	19894	AB	15-Aug	S	27	19848	C	17-Aug	R
2	19842	AB	15-Aug	S	28	19847	C	17-Aug	FM
3	19893	AB	15-Aug	S	29	19891	C	17-Aug	S
4	19853	AB	15-Aug	S	30	19907	C	17-Aug	FW
5	19844	AB	16-Aug	S	57	17981	C	21-Aug	FW
6	19837	AB	16-Aug	S	58	17983	C	21-Aug	S
7	19897	AB	16-Aug	S	59	17987	C	21-Aug	S
8	19840	AB	16-Aug	S	60	17974	C	21-Aug	FW
9	19852	AB	16-Aug	S	61	17971	C	21-Aug	S
10	19895	AB	16-Aug	S	62	17994	C	21-Aug	FW
11	19838	AB	16-Aug	S	63	17990	C	21-Aug	L
12	19850	AB	16-Aug	S	64	17604	C	21-Aug	R
13	19904	AB	16-Aug	S	65	17988	C	21-Aug	R
14	19903	AB	16-Aug	S	73	19925	C	23-Aug	L
15	19901	AB	16-Aug	S	74	19924	C	23-Aug	FW
16	19836	AB	16-Aug	S	75	19910	C	23-Aug	L
17	19846	AB	16-Aug	S	76	19854	C	23-Aug	S
18	19892	AB	16-Aug	L	77	19865	C	23-Aug	S
19	19841	AB	16-Aug	S	78	19911	C	23-Aug	S
20	19843	AB	16-Aug	S	79	19856	C	23-Aug	SB
49	17995	SL	20-Aug	S	80	19922	C	23-Aug	S
50	17609	SL	20-Aug	S	31	19896	T	18-Aug	SB
51	17991	SL	20-Aug	S	32	19906	T	18-Aug	S
52	17986	SL	20-Aug	S	33	19839	T	18-Aug	L
53	17975	SL	20-Aug	L	34	19845	T	18-Aug	L
54	17605	SL	20-Aug	S	35	19899	T	18-Aug	S
55	17972	SL	20-Aug	S	36	19898	T	18-Aug	S
56	17532	SL	20-Aug	S	37	17992	T	18-Aug	FW
21	19902	C	17-Aug	S	38	17989	T	18-Aug	SB
22	19890	C	17-Aug	S	39	17978	T	19-Aug	R
23	19851	C	17-Aug	R	40	17980	T	19-Aug	R
24	19905	C	17-Aug	S	41	17973	T	19-Aug	S
25	19900	C	17-Aug	S	42	17507	T	19-Aug	S
26	19849	C	17-Aug	S	43	17979	T	19-Aug	L
44	17608	T	19-Aug	FW	72	19864	T	22-Aug	R

45	17976	T	19-Aug	L
46	17552	T	19-Aug	S
47	17985	T	19-Aug	S
48	17993	T	19-Aug	L
66	17982	T	22-Aug	S
67	17602	T	22-Aug	R
69	19861	T	22-Aug	S
70	19862	T	22-Aug	S
71	19871	T	22-Aug	L
81	19918	T	24-Aug	FW
82	19909	T	24-Aug	FW
83	19866	T	24-Aug	S
84	19921	T	24-Aug	S
85	19908	T	24-Aug	L
86	19912	T	24-Aug	S
87	19868	T	24-Aug	S
88	19859	T	24-Aug	FW

Table 3. Means (± SE) and sample sizes for physiological measures for Gates Creek sockeye salmon caught by dip-net at Seton dam and then biopsy sampled immediately (control) or held in-river for a 5 hour recovery period (recovered).

Variable	Male - Control	n	Male - Recovered	n	Female - Control	n	Female - Recovered	n
Cortisol (ng/mL)	198.0 ± 23.5	11	216.2 ± 16.6	22	323.0 ± 31.9	6	389.9 ± 11.9	43
Testosterone (ng/mL)	9.98 ± 3.1	10	3.79 ± 2.09	22	22.9 ± 4.39	5	10.4 ± 1.51	42
Estradiol (ng/mL)	n/a	10	n/a	22	1.71 ± 0.27	5	1.48 ± 0.09	43
Lactate (mmol/L)	1.66 ± 0.27	11	1.3 ± 0.19	22	2.2 ± 0.37	6	1.93 ± 0.14	43
Glucose (mmol/L)	4.42 ± 0.41	11	5.86 ± 0.29	22	4.89 ± 0.55	6	8.4 ± 0.21	43
Na^+ (mmol/L)	163.6 ± 2.43	11	162.2 ± 1.72	22	155.2 ± 3.29	6	157.2 ± 1.23	43
K^+ (mmol/L)	2.54 ± 0.17	11	2.37 ± 0.12	22	3.81 ± 0.23	6	2.39 ± 0.087	43
Cl^- (mmol/L)	134.1 ± 1.54	11	129 ± 1.09	22	130.3 ± 2.1	6	128.3 ± 0.78	43
Osmolality (mOsm/kg)	310.1 ± 3.03	11	303.8 ± 2.14	22	303.5 ± 4.1	6	307.1 ± 1.53	43
GSE (MJ/kg)	5.62 ± 0.15	11	5.95 ± 0.11	21	6.49 ± 0.18	8	6.43 ± 0.078	43
Length (cm)	62.1 ± 0.96	12	58.8 ± 0.68	22	59.8 ± 1.06	9	57.6 ± 0.47	45

Table 4. *P*-values from two way ANOVA models with treatment (held for recovery period or immediately sampled control), sex and their interaction as effects, comparing physiological variables, energy and length for Gates Creek sockeye salmon caught by dip net from the Seton Dam Fishway. Analyses were conducted on $\log_{10}$-transformed data for variables that did not initially meet model assumptions. Results that are statistically significant at the 0.05 confidence level are in bold text and asterisks indicate significance after Bonferonni correction (P=0.005). Sample sizes are shown in Table 3.

Variable	Treatment	Sex	Interaction
Cortisol	0.0599	< 0.0001 *	0.28
Testosterone	< 0.0001 *	0.0006 *	0.5
Lactate	0.095	**0.0354**	0.74
Glucose	< 0.0001 *	0.0003 *	0.0063 *
Na^+	0.82	0.0035 *	0.4
K^+	< 0.0001 *	0.0005 *	0.0006 *
Cl^-	**0.038**	0.1	0.23
Osmolality	0.86	0.43	0.068
Gross somatic energy	0.33	< 0.0001 *	0.16
Length	0.0013 *	**0.03**	0.5

Table 5. *P*-values and degrees of freedom from two-way ANOVA models with fate (successful migrant or en-route mortality), sex and their interaction as effects, comparing physiological variables, energy and length Gates Creek sockeye caught in Seton Dam Fishway and released at one of two locations downstream of Seton dam. For the female specific variable estradiol a one-way ANOVA was used to compare fate groups. The factor 'fate' was not significant for any of the variables. Means for males and females are shown in Table 3.

Variable	Fate	Sex	Interaction	df (model,error)
Sockeye released in lower Seton River at Cayoosh Creek				
Cortisol	0.94	0.0038	0.79	3,20
Testosterone	0.9	0.0053	0.88	3,20
Estradiol	0.83	n/a	n/a	1,16
Lactate	0.88	0.25	0.78	3,20
Glucose	0.24	0.002	0.074	3,20
Na^+	0.13	0.53	0.94	3,20
K^+	0.39	0.53	0.09	3,20
Cl^-	0.6	0.04	0.28	3,20
Osmolality	0.19	0.0058	0.52	3,20
GSE	0.56	0.76	0.48	3,19
Length	0.077	0.2	0.25	3,21
Sockeye released at powerhouse tailrace on Fraser River				
Cortisol	0.72	< 0.0001	0.59	3,25
Testosterone	0.41	0.05	0.23	3,25
Estradiol	0.83	n/a	n/a	1,16
Lactate	0.49	0.026	0.54	3,25
Glucose	0.075	0.0003	0.34	3,25
Na^+	0.77	0.05	0.33	3,25
K^+	0.11	0.14	0.25	3,25
Cl^-	0.53	0.14	0.66	3,25
Osmolality	0.74	0.35	0.77	3,25
GSE	0.18	0.0006	0.27	3,25
Length	0.86	0.0075	0.99	3,26

Table 6. Fate of Gates Creek sockeye salmon captured from Seton Dam Fishway and released at four different locations: the 'Tailrace' site (T) was at the powerhouse tailrace on the Fraser River, the 'Cayoosh' site was on the lower Seton River at the confluence of Cayoosh Creek, the 'Above dam' was immediately upstream of the Seton dam, and the 'Seton Lake' site was at the outflow of Seton Lake. Release site locations are shown by lettered codes in Figure 3. Data are not shown for three sockeye (two released at tailrace, one released at Cayoosh) that successfully ascended the dam but descended while a gate was blocking the exit at the top of the fishway during sampling.

	Tailrace (T)		**Cayoosh (C)**		**Above dam (AB)**		**Seton Lake (SL)**	
Fate	#	%	#	%	#	%	#	%
Successful migrant	14	46.7	13	50.0	7	87.5	19	95.0
Failed in Anderson Lake	4	13.3	3	11.5	1	12.5	0	0.0
Failed in Seton Lake	3	10.0	0	0.0	0	0.0	1	5.0
Failed at fishway	5	16.7	5	19.2	n /a		n /a	
Did not reach dam	4	13.3	4	15.4	n/a		n/a	
Fishery removal	0	0.0	1	3.8	0	0.0	0	0.0
Total	30		26		8		20	

Table 7. Percentage of sockeye whose migration failed in different reaches en route to spawning grounds for Gates Creek sockeye released at two sites downstream of Seton dam in 2007. Total number of fish for each reach is the number of sockeye known to have reached that section of the migration route.

Study reach	Total # fish	# passed	# fail to pass	% failure
Sockeye released into Seton River at Cayoosh Creek				
Cayoosh to below dam	27	23	4	15
Fishway	23	18	5	22
Seton Lake	17	17	0	0
Anderson Lake	16	13	3	19
Sockeye released at the powerhouse tailrace				
Tailrace to below dam	32	28	4	13
Fishway	28	23	5	18
Seton Lake	21	17	4	19
Anderson Lake	17	14	3	18
All sockeye released below dam (Cayoosh and tailrace pooled)				
Release site to below dam	59	51	8	14
Fishway	51	41	10	20
Seton Lake	38	34	4	11
Anderson Lake	33	27	6	18

Table 8. Descriptive statistics of temperature exposure of Gates Creek sockeye salmon migrating from one of four release sites to spawning areas at Gates Creek. Release locations were above Seton dam (AB), Seton Lake (SL), Seton River at Cayoosh Creek (C) and the powerhouse tailrace on the Fraser River (T). Minimum, maximum and mean temperatures were calculated from the time of release to when fish left Anderson Lake and entered Gates Creek. Temperature exposure data was only obtained from fish whose archival temperature logger was recovered at spawning grounds and for one fish (#28) that was captured by fisheries in Portage Creek.

Fish #	Release site	Release date	Minimum temperature (^oC)	Maximum temperature (^oC)	Average temperature (^oC) (mean ± SD)
4	AB	15-Aug	9.3	18.1	13.8 ± 1.7
5	AB	16-Aug	9.3	18.1	13.5 ± 1.9
6	AB	16-Aug	10	18.4	13.5 ± 1.5
7	AB	16-Aug	9.1	18.3	13.3 ± 1.8
10	AB	16-Aug	6.8	17.5	12.3 ± 2.3
12	AB	16-Aug	9.6	17.3	13.0 ± 1.5
13	AB	16-Aug	8.4	17.1	13.1 ± 1.4
14	AB	16-Aug	8.8	17.5	13.7 ± 1.6
16	AB	16-Aug	9.6	18.8	13.6 ± 2.0
20	AB	16-Aug	9.6	17.6	13.6 ± 1.9
51	SL	20-Aug	10.8	17.5	14.4 ± 1.5
52	SL	20-Aug	5.9	20	12.4 ± 3.5
54	SL	20-Aug	10	17.5	13.6 ± 1.6
55	SL	20-Aug	9.8	18.5	14.0 ± 1.6
22	C	17-Aug	8.3	17.5	13.6 ± 1.9
28	C	17-Aug	12.4	18.4	16.0 ± 1.3
29	C	17-Aug	5.6	18	13.9 ± 2.5
58	C	21-Aug	11.3	19.1	15.0 ± 1.9
59	C	21-Aug	6.8	18	13.3 ± 2.2
76	C	23-Aug	7.9	17.9	13.3 ± 2.7
77	C	23-Aug	9.3	17.6	13.4 ± 2.1
80	C	23-Aug	9	17.9	13.7 ± 2.4
47	T	19-Aug	9.1	17.6	14.1 ± 1.5
84	T	24-Aug	8.3	17.5	14.4 ± 1.9
86	T	24-Aug	7.5	17.6	14.8 ± 2.4

Table 9. Seton River discharge and Cayoosh River dilution during 2007 Gates Creek sockeye migration.

Date	Seton dam spill discharge (m^3/s)	Percent Cayoosh water in Seton River
15-Aug	60.05	6
16-Aug	60.02	2
17-Aug	60.01	2
18-Aug	60.09	3
19-Aug	60.22	3
20-Aug	52.66	3
21-Aug	36.04	4
22-Aug	35.86	4
23-Aug	35.70	4
24-Aug	35.58	4
25-Aug	35.65	4
26-Aug	35.52	5
27-Aug	35.19	6
28-Aug	34.91	4
29-Aug	34.69	4
30-Aug	34.72	4
31-Aug	Not available	6

Table 10. Between-year comparison of fishway performance for telemetered sockeye salmon and environmental variables at Seton Dam.

Variable	2007	2005
Attraction efficiency	86% n = 51	77% n = 23
Passage efficiency	93% n = 44	100% n = 23
Ascent time (mean ± S.E.; minutes)	37.8 ± 4.6	63.5 ± 7.7 *
Seton Dam spill discharge (m^3/s)	35, 60	11.0, 12.7, 15.8
Water temperature (^oC) in Seton River near dam (17 -31 August; mean ± S.E)	14.3 ± 0.2	16.2 ± 0.3

* Protocols for ascent time were different in 2005 and 2007. In 2005 EMG-tagged sockeye were released directly into pool 3 of the fishway, and since fish spent some time re-orienting after release, actual average ascent time was closer to 30 minutes (Pon et al., 2006).

Table 11. Sex specific correlation coefficients and *p*-values (in parentheses) relating length, energy and physiological variables to fishway ascent time and below dam delay for Gates Creek sockeye released downstream of Seton dam. An asterisk indicates statistical significance at the 0.05 confidence level. No correlations were significant after Bonferonni correction (*P*=0.005)

Variable	Males				Females			
	Below dam delay	n	Fishway ascent time	n	Below dam delay	n	Fishway ascent time	n
Cortisol	-0.09 (0.78)	13	-0.03 (0.94)	11	-0.042 (0.84)	24	0.01 (0.96)	23
Testosterone	0.05 (0.86)	13	0.17 (0.62)	11	0.40 (0.052)	24	-0.09 (0.68)	23
Lactate	-0.17 (0.58)	13	0.19 (0.59)	11	-0.01 (0.07)	24	0.07 (0.76)	23
Glucose	0.06 (0.84)	13	-0.15 (0.65)	11	0.20 (0.35)	24	-0.16 (0.45)	23
Na^+	0.23 (0.44)	13	0.73 (0.011)*	11	-0.16 (0.44)	24	0.01 (0.95)	23
K^+	-0.24 (0.43)	13	-0.28 (0.41)	11	-0.11 (0.61)	24	0.05 (0.81)	23
Cl^-	-0.09 (0.77)	13	0.13 (0.70)	11	0.06 (0.79)	24	-0.19 (0.39)	23
Osmolality	-0.11 (0.72)	13	0.33 (0.32)	11	-0.03 (0.91)	24	-0.26 (0.23)	23
Gross somatic energy	-0.71 (0.01)*	12	-0.11 (0.75)	10	-0.09 (0.66)	25	-0.15 (0.47)	24
Length	0.20 (0.50)	13	0.14 (0.69)	11	-0.03 (0.89)	26	0.19 (0.35)	25

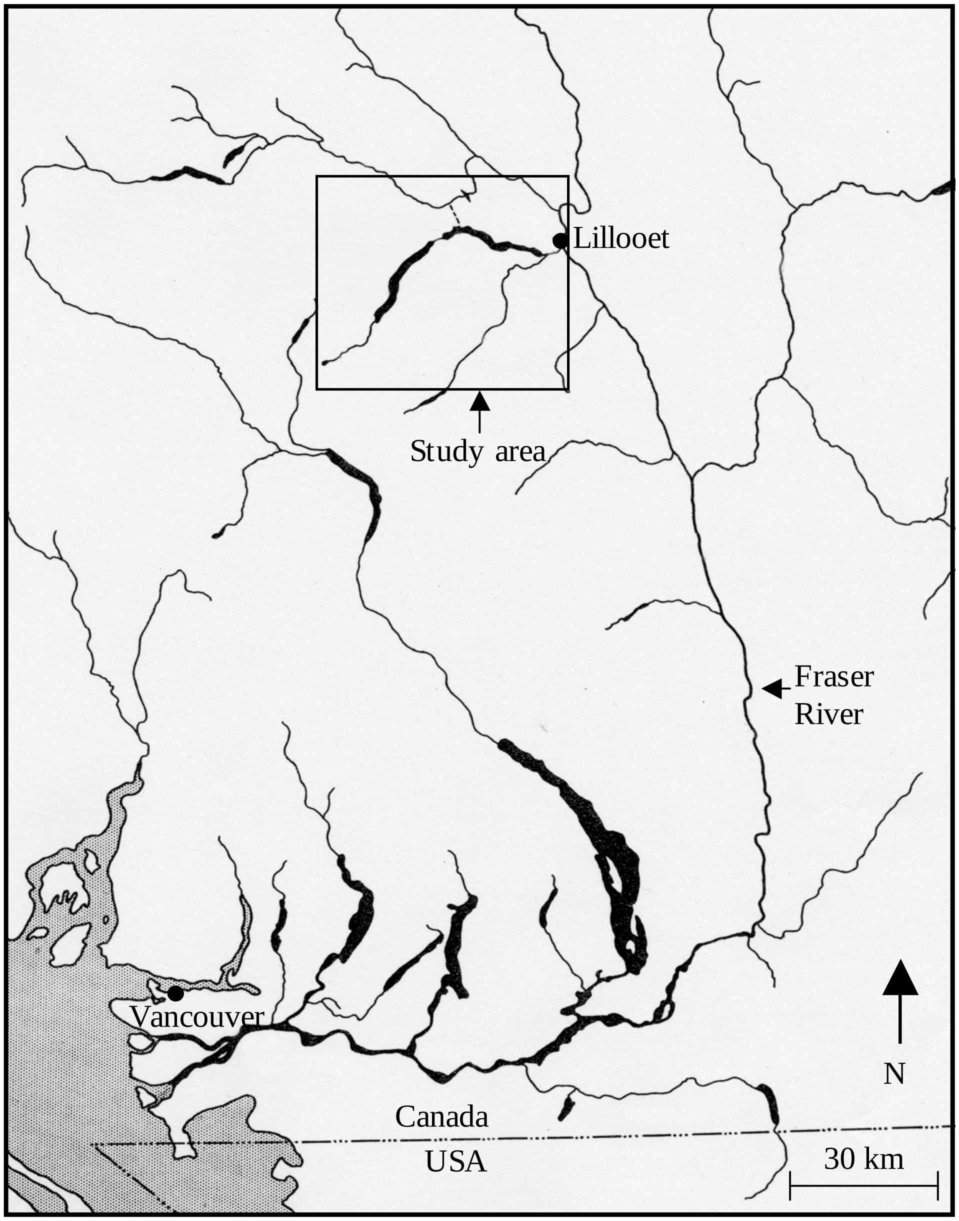


Figure 1. Map of the southwestern portion of British Columbia, Canada showing the location of the Seton-Anderson watershed (box), the Fraser River, and the cities of Vancouver and Lillooet. This map was adapted from Andrew and Geen (1958) and Pon et al. (2006).

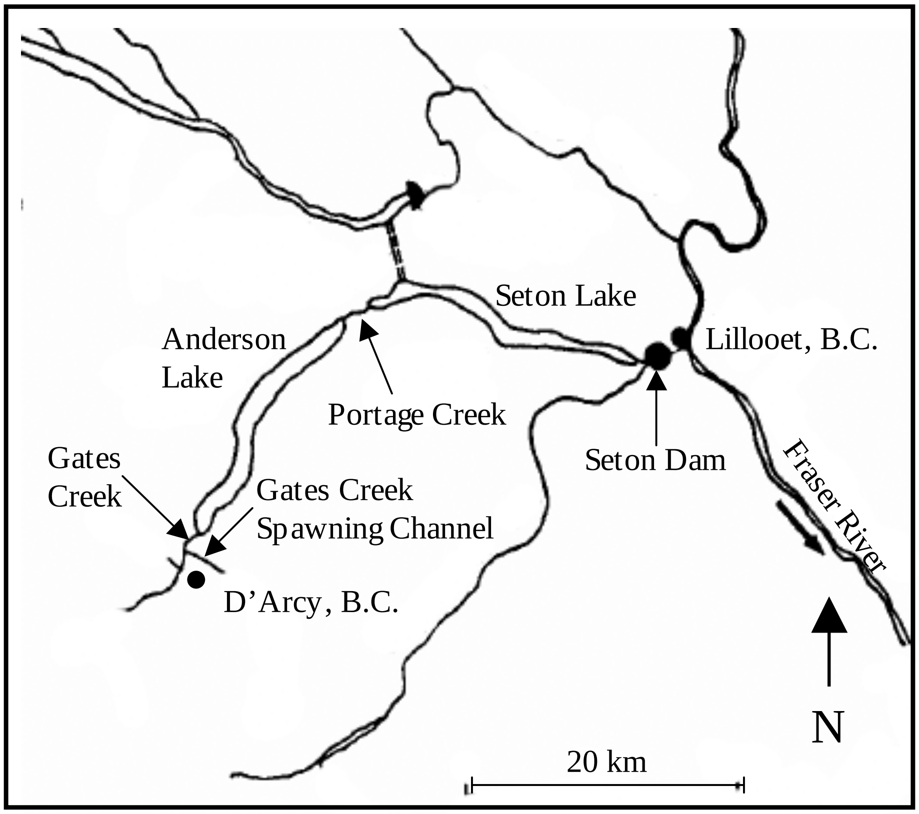


Figure 2. Map showing an overview of the study site in the Seton-Anderson watershed. Gates Creek sockeye were captured at Seton dam and tracked to spawning areas at Gates Creek. Figure adapted from Pon et al. (2006) and BCRP Seton River watershed strategic plan (BC Hydro, 2000).

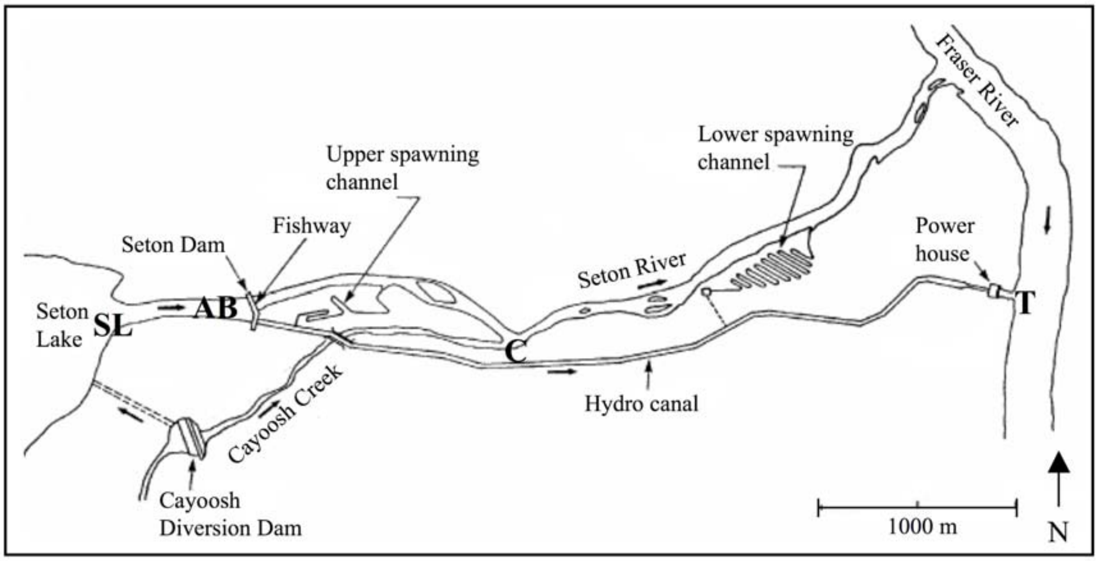


Figure 3. Map showing Seton River, some components of the Bridge hydroelectric complex, and four release sites, indicated by letters, where Gates Creek sockeye tagged with acoustic telemetry transmitters were released in 2007 . Seton dam and fishway, the hydro canal and powerhouse, and artificial spawning channels used primarily by pink salmon are shown. Arrows indicate flow direction. Release sites were as follows: 'T' was the powerhouse tailrace on the Fraser River, 'C' was the Seton River at the confluence of Cayoosh Creek, 'AB' was the Seton River immediately upstream of the dam, and 'SL' was Seton Lake near the outflow. Figure adapted from Pon et al. (2006) and BCRP Seton River watershed strategic plan (BC Hydro, 2000).

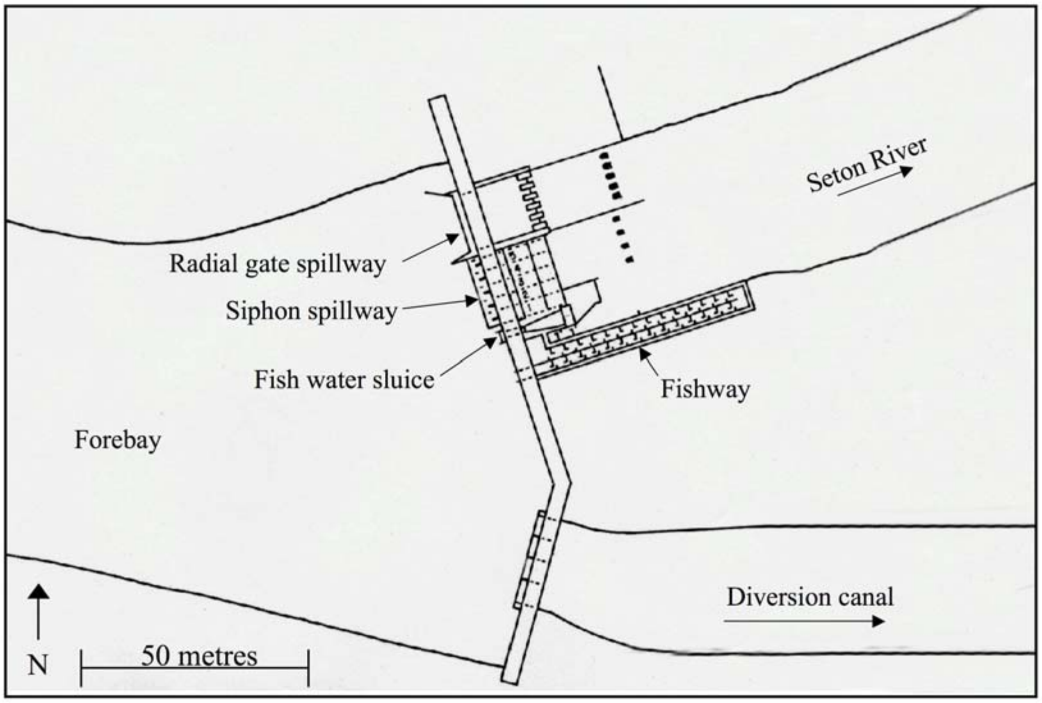


Figure 4. A detailed areal perspective of the Seton dam. The diversion canal leads to the Seton powerhouse, while Seton River continues to the confluence with the Fraser River. The location of the fishway is indicated along the South bank of Seton River, adjacent to Seton dam. Upstream of the forebay is Seton Lake. Figure adapted from Andrew and Geen (1958) and Pon et al. (2006).

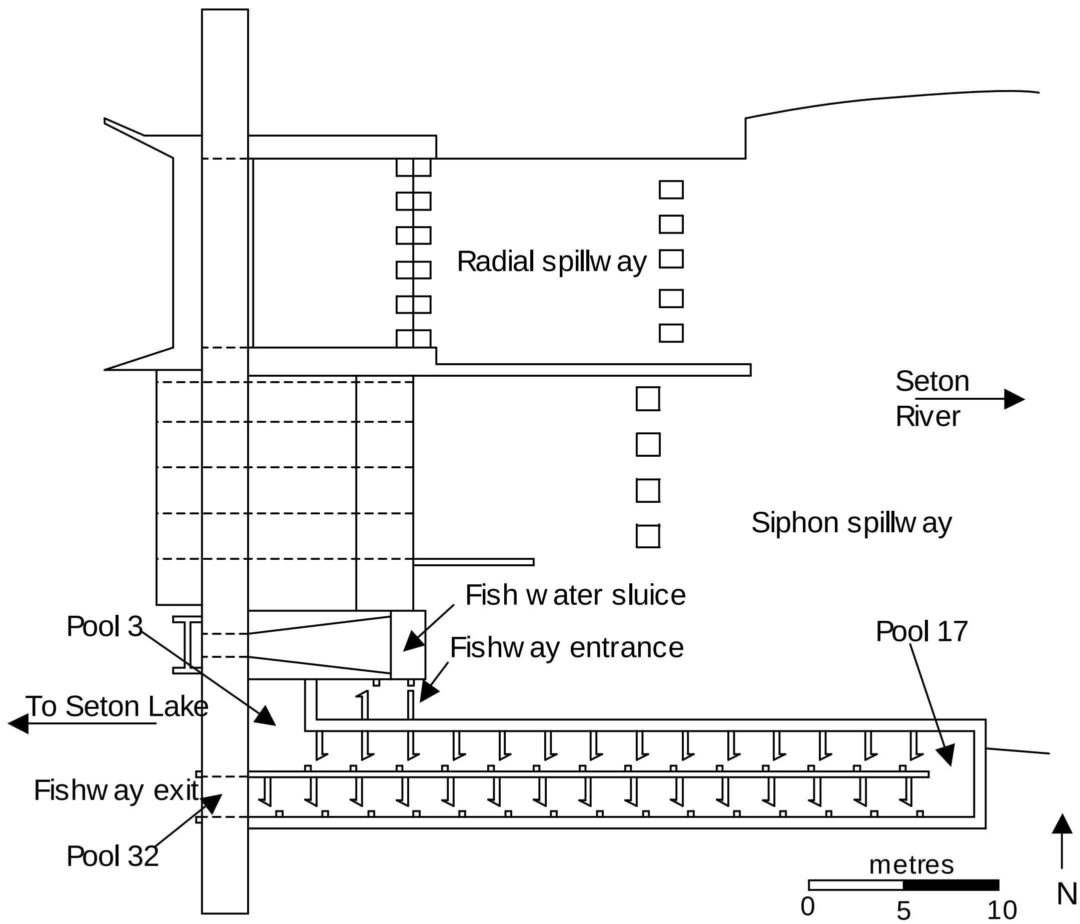


Figure 5. Areal perspective of the Seton dam and fishway showing the entrance, exit and pools 3, 17 and 32 where telemetry receiver stations were located. Figure adapted from Pon (2008).

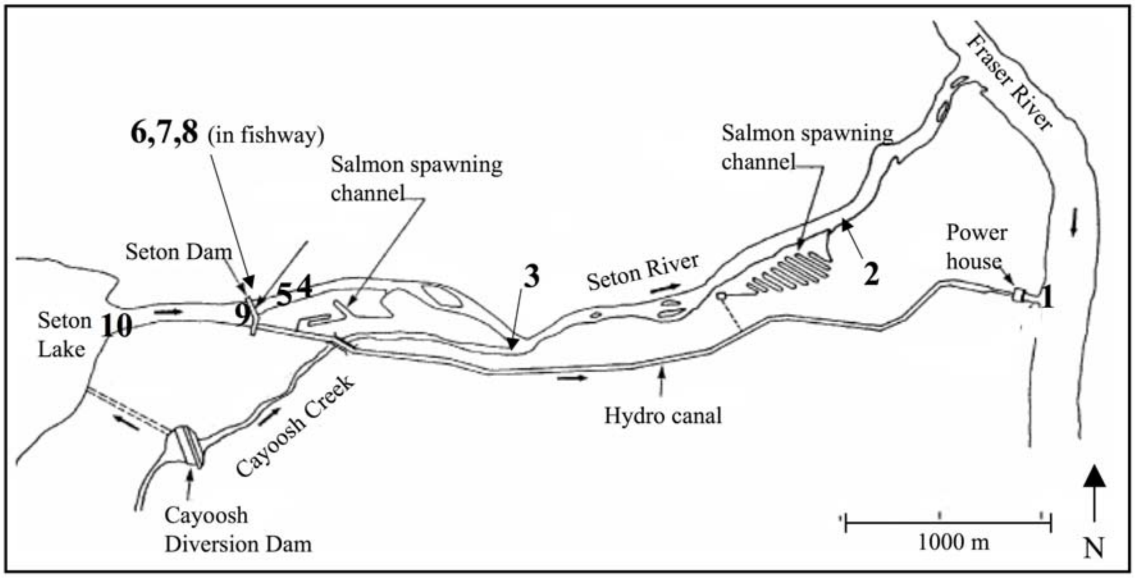


Figure 6. Map showing the general locations of numbered acoustic telemetry receiver stations used to track migrating Gates Creek sockeye from the powerhouse tailrace on the Fraser River to Seton Lake. See Table 1 for more information. Arrows show flow direction. Figure adapted from BCRP Seton River watershed strategic plan (BC Hydro, 2000) and Pon et al. (2006).

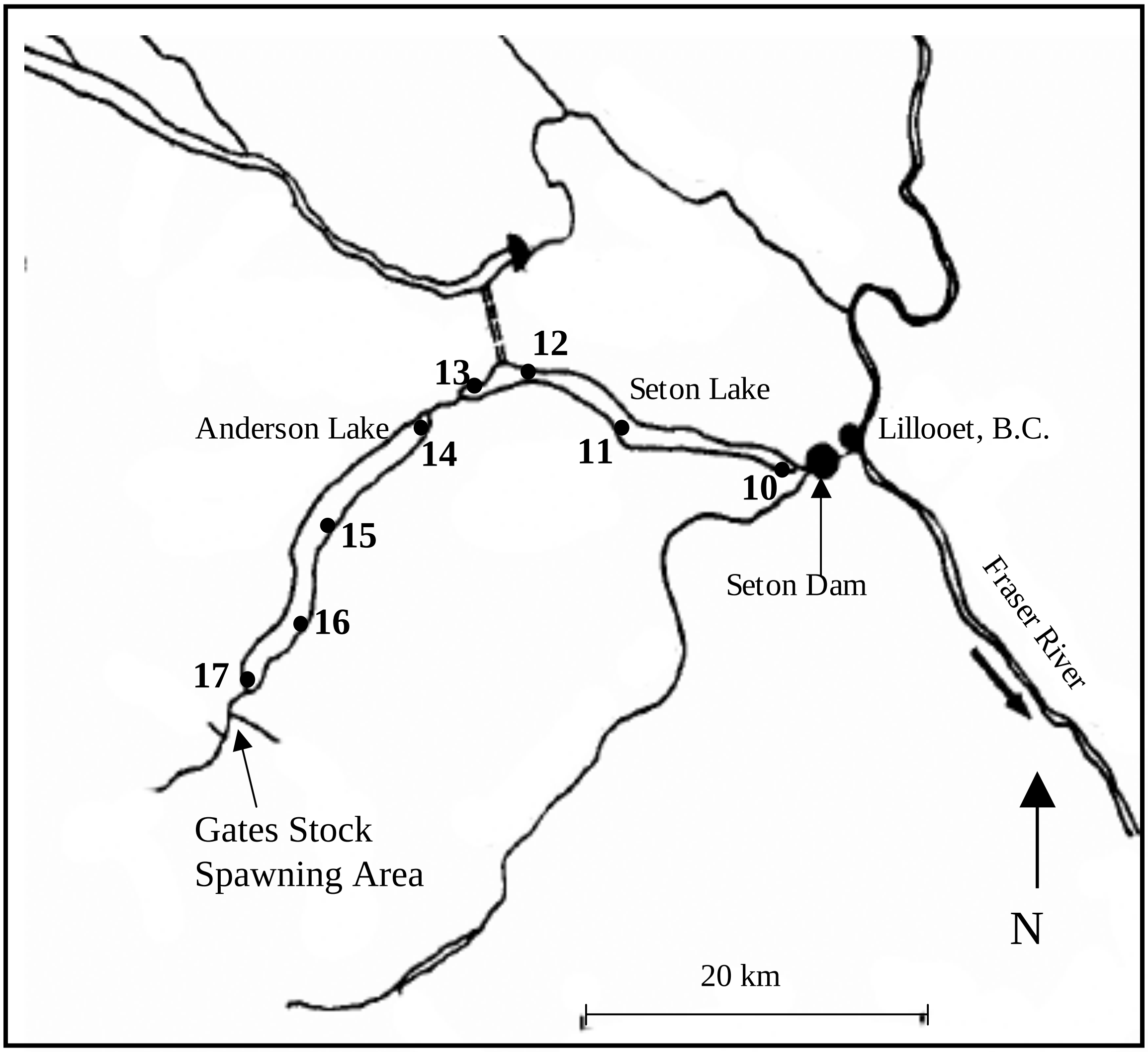


Figure 7. General locations of numbered acoustic telemetry receiver stations used to track migrating Gates Creek sockeye in Seton and Anderson lakes in 2007. See Table 1 for more information. Figure adapted from BCRP Seton River watershed strategic plan (BC Hydro, 2000) and Pon et al. (2006).

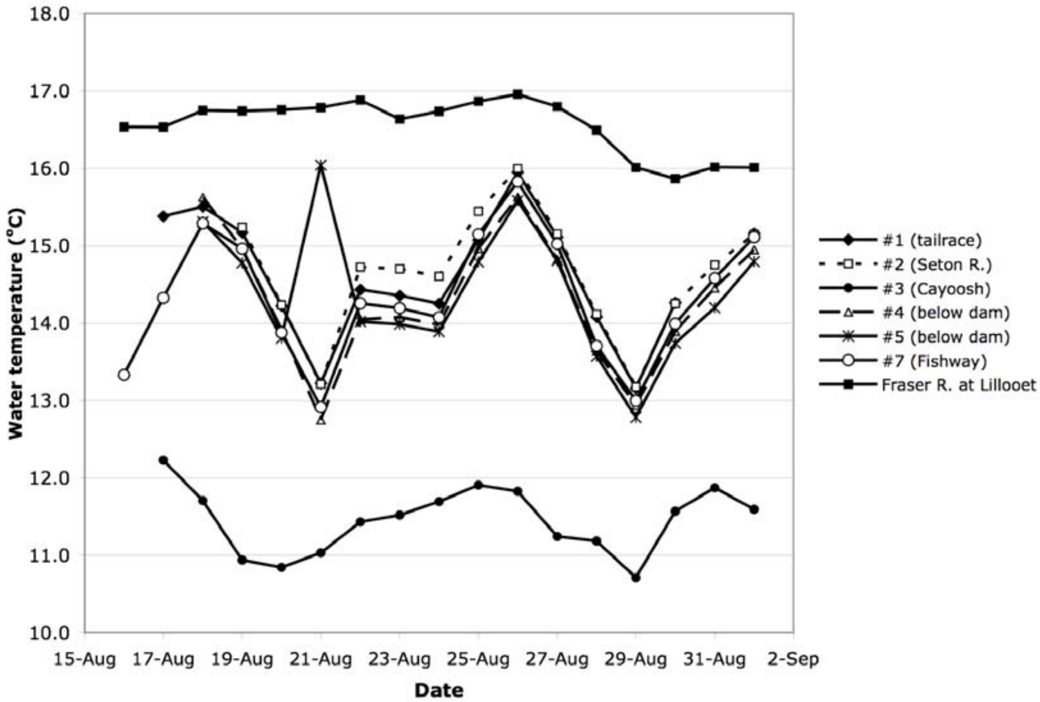


Figure 8. Water temperature measured by archival loggers at fixed telemetry stations in the lower Seton River and in the Seton dam fishway during part of the Gates Creek sockeye migration period in 2007. For information regarding the location of numbered telemetry stations see Figure 7 and Table 1. Fraser River temperature was obtained from the Fraser River Environmental Watch Program, Canadian Department of Fisheries and Oceans.

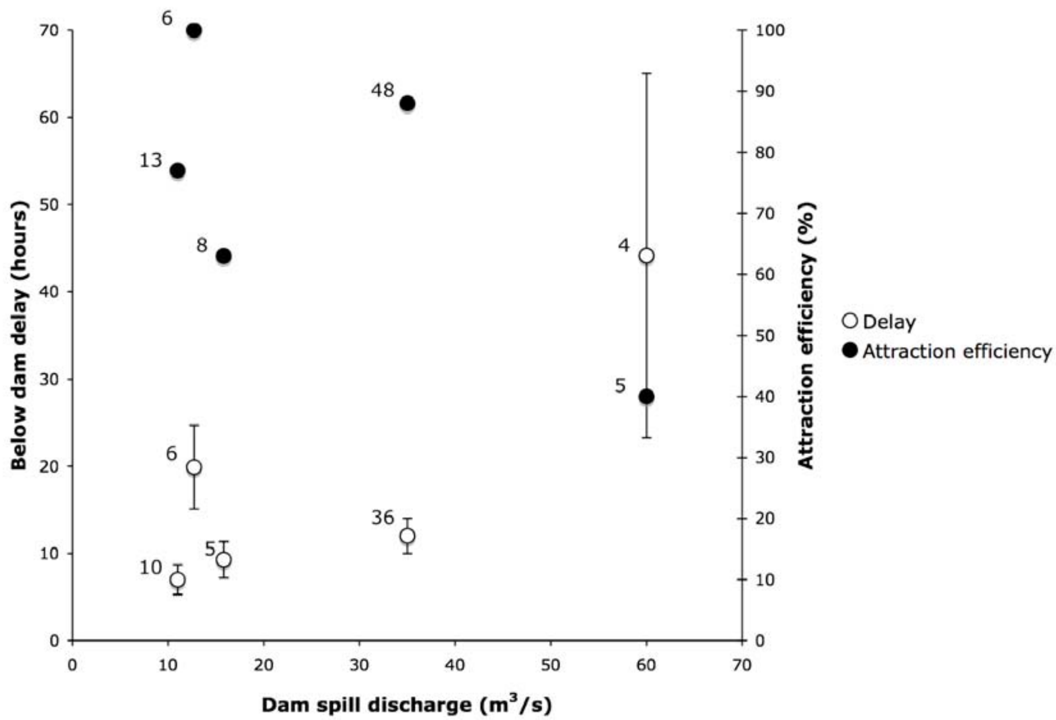


Figure 9. Delay before fishway entry and attraction efficiency of Gates Creek sockeye salmon at Seton dam during 5 different dam spill discharges in 2005 and 2007. Discharges were 11.0 m^3/s, 12.7 m^3/s and 15.8 m^3/s in 2005, and 35 m^3/s and 60 m^3/s in 2007. Standard error bars are shown for delay values and sample sizes are indicated by numerals next to data points.

Appendix 1 - Thermal history of 25 Gates Creek sockeye migrating between release site and spawning grounds during 2007 telemetry study

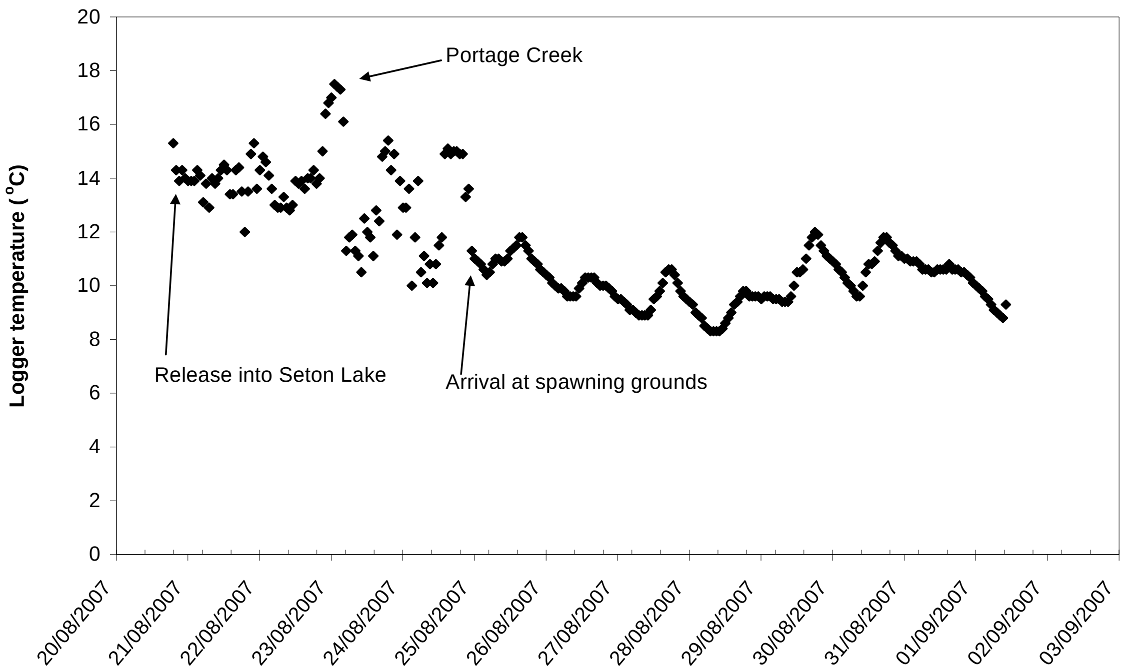


Figure A1. Temperature exposure history of Gates Creek sockeye, fish #54, during migration between release site at the outflow of Seton Lake to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

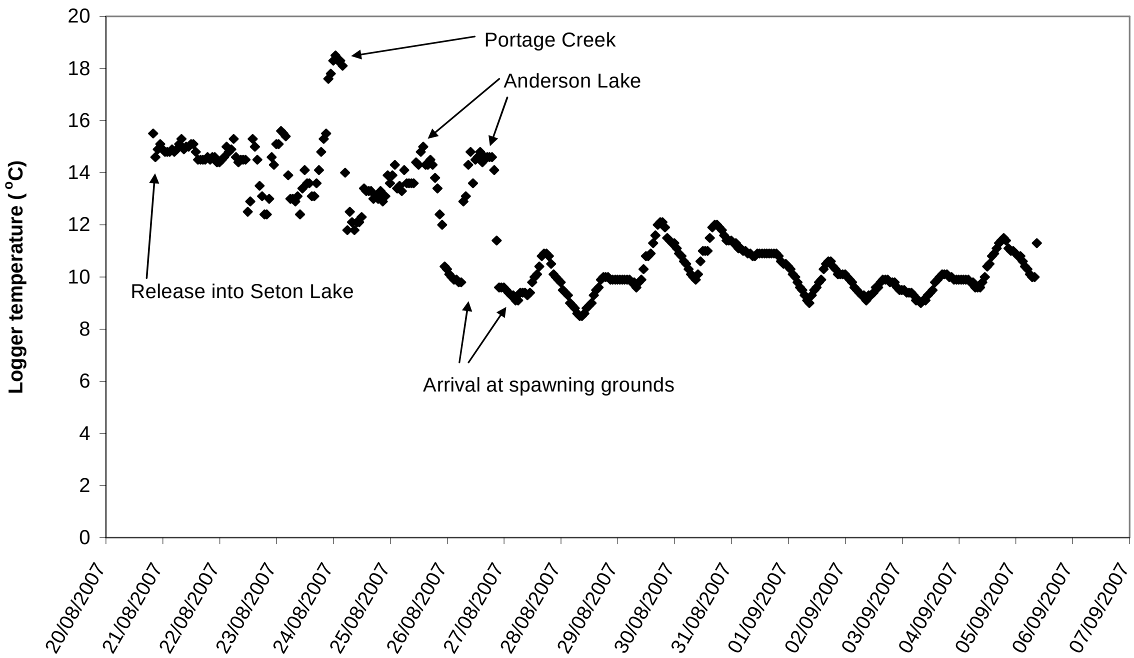


Figure A2. Temperature exposure history of Gates Creek sockeye, fish #55, during migration between release site at the outflow of Seton Lake to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

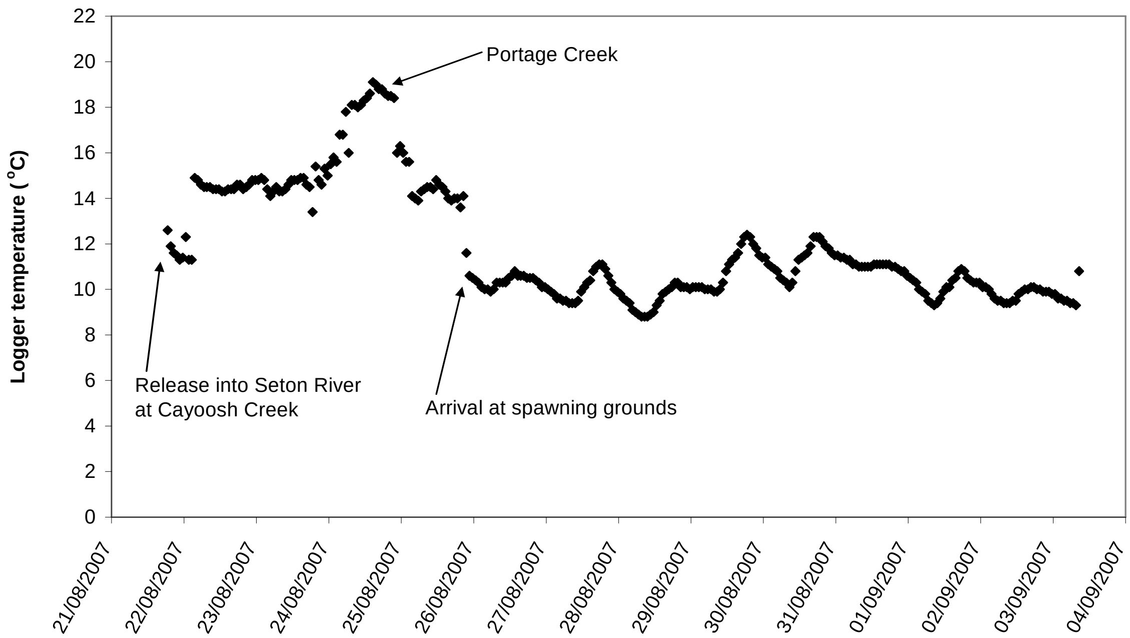


Figure A3. Temperature exposure history of Gates Creek sockeye, fish #58, during migration between release site in the lower Seton River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

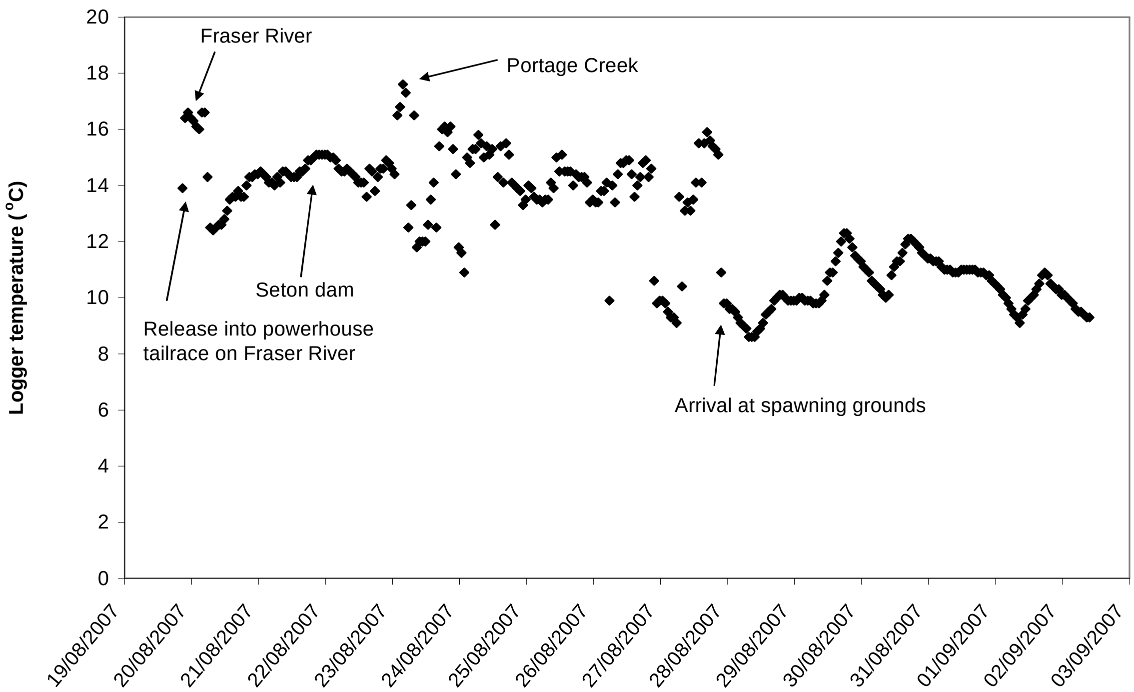


Figure A4. Temperature exposure history of Gates Creek sockeye, fish #47, during migration between release site at the powerhouse tailrace on the Fraser River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

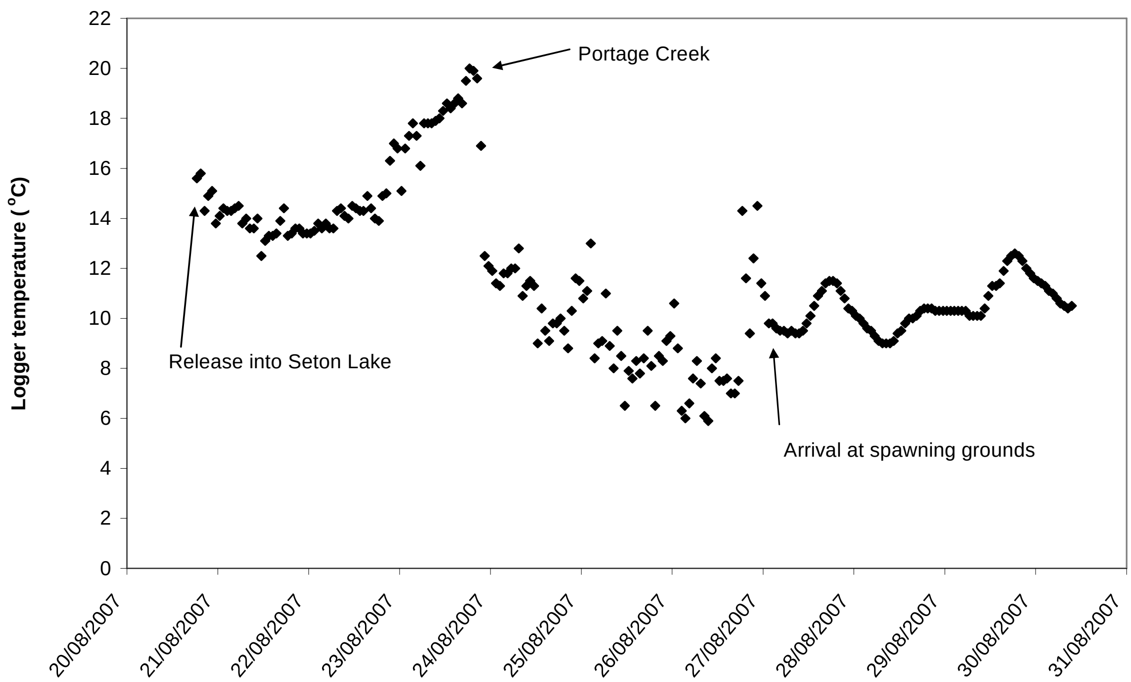


Figure A5. Temperature exposure history of Gates Creek sockeye, fish #52, during migration between release site at the outflow of Seton Lake to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

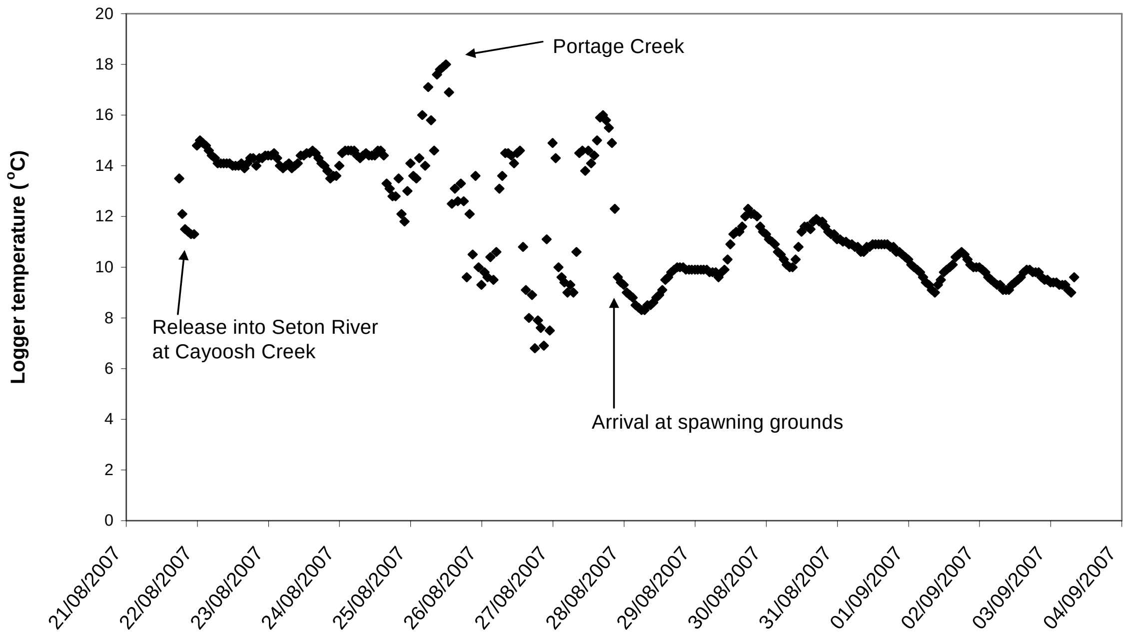


Figure A6. Temperature exposure history of Gates Creek sockeye, fish #59, during migration between release site in the lower Seton River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

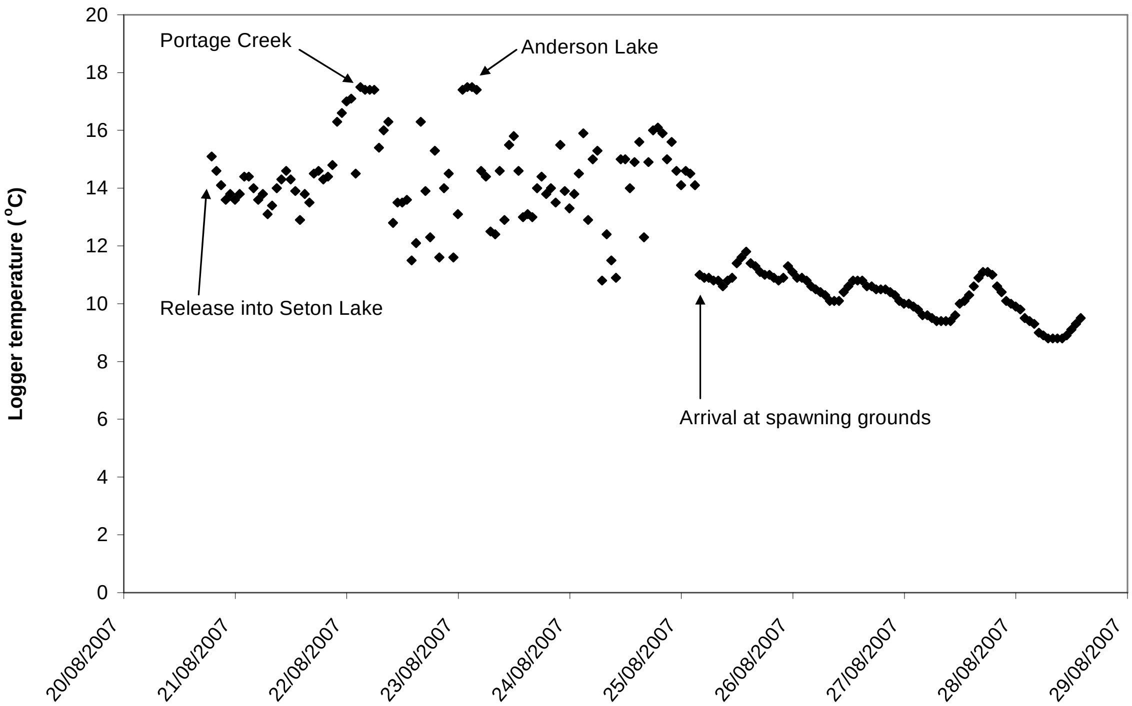


Figure A7. Temperature exposure history of Gates Creek sockeye, fish #51, during migration between release site at the outflow of Seton Lake to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

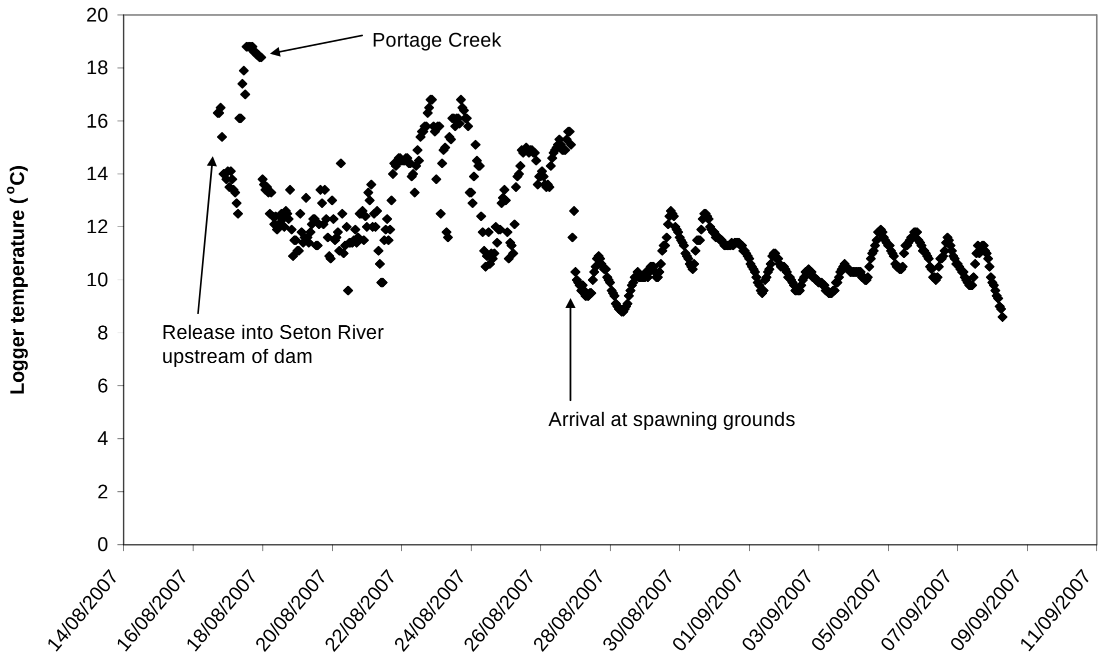


Figure A8. Temperature exposure history of Gates Creek sockeye, fish #16, during migration between release site in Seton River immediately upstream of the dam to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

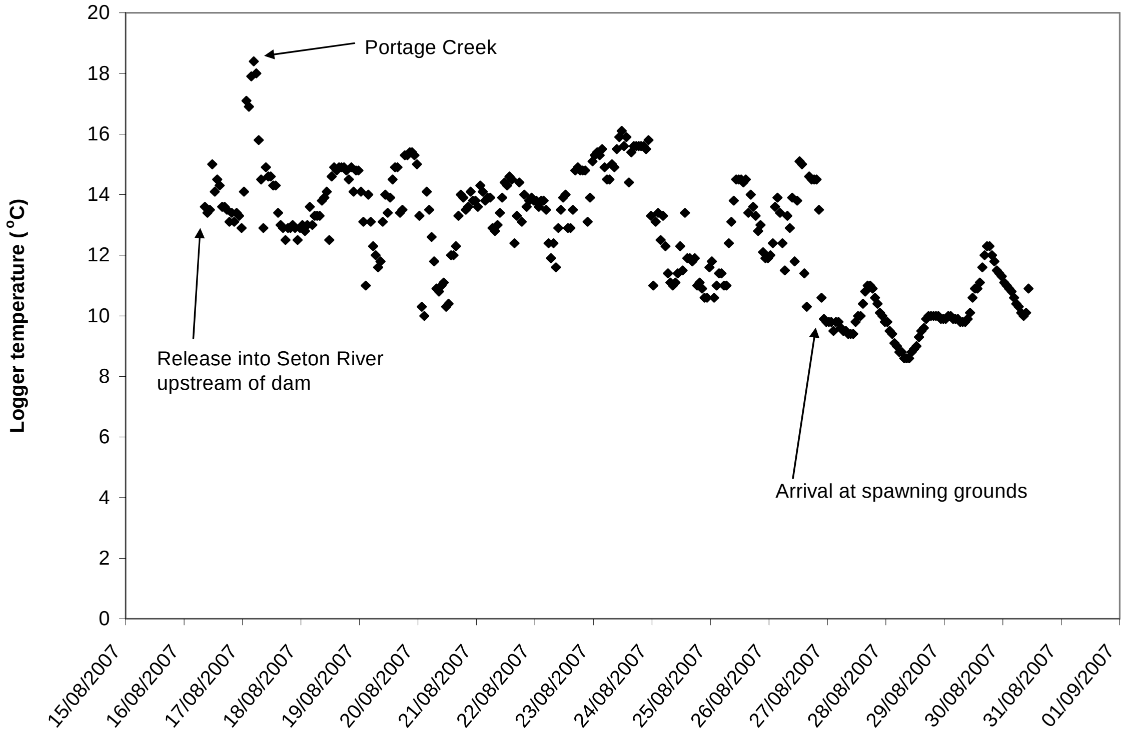


Figure A9. Temperature exposure history of Gates Creek sockeye, fish #6, during migration between release site in Seton River immediately upstream of the dam to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

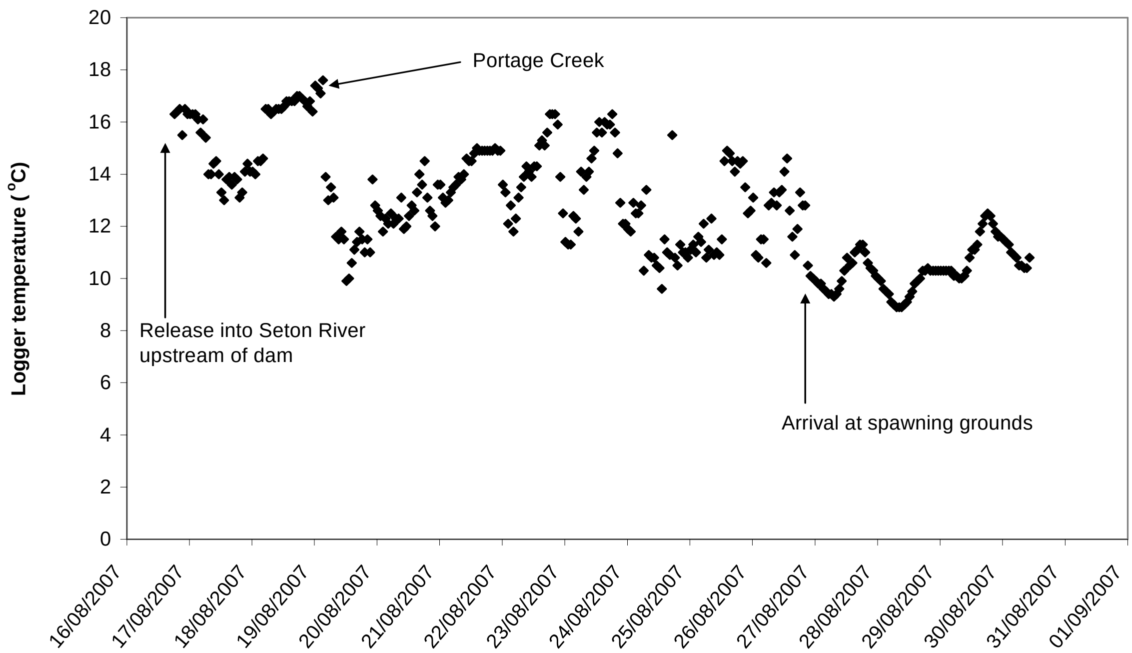


Figure A10. Temperature exposure history of Gates Creek sockeye, fish #20, during migration between release site in Seton River immediately upstream of the dam to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

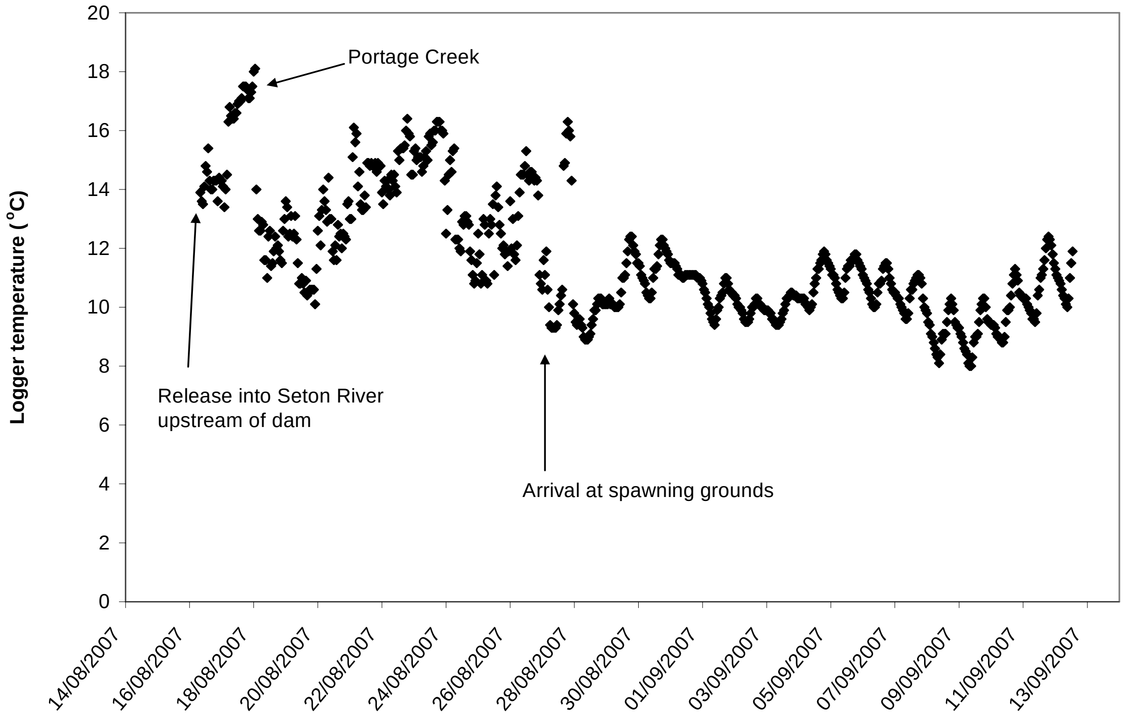


Figure A11. Temperature exposure history of Gates Creek sockeye, fish #5, during migration between release site in Seton River immediately upstream of the dam to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

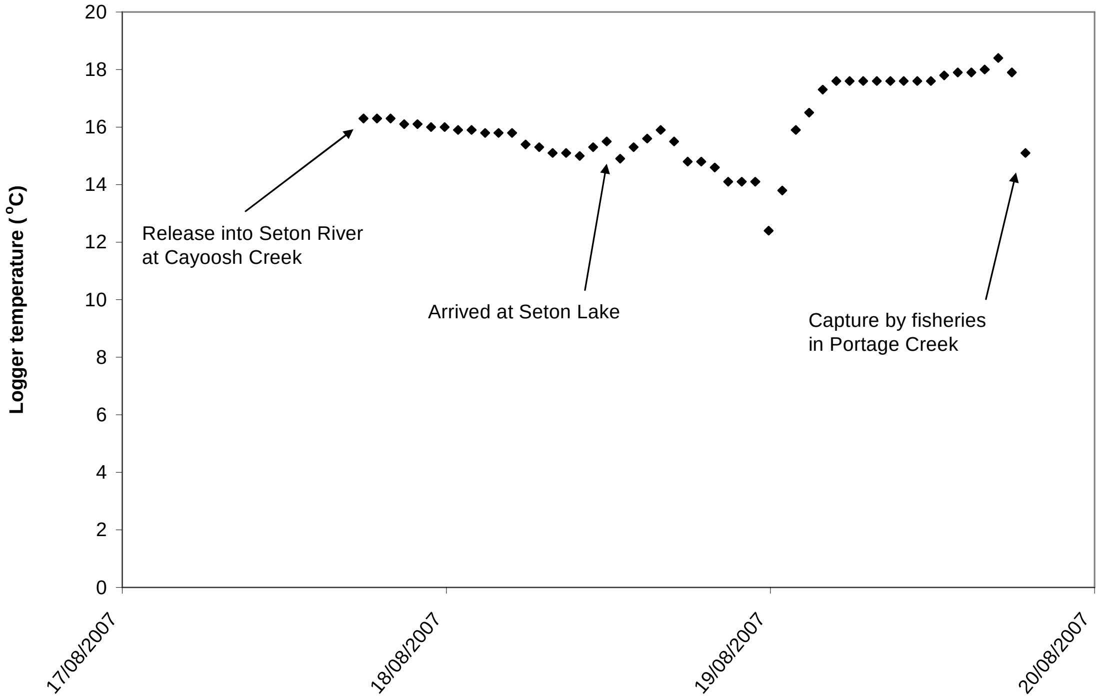


Figure A12. Temperature exposure history of Gates Creek sockeye, fish #28, from release into lower Seton River until capture by fisheries in Portage Creek, as measured by gastrically inserted archival logger.

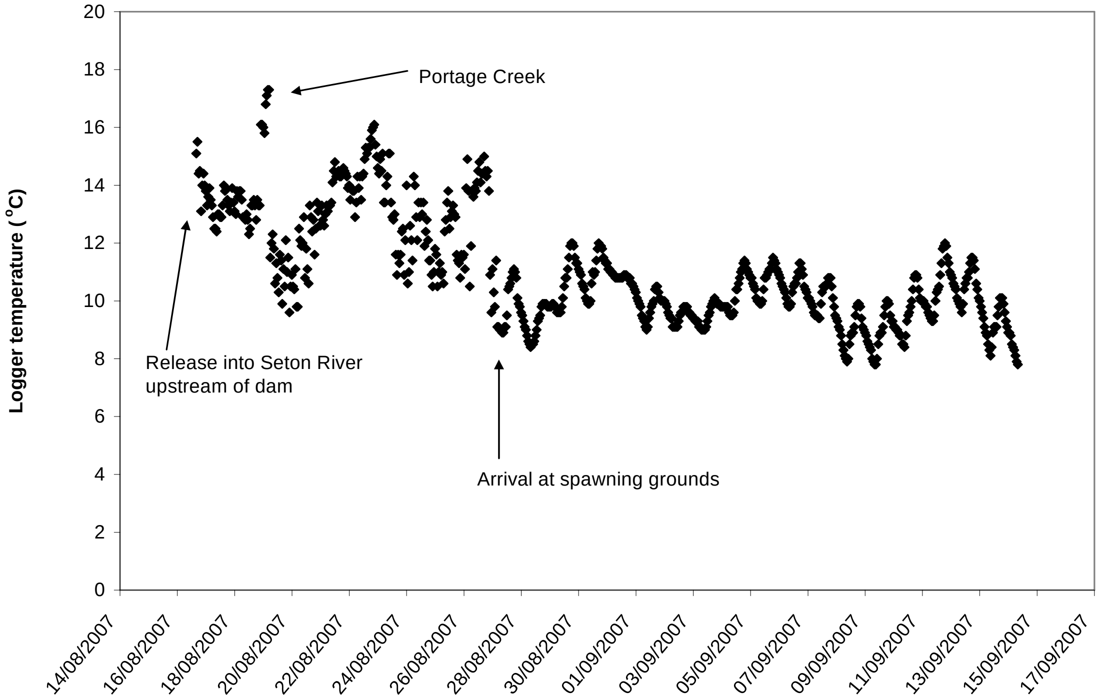


Figure A13. Temperature exposure history of Gates Creek sockeye, fish #12, during migration between release site in Seton River immediately upstream of the dam to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

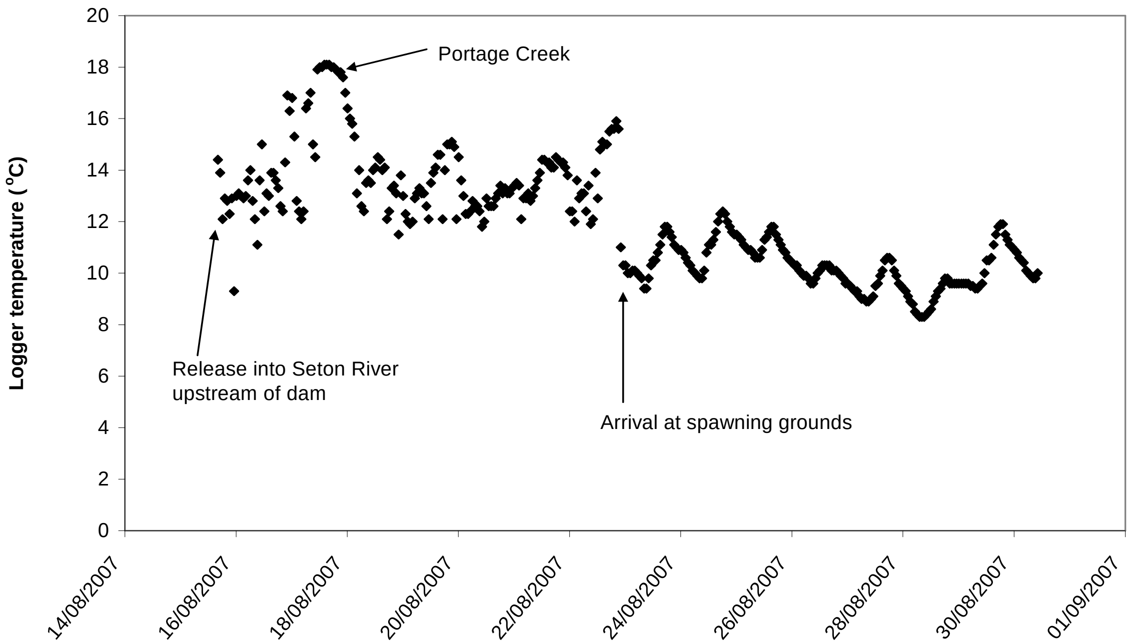


Figure A14. Temperature exposure history of Gates Creek sockeye, fish #4, during migration between release site in Seton River immediately upstream of the dam to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

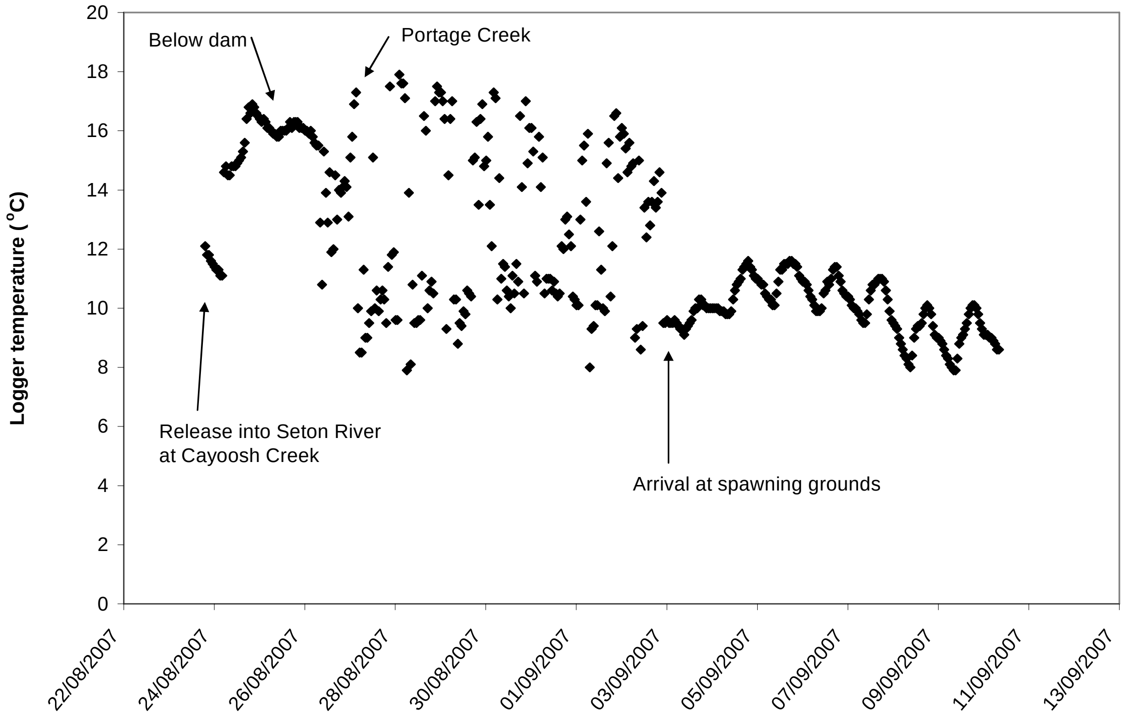


Figure A15. Temperature exposure history of Gates Creek sockeye, fish #76, during migration between release site in lower Seton River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

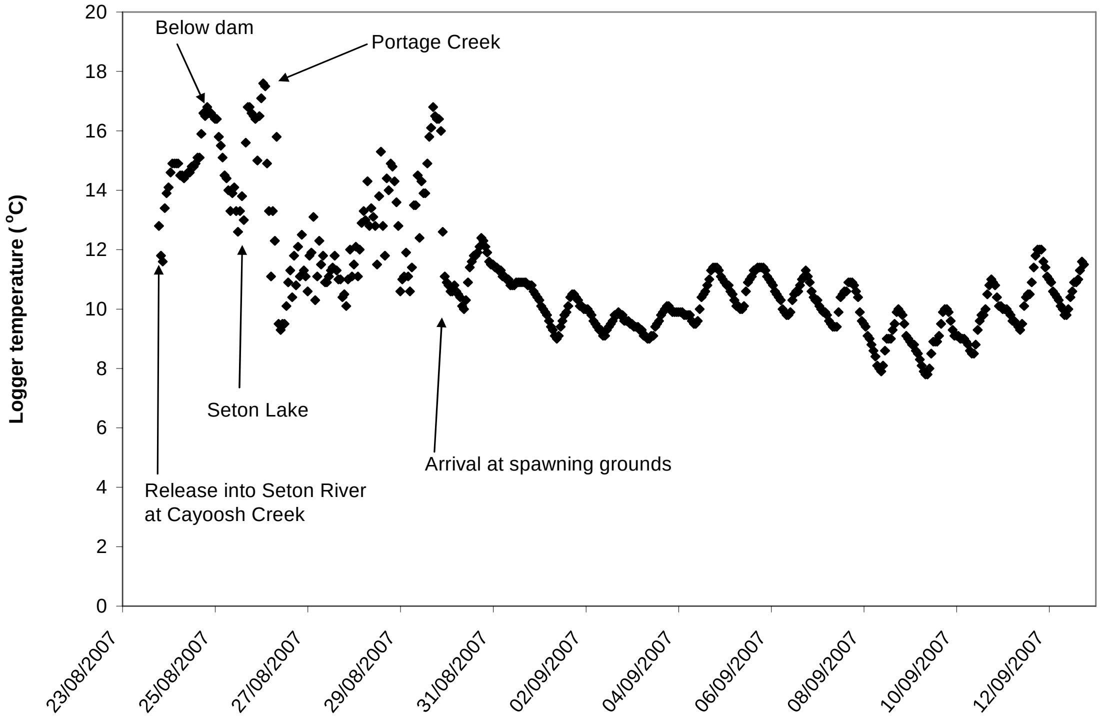


Figure A16. Temperature exposure history of Gates Creek sockeye, fish #77, during migration between release site in lower Seton River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

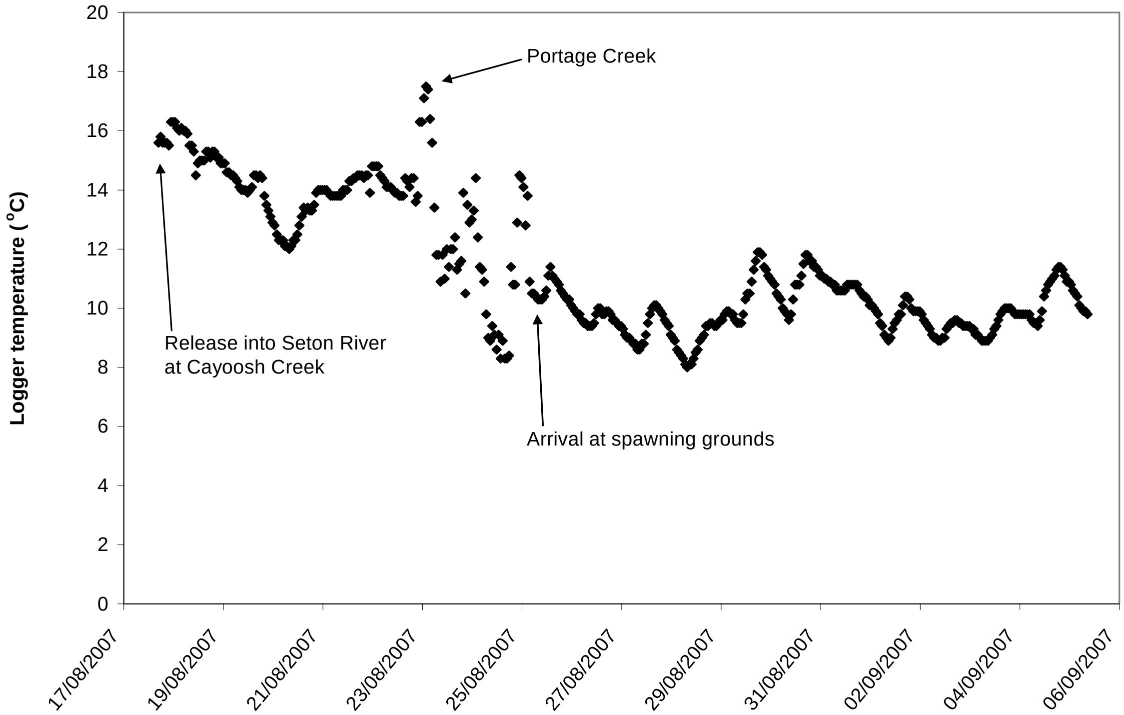


Figure A17. Temperature exposure history of Gates Creek sockeye, fish #22, during migration between release site in lower Seton River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

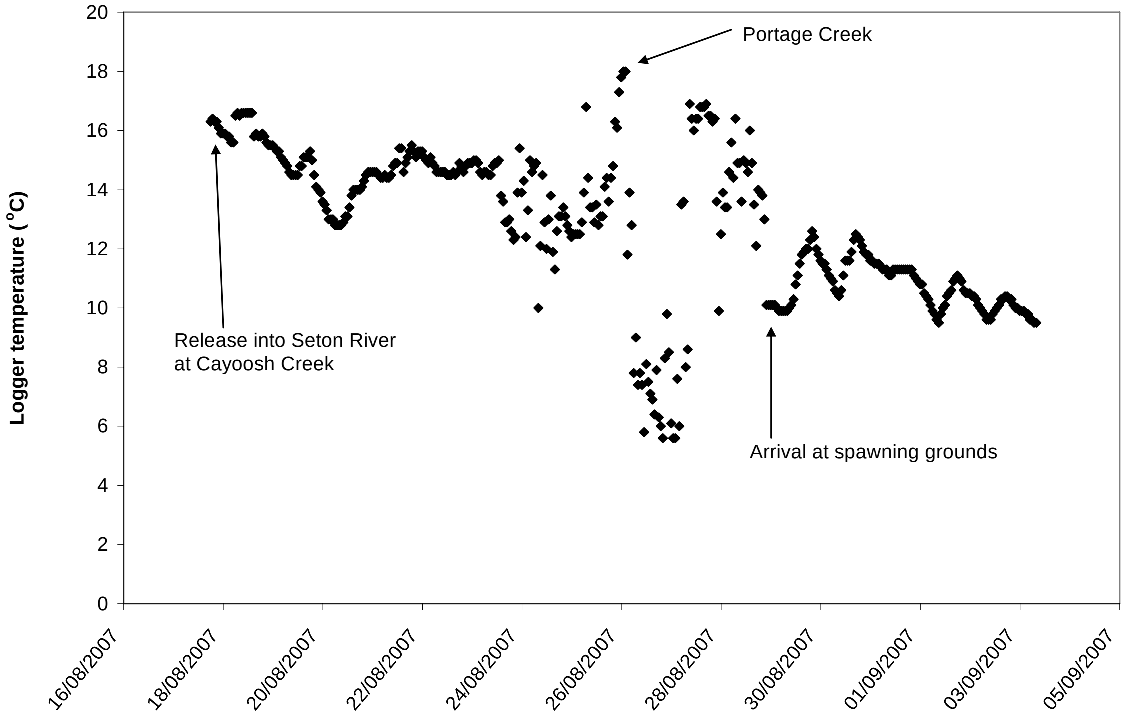


Figure A18. Temperature exposure history of Gates Creek sockeye, fish #29, during migration between release site in lower Seton River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

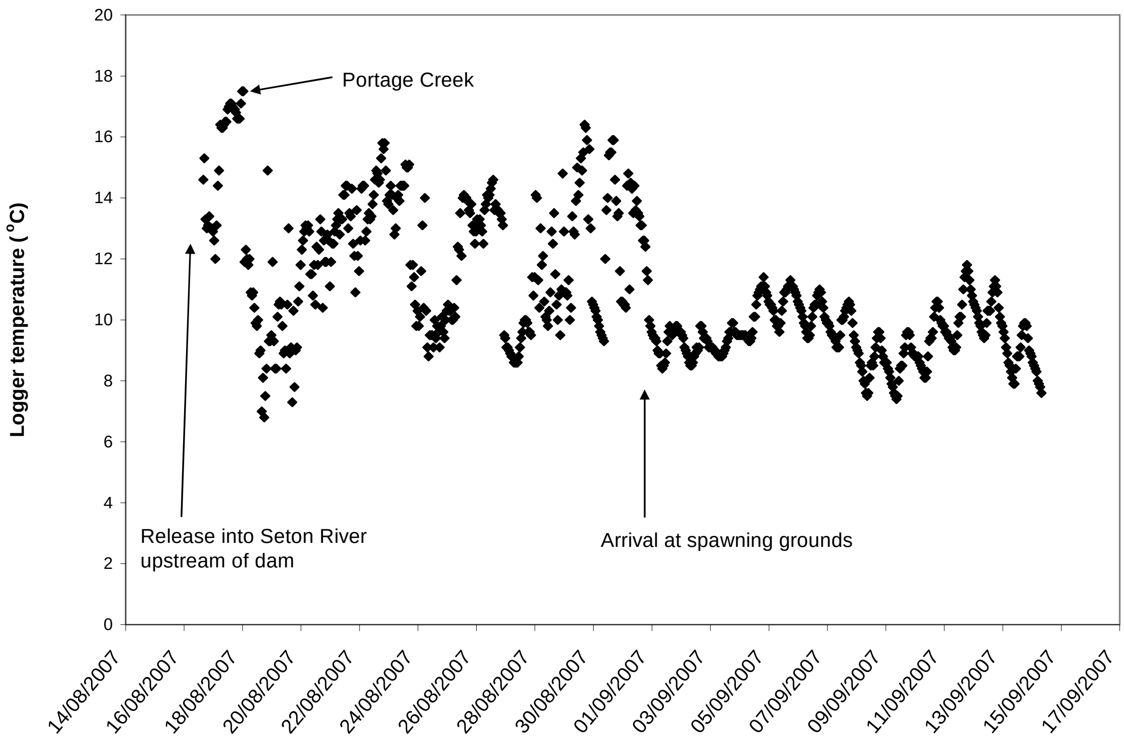


Figure A19. Temperature exposure history of Gates Creek sockeye, fish #10, during migration between release site in Seton River immediately upstream of the dam to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

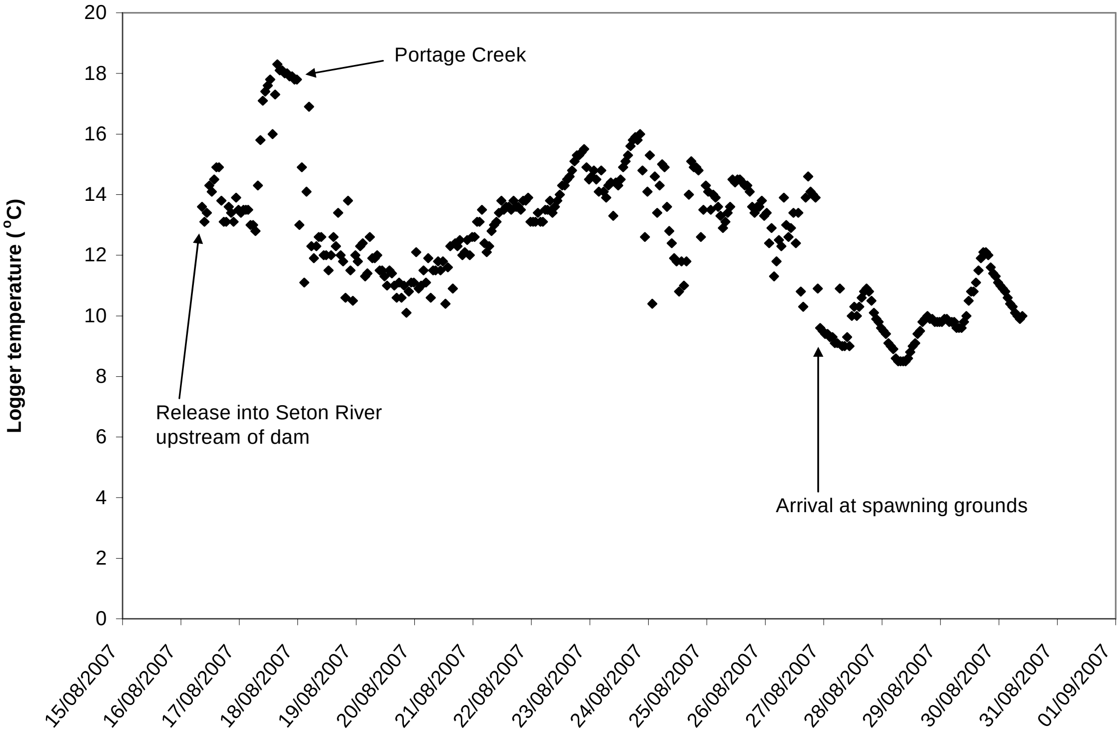


Figure A20. Temperature exposure history of Gates Creek sockeye, fish #7, during migration between release site in Seton River immediately upstream of the dam to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

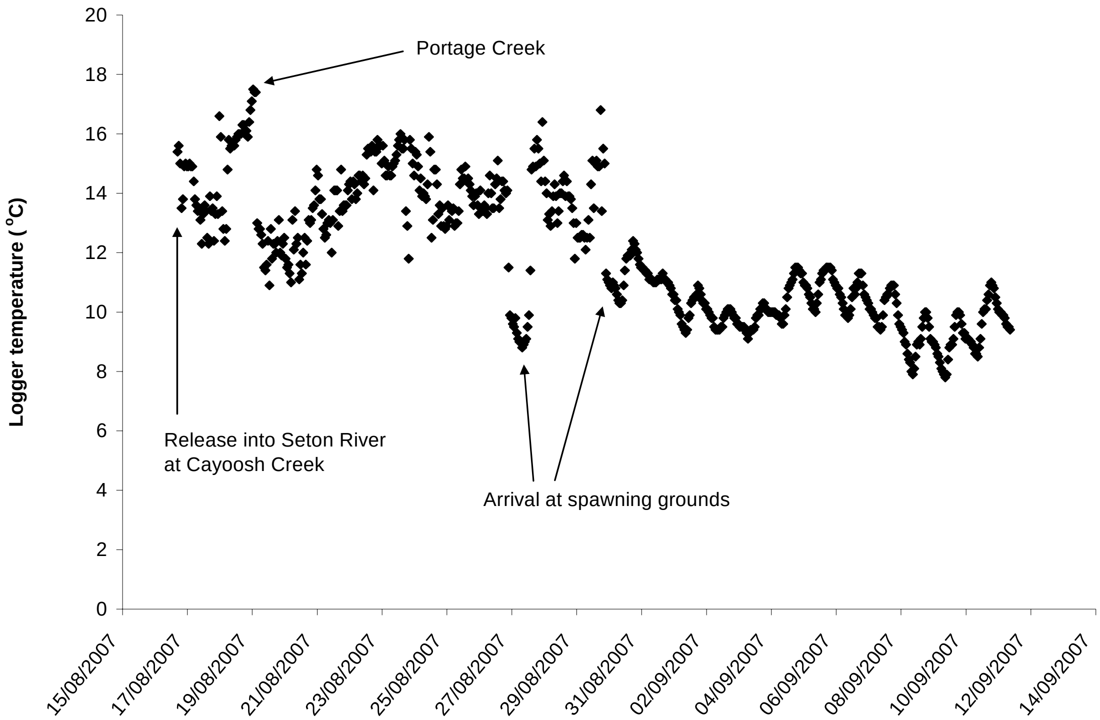


Figure A21. Temperature exposure history of Gates Creek sockeye, fish #14, during migration between release site in lower Seton River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

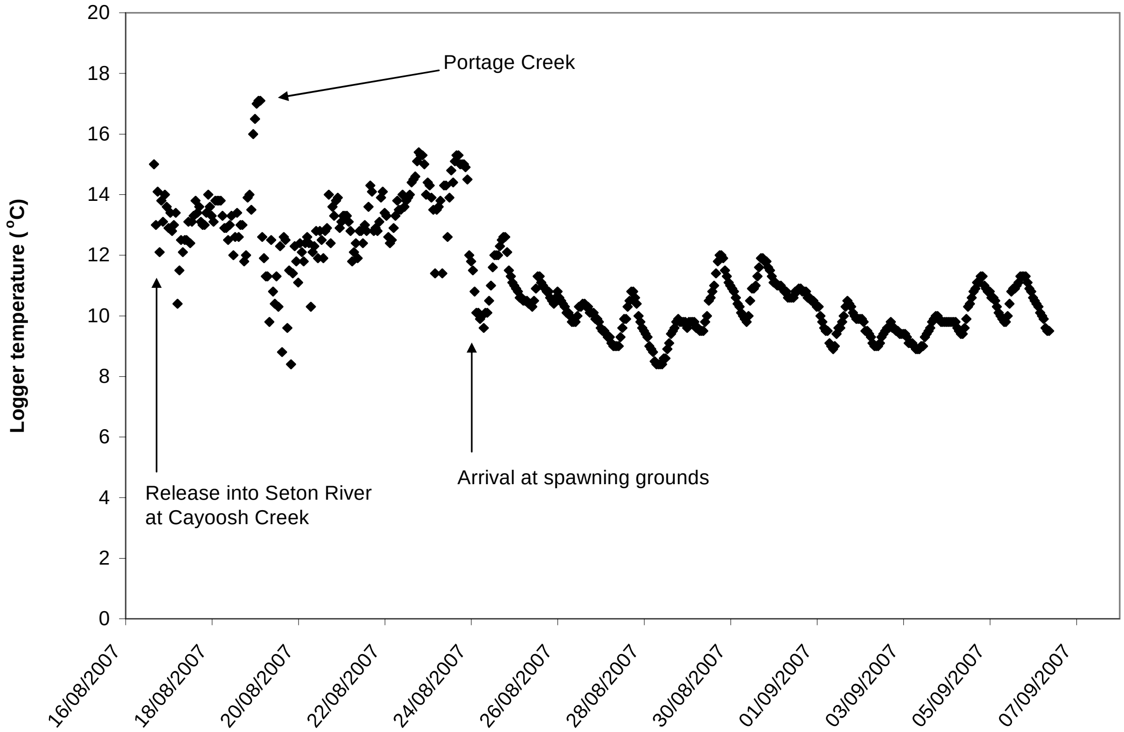


Figure A22. Temperature exposure history of Gates Creek sockeye, fish #13, during migration between release site in lower Seton River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

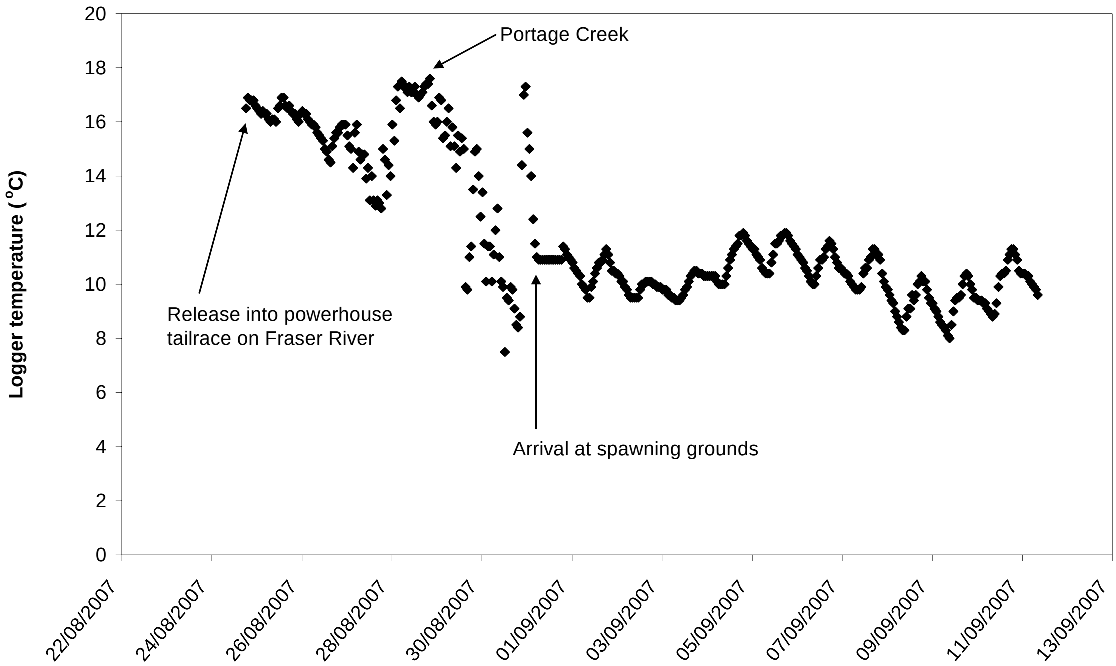


Figure A23. Temperature exposure history of Gates Creek sockeye, fish #86, during migration between release site the powerhouse tailrace on the Fraser River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

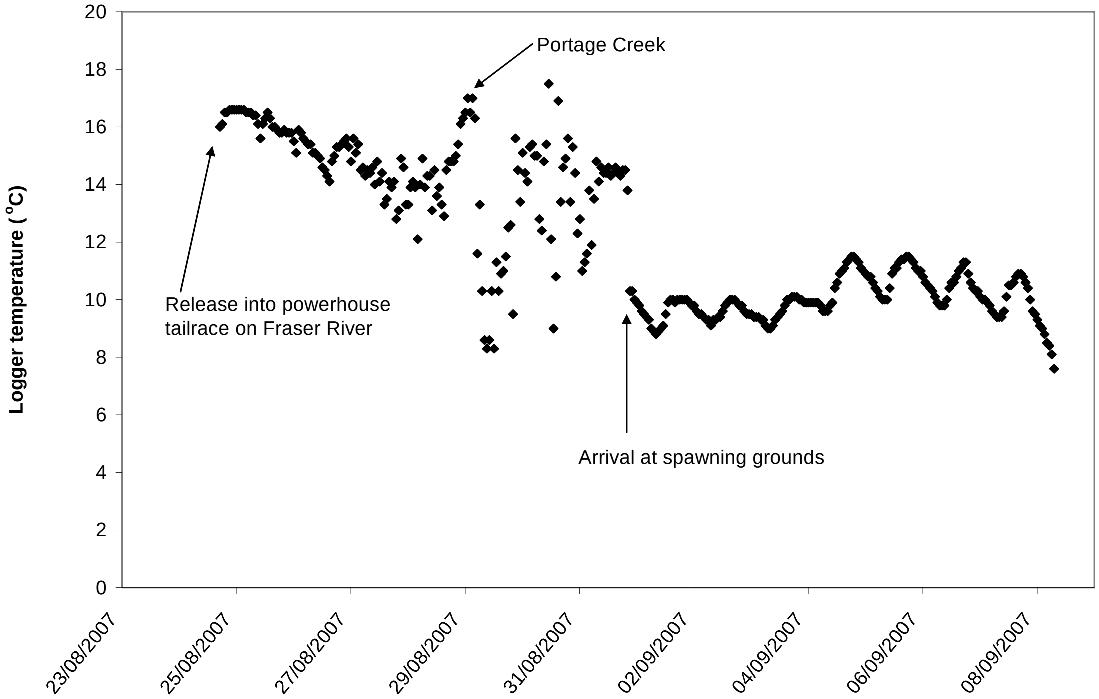


Figure A24. Temperature exposure history of Gates Creek sockeye, fish #84, during migration between release site the powerhouse tailrace on the Fraser River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

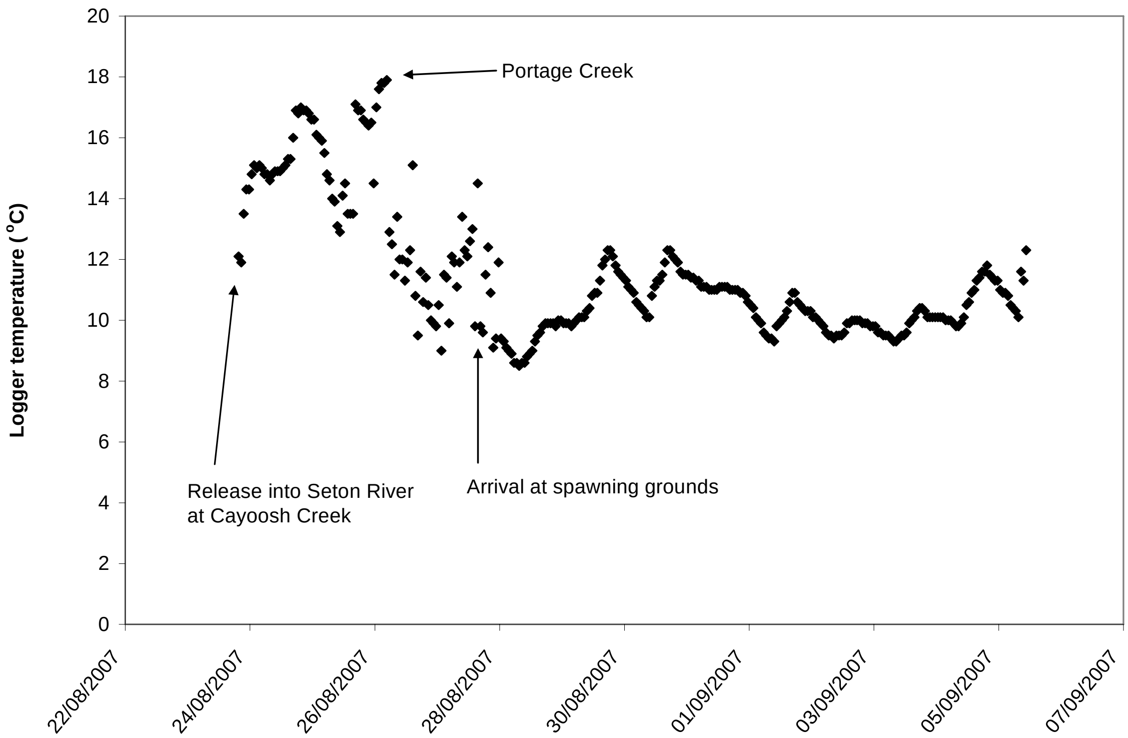


Figure A25. Temperature exposure history of Gates Creek sockeye, fish #80, during migration between release site the powerhouse tailrace on the Fraser River to spawning grounds at Gates Creek, as measured by gastrically inserted archival logger.

Project # 07.BRG01

Financial Statement Form

	BUDGET		ACTUAL	
	BCRP	**Other**	**BCRP**	**Other**
INCOME				
Total Income by Source	107,519.40		0.00	
Grand Total Income (BCRP + other)	107,519.40		0.00	
EXPENSES				
Project Personnel				
Wages	32,180.00		38,678.58	
Consultant Fees	6,000.00		3,712.41	
(List others as required)				
Materials & Equipment				
Equipment Rental				
Materials Purchased	51,225.00		40,779.17	
Travel Expenses	10,150.00		16,384.94	
Permits				
(List others as required)				
Administration				
Office Supplies				
Photocopies & printing				
Postage				
(List others as required) ForestryAdminFee	7,964.40		7,964.30	
Total Expenses	107,519.40	0.00	107,519.40	0.00
Grand Total Expenses (BCRP + other)	107,519.40		107,519.40	
BALANCE (Grand Total Income – Grand Total Expenses)	*The budget balance should equal $0* 0.00		*The actual balance might not equal $0** -107,519.40	

* Any unspent BCRP financial contribution to be returned to: BC Hydro, BCRP
6911 Southpoint Drive (E14)
Burnaby, B.C. V3N 4X8
ATTENTION: JANICE DOANE

Project # 07.BRG01

Performance Measures

Using the performance measures applicable to your project, please indicate the amount of habitat actually restored/enhanced for each of the specified areas (e.g. riparian, tributary, mainstream).

Performance Measures – Target Outcomes												
			Habitat (m²)									
Project Type	**Primary Habitat Benefit Targeted of Project (m²)**	**Primary Target Species**	Estuarine	In-Stream Habitat – Mainstream	In-stream Habitat – Tributary	Riparian	Reservoir Shoreline Complexes	Riverine	Lowland Deciduous	Lowland Coniferous	Upland	Wetland
Impact Mitigation												
Fish passage technologies	Area of habitat made available to target species	sockeye		5300	ha.							
Drawdown zone revegetation/stabilization	Area turned into productive habitat											
Wildlife migration improvement	Area of habitat made available to target species											
Prevention of drowning of nests, nestlings	Area of wetland habitat created outside expected flood level (1:10 year)											
Habitat Conservation												
Habitat conserved – general	Functional habitat conserved/replaced through acquisition and mgmt											
	Functional habitat conserved by other measures (e.g. riprapping)											
Designated rare/special habitat	Rare/special habitat protected											
Maintain or Restore Habitat forming process												
Artificial gravel recruitment	Area of stream habitat improved by gravel plmt.											
Artificial wood debris recruitment	Area of stream habitat improved by LWD plcmt											
Small-scale complexing in existing habitats	Area increase in functional habitat through complexing											
Prescribed burns or other upland habitat enhancement for wildlife	Functional area of habitat improved											
Habitat Development												
New Habitat created	Functional area created											

Appendix 4 – Confirmation of BCRP recognition

Summary of communication and BCRP recognition

• Prior to commencement of fish sampling, articles about the study were published in the Lillooet Bridge River News (August 1 2007) and the St'at'imc Runner newspaper (August 2007). These articles (see attached) outlined the goals of the study, informed fishers about the return of fish tags, and identified BCRP as a primary supporter and funding source for the project.

• Two brief email updates on research progress were sent out during the project to our BC Hydro contacts and other interested parties.

• On September 22, 2008, a presentation concerning this project and a previous (2005) BCRP-funded fish passage study (Pon et al., 2006) was given at a meeting of the Lillooet Naturalist's Society and the Rivershed Society of British Columbia by M.Sc. student David Roscoe. Members of the community and local First Nation's Bands were invited to the event (see attached).

• M.Sc. student David Roscoe spoke about the project and recognized support from BCRP in a recorded interview aired on Radio Lillooet in late September, 2008.

• Interim results of this study were presented by M.Sc. student David Roscoe to representatives from the St'at'imc Nation, the Department of Fisheries and Oceans Canada, and BC Hydro at a meeting of the St'at'imc Hydro Fisheries Co-operative Group on February 19, 2008.

• Results of this study are scheduled for an oral presentation by M.Sc. student David Roscoe at the American Fisheries Society annual conference in Ottawa, Ontario, August 20, 2008.

Sockeye research project starts Aug. 6

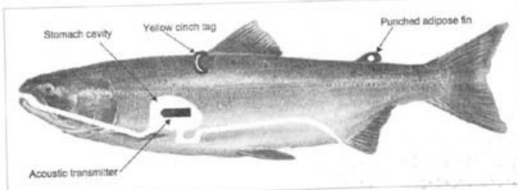
Watch out for tagged fish

Work has begun in the Lillooet area this summer on a research project studying passage of adult sockeye salmon through the Seton hydroelectric dam complex.

Researchers from the University of British Columbia working in conjunction with fisheries staff from the St'at'imc Nation will be examining factors that hinder migration and limit the production of Seton-Anderson watershed sockeye. Funding for the study is being provided by BC Hydro's Bridge Coastal Restoration Program, the Natural Sciences and Engineering Research Council of Canada and the Watershed Watch Salmon Society.

The research project was initiated due to concerns about high mortality and difficult passage at the hydroelectric powerhouse on the Fraser River and at the Seton dam fishway. The Gates Creek and Portage Creek salmon stocks that spawn above the Seton dam have both experienced sharp declines in recent years. The results of this study will determine passage efficiency of sockeye migrating through the Seton hydroelectric dam complex and identify factors limiting successful spawning migration, says UBC researcher David Roscoe.

One hundred and twenty adult sockeye will be captured in early August and implanted with acoustic telemetry transmitters that allow researchers to track them during their migration to spawning grounds. Sockeye will also be equipped with a temperature recording device that upon retrieval will provide researchers with a history of the temperatures encountered by each fish. Water temperature is known to be an important factor affecting successful spawning migration.



Local fishers should keep a lookout for tagged sockeye salmon similar to this fish.

The tagging program begins Aug. 6 and local fishers are asked to keep an eye out for tagged fish for the remainder of the summer. Study fish will have an acoustic telemetry transmitter in their stomach, an external yellow tag near the dorsal fin and a punched adipose fin. There will be no visible antenna and no external incision as transmitters are inserted down the throat.

Anyone who catches a tagged sockeye is asked to remove the black cylindrical transmitter from the stomach and the yellow dorsal tag and return both pieces to the Northern St'at'imc Fisheries office at 917 Main Street, Lillooet (P.O. Box 1420), V0K 1V0.

Information obtained with the co-operation of local fishers in returning tags will directly contribute to the improved conservation and management of Seton-Anderson watershed sockeye.

Anyone who has caught a tagged sockeye or has questions regarding this study can contact the Northern St'at'imc Fisheries office (250-256-4332) or the Pacific Salmon Ecology and Conservation Laboratory at the University of British Columbia (604-822-9377).

Sockeye tagging for spawning migration study

By David Roscoe

Work has begun in the Lillooet area this summer on a research project studying passage of adult sockeye salmon through the Seton hydroelectric dam complex. Researchers from the University of British Columbia working in conjunction with fisheries staff from the St'át'imc Nation will be examining factors that hinder migration and limit the production of Seton-Anderson watershed sockeye.

The research project was initiated due to concerns about high mortality and difficult passage at the hydroelectric powerhouse on the Fraser River and at the Seton dam fishway. The Gates Creek and Portage Creek salmon stocks that spawn above the Seton dam have both experienced sharp declines in recent years. The results of this study will determine passage efficiency of sockeye migrating through the Seton hydroelectric dam complex and identify factors limiting successful spawning migration.

One hundred and twenty adult sockeye will be captured in early August and implanted with acoustic telemetry transmitters that allow researchers to track them during their migration to spawning grounds. Sockeye will also be equipped with a temperature recording device that upon retrieval will provide researchers with a history of the temperatures encountered by each fish. Water temperature is known to be an important factor affecting successful spawning migration.

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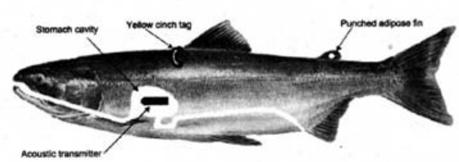

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Information obtained with the cooperation of local fishers in returning tags will directly contribute to the improved conservation and management Seton-Anderson watershed sockeye. Anyone who has caught a tagged sockeye or that has questions regarding this study can contact the Northern St'át'imc Fisheries office (250-256-4332) or the Pacific Salmon Ecology and Conservation Laboratory at the University of British Columbia (604-822-9377).

This photo was taken along the Duffy Lake Road

Salmon in the Seton – Anderson Watershed

The *Lillooet Naturalist Society* invites you to a presentation by the researcher, David Roscoe, about our local salmon:

Fishway passage, water diversion and warming temperatures: Factors limiting the production of Seton-Anderson watershed sockeye. *Spawning escapement of sockeye salmon in the Seton-Anderson watershed has declined in recent years. The Gates Creek and Portage Creek sockeye that spawn in the watershed must migrate through a highly engineered and hydrologically altered system to reach spawning grounds. Our research examines the passage efficiency of sockeye migrating through the Seton hydroelectric complex and the factors limiting successful spawning migration*

Lillooet Friendship Centre

Date: Saturday, September 22, 2007

Time: 7:30 pm – door open to public at 7 pm. Everyone is welcome - donations for the Friendship Centre Food Bank appreciated

Lillooet Naturalist Society

BC HYDRO FISH & WILDLIFE BRIDGE COASTAL RESTORATION PROGRAM