Yukon Energy – Resource Planning Department

Whitehorse Rapids Generating Station Juvenile Chinook Salmon Entrainment Assessment

Prepared for:

Whitehorse Rapids Generating Station Technical Working Group
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EXECUTIVE SUMMARY

In response to recent declines in Chinook Salmon returns to the Whitehorse area of the Yukon River and the relicensing of the Whitehorse Rapids Generating Station (WRGS), the Whitehorse Rapids Generating Station Relicensing Project - Technical Working Group (WRGS TWG) was developed comprising Kwanlin Dün First Nation, Ta'an Kwäch'än Council, Carcross/Tagish First Nation, and Yukon Energy Corporation. The WRGS TWG requested an assessment of juvenile Chinook Salmon mortality associated with downstream migration through the WRGS with the goal of informing strategies to improve Yukon River Chinook Salmon abundance and long-term sustainability of adult returns. The entrainment assessment included two phases.

1. Desktop assessment: The first phase involved reviewing reports completed elsewhere to understand the potential impacts of dams on the downstream migration of juvenile Chinook Salmon (Desktop Assessment). Through this process we identified a model that could be used to estimate impacts to salmon based on the unique characteristics of the WRGS and the local Chinook Salmon population.
2. Pilot studies: The second phase involved four preliminary field studies that had the goals of understanding fish behaviour in Schwatka Lake (Hydroacoustic Scanning), conditions experienced by juvenile Chinook Salmon during downstream passage through the dam (Sensor Fish), predation risk to juvenile Chinook Salmon after passing through the dam (Predator Surveys), and monitoring of total gas pressure (TGP) levels to assess the potential for Gas Bubble Trauma (Total Gas Pressure Monitoring). Studies were completed during the anticipated peak of juvenile outmigration (June 28 – July 7th, 2023).

Desktop Assessment

The desktop assessment characterized juvenile Chinook Salmon downstream movement and mortality through the WRGS, recognizing that many data gaps still exist related to juvenile Chinook Salmon ecology in the area. At the WRGS, Chinook Salmon may move through any of the four turbine intakes, the spillway, or the fishway to move downstream on their journey to the ocean. Based on the amount of water flowing down each route, it was estimated that most age-0 hatchery and age-1 wild Chinook Salmon move through the spillway, while a greater proportion of age-0 wild salmon move through the turbines. In general, older and larger fish have greater mortality rates as they are more likely to be struck by the turbine blades. Based on a review of other reports and consideration of the design of the spillway (bottom-release), it was estimated mortality was <1% for juvenile salmon.

Hydroacoustic Scanning

A sonar was deployed on a rotational basis at the spillway and the turbine intakes to monitor salmon movement past the dam. Overall, 72 fish were observed during hydroacoustic scanning across all three intakes (101 mm to 458 mm). Only three fish were identified with sizes expected for wild 1+ juvenile salmon (i.e., 101 mm, 119 mm, and 136 mm). Fish density was greatest at the spillway (15.5 fish/day), followed by the upper powerhouse (7.7 fish/day), and lower powerhouse by the power canal (4.2 fish/day).

Sensor Fish

A data logger known as the Sensor Fish was deployed through the turbine intakes to characterize the conditions experienced by juvenile salmon. Overall, it was found that the greatest mortality risk to fish was due to strikes/collisions (primarily in the turbine runner region), followed by barotrauma, and shear stress. Passage conditions were ~2x more severe at the upper powerhouse than WH3 of the lower powerhouse, which corresponded to higher mortality estimates for salmon passing through the upper powerhouse. For this preliminary study only a limited number of loggers were available and despite repeat trials they were all eventually lost or destroyed. Although only a small number of Sensor Fish deployments were completed, the data provide interesting insights into conditions for juvenile Chinook Salmon.

Predator Surveys

Predator surveys were undertaken to see if juvenile salmon were at high vulnerability to bird and fish predation after passing through the dam. Potential predators were captured by angling at and away from the dam. Overall, fish density was low, particularly in the immediate outflows of the turbines and spillway. No juvenile Chinook Salmon were identified in the stomachs of the 14 fish lethally sampled, though a few unidentified juvenile fish were observed.

Bird surveys were completed at and downstream of the dam by volunteers between May 4 and July 29, 2023. The abundance of birds during each survey week was highly variable, and there did not appear to be any strong indication that birds were keying in on juvenile salmon at the dam compared to other locations along the river. Overall, little bird fishing activity was observed across any survey.

There was little evidence to suggest either fish or bird predation were great sources of mortality for juvenile salmon moving through the WRGS. However, Chinook Salmon abundance in the area is likely very low given recent adult returns, which decreased the likelihood of observing predation.

Total Gas Pressure Monitoring

Dams can increase total gas pressure in water such that it becomes harmful to fish. Total Gas Pressure (TGP) loggers were deployed at the dam while the dam was actively spilling water. Total Gas Pressure was found to be highest immediately downstream of the spillway. Although the spillway was associated with some elevated TGP levels (i.e., >110%), based on the small area impacted, depth of the

Yukon River, and ecology of local fish populations, TDG supersaturation likely has negligible effects on the local fish community. TGP levels were not elevated downstream of the turbines.

Overall Mortality Estimate

Overall mortality estimates are provided that combine the findings from the desktop model and Sensor Fish deployments. The following equation was used to estimate mortality associated with each route at the WRGS for each life-stage of juvenile Chinook Salmon.

Mortality of route = Proportion of population entering route × route-specific mortality rate.

Based on various assumptions and analyses described throughout the report, it was estimated that 26.0% of age-0 and 33.6% of age-1 wild juveniles are killed during passage through the project across all routes (spillway, turbines). Although larger age-1 juveniles have higher mortality during passage, it was estimated that more age-1 juveniles would use the spillway given their propensity for mid-channel habitat. It was estimated that 23.0% of hatchery juveniles would succumb to mortality during passage through the project. This estimate reflects the intermediate size of hatchery juveniles, and assumption that they would behave like age-1 juveniles (i.e., move in proportion to the amount of discharge and therefore use the spillway more often). Little information exists to evaluate the proportion of juveniles moving past the dam as either age-0 or age-1. However, using the trapping data at the dam from Brown *et al.* (1976), and the corresponding spawner counts from the preceding two years, it can be estimated that 13% of wild juveniles migrate downstream as age-1 fish, as such, the overall mortality rate for the wild juvenile population would be closer to that of age-0 wild fish (i.e., 27.0%).

Recommendations

Based on the findings of our study and existing data gaps, we suggest the following be considered for future work;

- Increase knowledge of juvenile Chinook Salmon ecology passing through the WRGS, including confirming the timing of salmon outmigration and route choice. Longer-term sonar deployments would be useful for providing this information. Other approaches may also be useful (e.g., trapping, fish tagging)
- The useful application of Sensor Fish was confirmed for the WRGS at WH3 and WH4. To provide better mortality estimates, additional Sensor Fish could be deployed through each intake (particularly those intakes not assessed in 2023).
- Predator surveys are likely not needed moving forward unless a substantial Chinook Salmon run occurs and increases juvenile salmon densities.
- Additional TGP monitoring could be useful during spill periods that exceed 500 m^3/s. These conditions may not occur every year but have been observed in recent years.

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Age-0 – Age 0 Chinook Salmon (i.e., salmon during their first year as free-swimming fry)

Age-1 – Age 1 Chinook Salmon (i.e., salmon during their second year as free-swimming fry/smolt)

CPUE – Catch per Unit Effort

DFO – Department of Fisheries and Oceans Canada

Entrainment – The passage of fish through an intake

g – acceleration of gravity (unit)

GBT – Gas Bubble Trauma

HBET – Hydropower Biological Evaluation Toolset

LOESS – Locally weighted scatterplot smoother

P125 – Powerhouse 125 (inclusive of WH1, WH2, WH3)

P127 – Powerhouse 127 (inclusive of WH4)

RPM – rotations per minute

RSW – Robert Service Way

TDG – Total Dissolved Gas

TGP – Total Gas Pressure

TWG - Whitehorse Rapids Generating Station Technical Working Group

YEC – Yukon Energy Corporation

WRGS – Whitehorse Rapids Generating Station

WH1 – Whitehorse Hydro Turbine #1 (Kaplan)

WH2 – Whitehorse Hydro Turbine #2 (Kaplan)

WH3 – Whitehorse Hydro Turbine #3 (Propeller)

WH4 – Whitehorse Hydro Turbine #4 (Propeller)

1. INTRODUCTION AND OBJECTIVES

The Whitehorse Rapids Generating Station (WRGS) began operation in 1958 to provide energy to the Yukon. The facility has expanded over time, and now has four turbines providing up to 40 MW of power during summer months. During the summer, adult Chinook Salmon return from the ocean and travel more than 2,800 km up the Yukon River to spawning grounds upstream of the dam. Adult salmon migrate past the dam using the Whitehorse Rapids Fish Ladder, with most salmon swimming ~100 km further upstream to spawn in Michie Creek. Juvenile salmon from these upstream areas migrate past the dam through the turbines, spillway, or fishway. In 1960 and 1973 assessments were undertaken to estimate juvenile salmon mortality through the turbines, though the methods are unclear, and this was undertaken prior to construction of WH4 (Brown *et al.* 1976). In 1984, to offset turbine-induced mortalities, the Whitehorse Rapids Fish Hatchery began supplementing wild Chinook Salmon.

In response to recent declines in Chinook Salmon returns to the Whitehorse area of the Yukon River and the relicensing of the Whitehorse Rapids Generating Station (WRGS), the Whitehorse Rapids Generating Station Relicensing Project - Technical Working Group (WRGS TWG) was developed comprising Kwanlin Dün First Nation, Ta'an Kwäch'än Council, Carcross/Tagish First Nation, and Yukon Energy Corporation. These three First Nations have long had an important relationship with salmon centred around respect and reciprocity (Herkes 2023). The WRGS TWG requested an assessment of entrainment (i.e., passage of fish through an intake) and mortality of juvenile Chinook Salmon at the WRGS with the goal of informing strategies to improve Yukon River Chinook Salmon abundance and long-term sustainability of adult returns. The entrainment assessment included two phases:

1. Desktop assessment: A general review of mortality from entrainment and a site-specific evaluation. The site-specific evaluation included a review of juvenile Chinook ecology in Whitehorse, as well as entrainment risk and expected mortality for juvenile Chinook Salmon migrating through the WRGS.
2. Pilot studies: Four pilot studies that included hydroacoustic scanning to characterize fish behaviour during downstream passage, deployment of sensor fish to evaluate conditions experienced by juvenile Chinook Salmon during downstream passage through all intakes, predator surveys to assess predation risk to juvenile Chinook Salmon following entrainment, and monitoring of total dissolved gas (TDG) levels to assess the potential for Gas Bubble Trauma.

We approached the field components of this project as 'pilot' studies, with the intent being to evaluate and determine the effect pathways that are most likely to drive any entrainment effect. Further, these pilot studies will provide important insight into the design of additional, targeted entrainment studies in the future. By bringing together the findings of Phase 1 and 2, we generate multiple lines of evidence to evaluate the risk of entrainment for juvenile Chinook Salmon at the WRGS. Findings from each phase (and component) of work are presented separately below and can be read as stand-alone with their own introduction, methods, results, and discussions, with a final synthesis section integrating the findings of each phase (Section 3). This report and a presentation to the WRGS TWG are the deliverables of the assessment, which will conclude in September 2023. Inclusion of local knowledge was provided through the support from First Nation partners in preparation for and throughout the field programs. First Nation staff provided critical support to fieldwork execution.

2. PROJECT COMPONENTS

2.1. Desktop Assessment

2.1.1. Background

2.1.1.1. Entrainment

Hydropower dams can entrain fish that come near the various intakes along the dam (e.g., fishway, spillway, and turbine intakes). For the purposes of this report, entrainment is considered as the passage of fish through an intake at a hydropower station. The rate of entrainment across intakes is dependent on many factors related to the ecology of the population and the design and operation of the hydropower dam. For salmon species, juvenile fish upstream of a dam must pass downstream of the dam to progress through their lifecycle (i.e., migrate to the marine environment), meaning all fish will be entrained. Salmon entrainment through the various intakes at a dam will be influenced by their biology including habitat preferences (depth and lateral distribution), movement behaviour (seasonal, diel, orientation to flow), and fish morphology (e.g., swimming ability, sensory ability). In general, route selection in salmonids is primarily influenced by relative flow through each route (Moser *et al.* 1991; Moore *et al.* 1995, 1998; Steel *et al.* 2013; Coutant and Whitney 2000) such that higher levels of discharge increase the likelihood of entrainment.

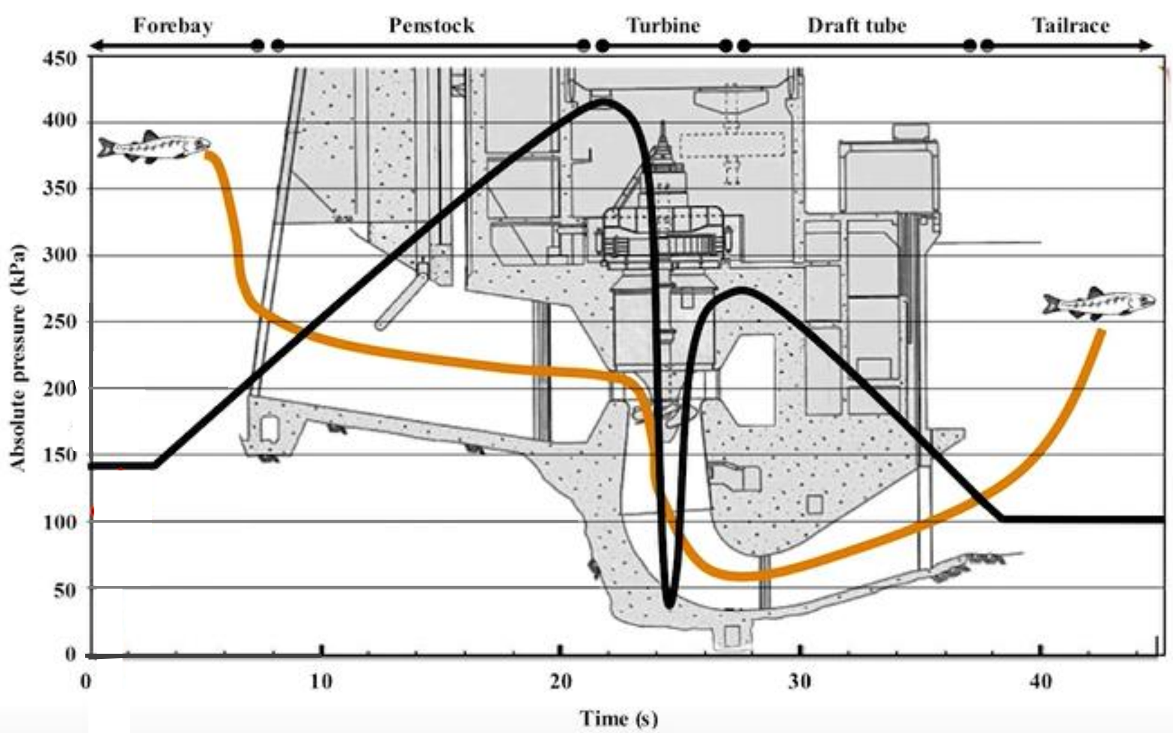
2.1.1.2. Passage Mortality

Entrained fish may succumb to injury and mortality associated with passage past the dam, which is dependent on their route through the dam. Mortality is typically greatest through the turbines, followed by the spillway and fishway (Algera *et al.* 2020); however, passage outcomes are highly dependent on facility design and operation.

2.1.1.3. Turbines

Turbines can cause various forms of injury including mechanical damage, pressure changes, fluid-related damage (i.e., shear stress), and delayed effects (e.g., predation, disease; Franke *et al.* 1997). Injuries are typically associated with the runner region where fish pass the runner blades (i.e., turbines) themselves but can also occur as fish approach the turbines (i.e., within the wicket gate/stay vane region), and after the turbines (i.e., in the draft tube; Figure 1). Mechanical damage refers to injuries associated with fish encountering various mechanical components (e.g., colliding with walls, blades, gates). Turbine blade strikes are typically the leading cause of mechanical damage, and it is assumed that most fish struck by the blades will die (Franke *et al.* 1997). The likelihood of blade strike is primarily dependent on the type of turbine, number and size of blades, fish size, discharge, and rotations per minute (RPM; Franke *et al.* 1997). In addition to blade strike injuries, fish may also experience barotrauma from rapid decompression within the runner region (Brown *et al.* 2012; Figure 1). The expansion of gases within the body can lead to injury and mortality. Provided that the swim bladder (or other structures) has not ruptured, the fish will re-acclimate to normal pressure in the tailrace. Barotrauma-related injuries typically increase with the height of the dam and injury rates are typically lower at lower dam head heights (Čada *et al.* 1997). Finally, fluid-related injuries (i.e., sheer stress) occur when fish encounter flow that has turbulence, velocity gradients, or vortices (Čada *et al.* 1997). When these conditions are severe, forces on the body of the fish can be sufficiently high to result in injury and mortality. Mortality associated with fluid forces are typically low for fish during turbine passage (Neitzel *et al.* 2000). In addition to the more common mechanisms described above, fish may also be injured when sliding against turbine structures (abrasion), striking flat surfaces like walls, getting stuck in gaps (i.e., gap grinding), and through cavitation (the collapse of air bubbles; Franke *et al.* 1997).

Figure 1. Conceptual diagram of pressure changes (black) experienced by a fish during the various phases of dam passage (orange) through the turbines (Source: Rich Brown, PNNL).



2.1.1.4. Spillway

Spillways allow excess water in the reservoir to be spilt downstream. Although these structures usually are not designed to pass fish, they are often viewed as viable fish passage routes (Duncan *et al.* 2018). However, fish may incur injuries and mortality during spillway passage related to hydraulic conditions (e.g., turbulence, pressure change), abrasion, falling (e.g., terminal velocity impact, collisions with hard surfaces), and total dissolved gas supersaturation (Franke *et al.* 1997). Total dissolved gas supersaturation may occur below spillways when high speed, turbulent water spills over the dam, and air becomes entrapped in plunge pools (See Empirical Study - TDG Monitoring). In general, mortality at spillways is low but is likely to increase with increased spillway height (Algera *et al.* 2020).

2.1.1.5. Fishway

Fishways are ideal routes for fish passage to avoid mortality associated with entrainment through more harmful routes (e.g., turbines). The success of a fishway for downstream passage will be dependent on its location, discharge, and fish behaviour. Although no mortality is expected during fishway passage, the confinement of fish at the fishway exit may increase their susceptibility to predators (McLaughlin *et al.* 2013).

2.1.1.6. Latent Effects

Some effects related to downstream passage through the dam may have delayed impacts to fish and result in indirect mortality. Latent effects are most likely to occur following passage through the turbines and the spillway. Following downstream passage, fish may be injured, stressed, disoriented, and have sensory impairment that can increase their likelihood of predation, infection, and acquiring food (Franke *et al.* 1997). Predation following entrainment has been studied most extensively (e.g., Jepsen *et al.* 1998), and appears to be the primary concern for fish surviving entrainment. Predators may cue in on outflows in the tailrace where there are high densities of compromised prey (discussed in Mesa 1994).

2.1.2. Objectives

The objective of this desktop assessment was to use existing literature and design specifications for the WRGS to evaluate route-specific entrainment and mortality of juvenile Chinook Salmon. We characterized the behaviour of juvenile chinook salmon of different age classes upstream of the dam, and evaluated the design and operational features influencing entrainment and mortality of juvenile salmon moving through infrastructure associated with the WRGS. Specifically, we provide a summary of juvenile chinook salmon ecology in the area, infrastructure-specific entrainment and mortality rates, overall mortality estimates, and briefly identify potential mitigation options to reduce mortality.

2.1.3. Methods

The desktop assessment of Chinook Salmon mortality through the WRGS involved a calculation of both entrainment and mortality rates through dam infrastructure. To gain insight into these aspects of downstream passage, we first characterized the infrastructure and operations associated with downstream migration at the WRGS and local juvenile Chinook Salmon ecology (and how this may influence interactions with hydropower infrastructure). Design and operational data used to characterize project infrastructure was provided by Yukon Energy Corporation (operational data from 2013-2022). Information on local juvenile Chinook Salmon ecology was obtained from past reports (e.g., DFO, Yukon River Panel) and discussions with local experts (i.e., Al von Finster, Nicholas DeGraff, Environmental Dynamics Inc., Whitehorse Rapids Fish Hatchery staff) and the Technical Working Group. This information was then used to model intake-specific entrainment and mortality rates for entrained salmon throughout the presumed outmigration period. Findings from the desktop assessment are combined with those from the Sensor Fish Study to provide an overall estimate of mortality for each origin x life stage of juvenile salmon (see Section 3).

2.1.3.1. Calculations

The rates of entrainment through the various intakes of the WRGS were estimated daily throughout the presumed Chinook Salmon outmigration period for each life history stage. The timing of outmigration was modelled (smoothed relationship) using sampling data from the WRGS tailrace in 1973. No data were available for hatchery salmon outmigration timing; however, based on release dates of hatchery salmon into Michie Creek and their propensity to quickly begin outmigration (DeGraff 2012), it was assumed that the timing was delayed one week relative to Age-1 wild salmon. Salmon were assumed to be entrained in relation to discharge through each intake, taking into account that age-0 fry are unlikely to occupy the middle of the reservoir (described further in Section 2.1.4.6; Coutant and Whitney 2000).

Mortality through project infrastructure was assessed via two methods. The first method adopted a previously published approach to calculate the probability of blade strike (Franke *et al.* 1997) using Equation 1. For this calculation, information on the design and operation of the Project, as well as the length of juvenile Chinook Salmon throughout the outmigration period were included as inputs (DeGraff 2012). It was assumed that fish grew throughout the year, such that a linear growth rate was applied using the start and end of season sizes from Michie Creek (DeGraff 2012). The equation was completed for each life stage of salmon (i.e., wild age-0 and age-1, and hatchery age-0) through each turbine. To take a precautionary approach, it was assumed that all blade strikes result in mortality, though values as low as 20% have been recommended (Franke *et al.* 1997). This lack of mortality due to blade strike can be related to various factors including that fish may not lie entirely inline with flow, that strikes to certain regions of the body may be more damaging than others, and local flow at the leading edge of a blade may transport a fish in a manner that can carry it around the leading edge (Franke *et al.* 1997). It was also assumed that fish tend to enter the turbine 80% along the length of the blade (a precautionary estimate; Franke *et al.* 1997). Entrance closer to the blade increases the strike rate as the distance between the blades decreases. However, varying this parameter only influenced the mortality rate by a small percentage. We were unable to obtain turbine efficiency values, so we assumed an efficiency value of 0.9 which represents a moderate value within Franke *et al.* 1997. Regardless, turbine efficiency had a negligible impact on mortality estimates.

Equation 1. Equations sourced from Franke *et al.* (1997) to evaluate the probability of blade strike based on various design, operational, and fish data.

$$P = \lambda \frac{N \cdot L}{D} \cdot \left[\frac{\cos \alpha_a}{8Q_{\omega d}} + \frac{\sin \alpha_a}{\pi \frac{r}{R}} \right] \qquad \text{(Equation 2)}$$

Where:

$$\tan \alpha_a = \frac{\pi E_{\omega d} \cdot \eta}{2Q_{\omega d} \frac{r}{R}}$$

P	Probability of strike
N	Number of blades or buckets
L	Fish length
D	Diameter of runner
α_a	Angle to axial of absolute flow upstream of runner
$Q_{\omega d}$	Discharge coefficient $= \frac{Q}{\omega D^3}$
r	Radius
R	Maximum radius
λ	Strike mortality correlation factor to account for other factors. (estimated to have a value of 0.1)

Propeller Turbine Leading Edge Strike Probability:

$$P = \lambda \frac{N \cdot L}{D} \cdot \left[\frac{\cos \alpha_a}{8Q_{\omega d}} + \frac{\sin \alpha_a}{\pi \frac{r}{R}} \right] \qquad \text{(Equation 3)}$$

Where:

$$\tan \alpha_a = \frac{\frac{\pi}{2} E_{\omega d} \cdot \eta}{Q_{\omega d} \frac{r}{R}} + \frac{\frac{\pi}{8} \frac{r}{R}}{Q_{\omega d}} - \tan \beta$$

While less quantitative information exists to estimate mortality through the spillway and fishway, considerable literature exists to evaluate these values. Our second approach to estimate mortality involved filtering a recent review on fish mortality during downstream passage through hydropower infrastructure to evaluate typical mortality rates for salmon at similar infrastructure to that of the WRGS.

2.1.4. Results

2.1.4.1. Infrastructure Characterization

The WRGS was built in 1958. It originally consisted of two turbines (WH1, WH2), with a third built in 1969 (WH3). Together, these three turbines are referred to as Powerhouse 125 (P125). A power canal funnels water from the reservoir to the powerhouse on river left. A fourth turbine was added in 1985 called WH4 (within a separate powerhouse; P127). Today, the plant has the capacity of producing 40 MW and has a head height of ~18 m (though this varies throughout the year). Water that is not passed through the turbines is spilled through the spillway or fishway. Most water passed through the WRGS goes through the spillways (Figure 2). Chinook salmon juveniles located upstream of the dam may migrate downstream via any of the four turbine intakes, the spillway, or fishway (Table 1; Figure 3; Figure 4).

Figure 2. **Discharge through various intakes at the Whitehorse Rapids Generating Station during the anticipated juvenile Chinook Salmon outmigration period from 2013-2022.**

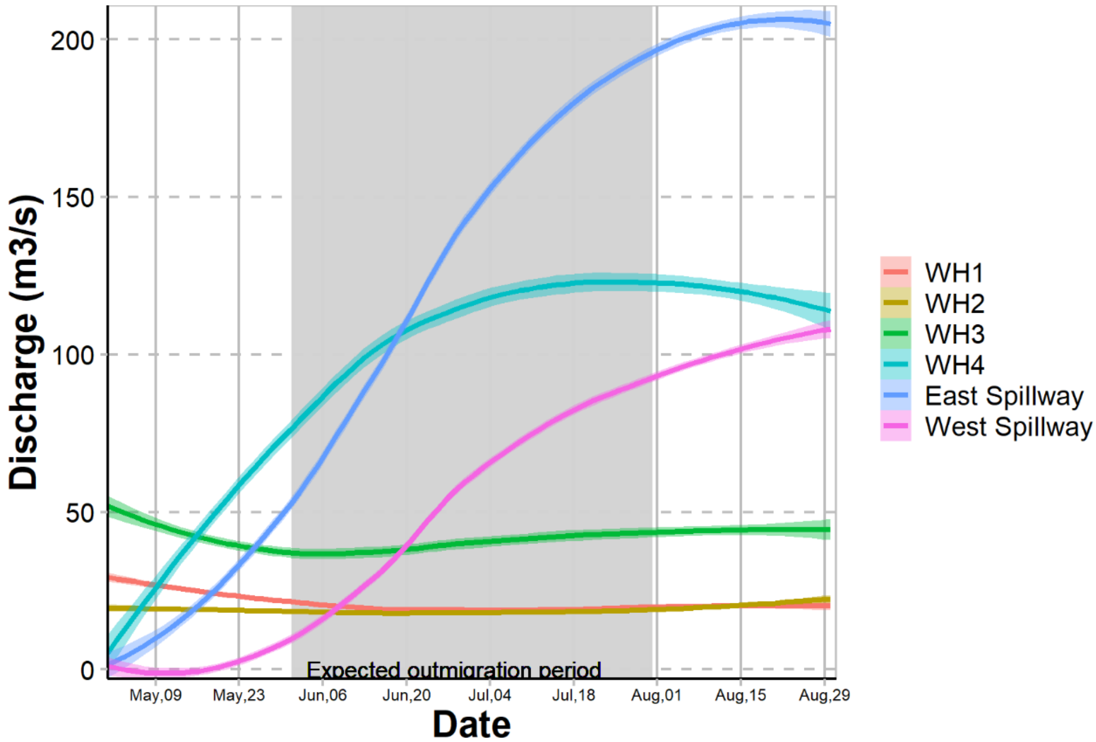


Figure 3. Downstream (A) and upstream (B) aerial photographs of the Whitehorse Rapids Generating Station highlighting the various routes fish may be entrained through (red lines; Modified from Yukon Energy Corporation, 2023).

A).

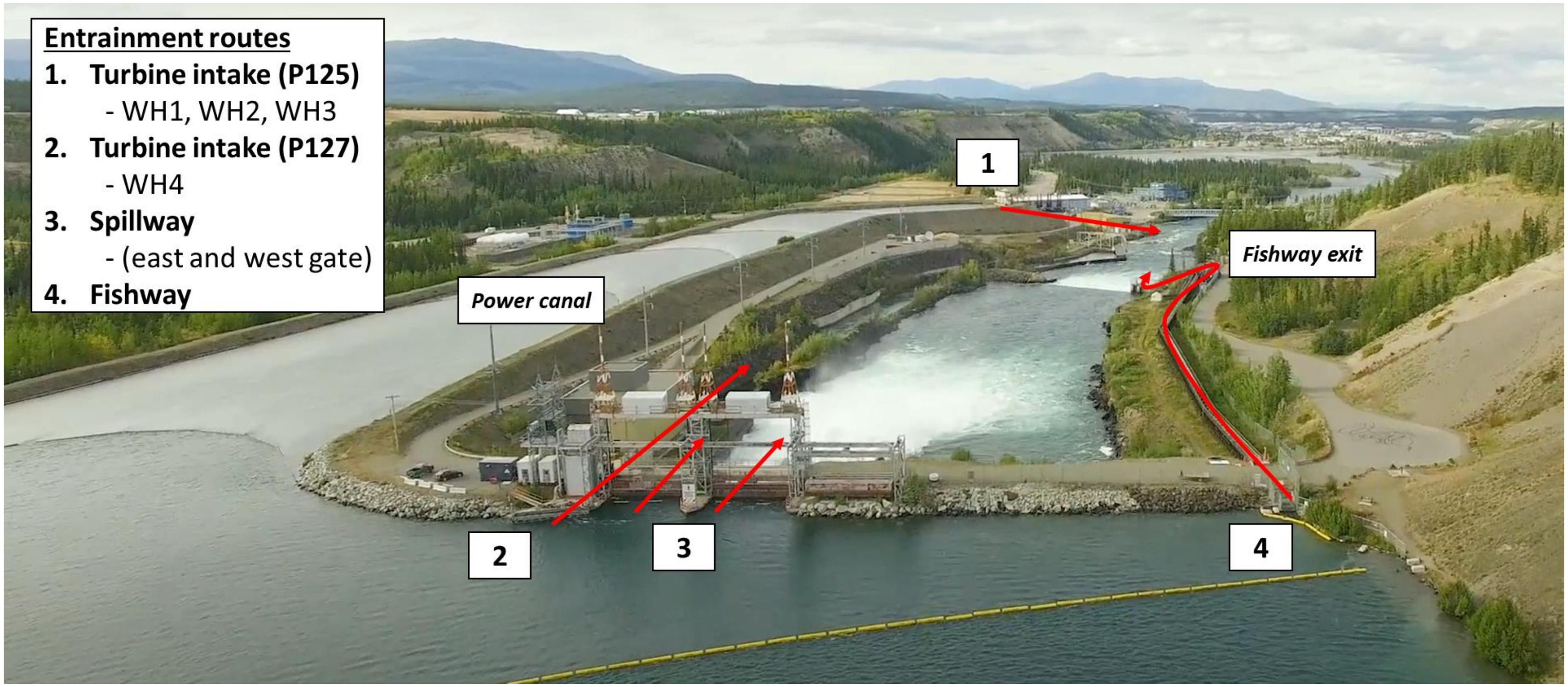


Figure 3. Continued.

B).

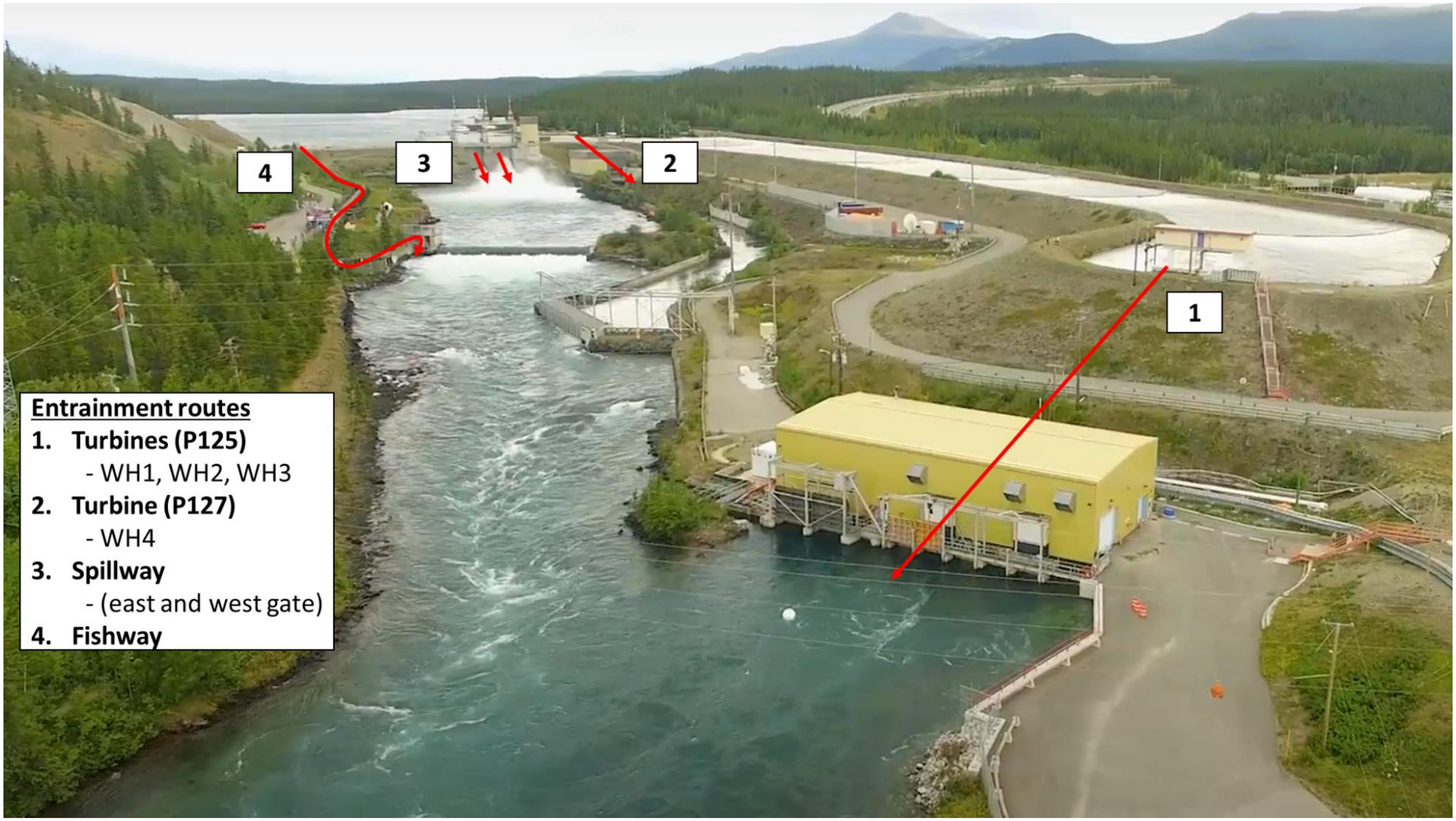
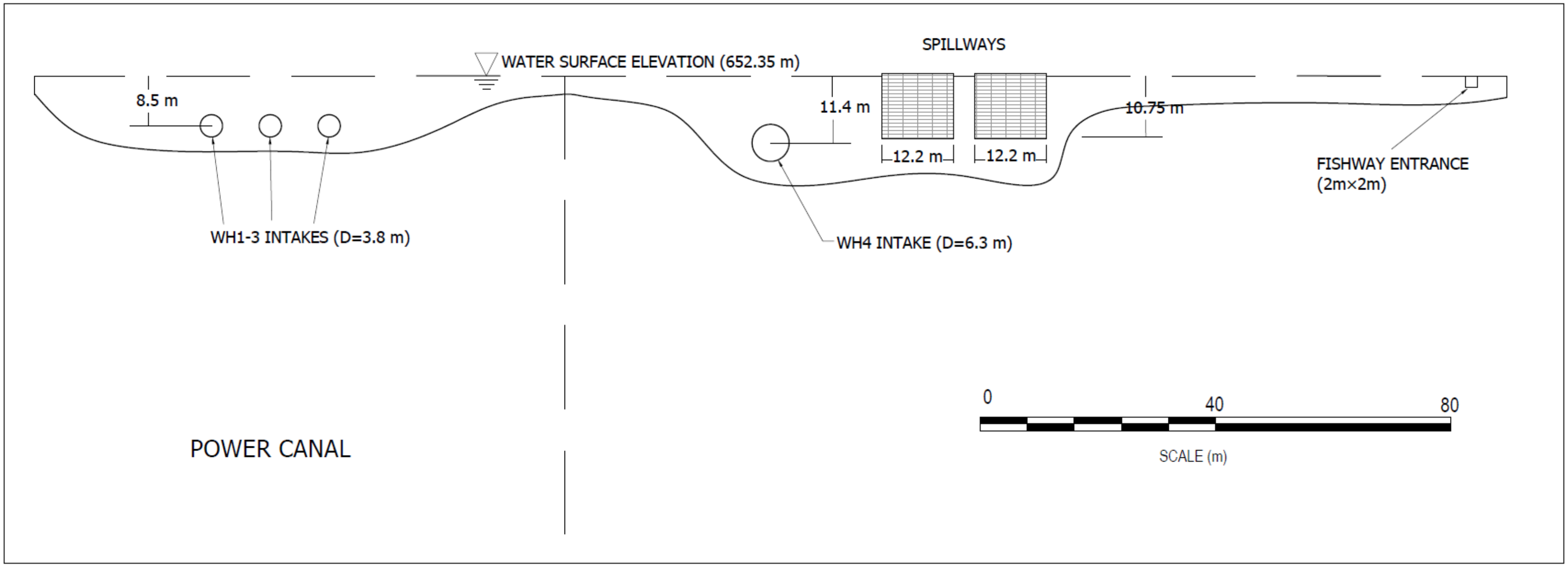


Figure 4. Schematic of the various intakes at the Whitehorse Rapids Generating Station highlighting the various routes fish may be entrained through. The schematic is provided as a relative indication of the sizes and depths of the various intakes on an approximate scale (2022 summer operational data).



2.1.4.2. Turbines

Powerhouse P125 is located on river left at the end of the power canal and includes three intakes leading to two Kaplan and one propeller style turbine, respectively. Propeller style turbines are similar to Kaplan turbines. The primary difference between the two is that the runner blades in a propeller turbine are fixed while the runner blades of a Kaplan turbine have an adjustable inclination. There are four blades per turbine. From 2013-2022, discharge was higher through WH3 than WH1 and WH2 in P125 throughout the outmigration period. The intakes for these turbines extend from 6.63 m deep to 10.44 m deep (i.e., intake diameters of 3.81 m). Powerhouse P127 is located adjacent to the west gate of the spillway and includes one propeller style turbine with five blades. The intake extends from 8.25 m deep to 14.55 m deep (i.e., 6.3 m diameter). Trash racks are located at each turbine intake with clear spacing of 67 mm (P125) and 85 mm (P127). The racks are located about 1-3 m below the surface to a depth of about 6-8 metres to cover the openings of the penstocks. A fish screen is located in the outflow of P127 to prevent adult Chinook Salmon from migrating towards P127. P127 tends to have more discharge than P125 during the outmigration period.

2.1.4.3. Spillway

There are two spillgates located adjacent to each other and the intake to P127. The width of the spillway intakes is 12.2 m (each), with a sill depth of 10.75 m. The spillway gate lifts from the bottom to adjust spill discharge. During the outmigration period, discharge through the spillway increases with increasing inflows (Figure 2). From 2013-2022, discharge through the spillway accounted for 50% of total river discharge from May-August. From 2013-2022, discharge was higher through the east spill gate than the west spillgate.

2.1.4.4. Fishway

The fishway entrance is located on the river right bank and extends ~366 m to the area downstream of the barrier weir. Discharge through this structure is low relative to other intakes along the dam. The fishway tends to be watered from late May until end of September.

Table 1. Specific design and operational details pertaining to P125 (WH1-WH3) and P127 (WH4). Operational details are calculated as averages for May - August, 2013-2022.

Variable	WH1	WH2	WH3	WH4	Spillway
Powerhouse	P125	P125	P125	P127	-
Type	Kaplan	Kaplan	Propeller	Propeller	-
Number of blades or buckets	4	4	4	5	-
Diameter of runner (mm)	2226	2228	2791	4159	-
Turbine discharge (cms)	21.1 (annual range; 5.6 to 29.9)	19.0 (annual range; 0 to 32.4)	41.6 (annual range; 30.6 to 55.0)	95.1 (annual range; 65.1 to 112.0)	176.4 (annual range; 103 to 312)
RPM	300	300	200	150	-
Turbine net head (m)	18.32	18.32	18.32	17.66	-
Schwatka elevation (m)	653	653	653	653	653
Depth of intake entrances (m)	Invert depth = 11.1	Invert depth = 11.1	Invert depth = 11.1	Invert depth = 15.2	Invert depth = 11.4
	Top depth = 7.3	Top depth = 7.3	Top depth = 7.3	Top depth = 8.9	Top depth = variable
Width of intake entrances (m)	3.8	3.8	3.8	6.3	12.2

2.1.4.5. Juvenile Chinook ecology in Whitehorse

Juvenile Chinook Salmon upstream of Whitehorse are fish of different year classes and origins, including wild 0+ and 1+, as well as hatchery 0+. Differences in size and behaviour influence entrainment probabilities, mortality risk, and overall mortality at the WRGS. Below we provide a brief description of the ecology of each age class in the context of interactions with the WRGS.

Age-0 wild Chinook Salmon

In the Upper Yukon River, eggs incubate over the winter, and the young salmon ('alevin') hatch and emerge from gravel as fry early May (von Finster 1996a) and late June (von Finster 1996b) between 35 and 38 mm (Duncan *et al.* 2004). This is consistent with trapping in Michie Creek that has observed juveniles at the end of May with a length of ~35-39 mm (DeGraff 2012). Age-0 salmon typically remain near the spawning grounds, but by June an undetermined, but considerable and perhaps dominant, portion of the cohort migrate downstream and then ascend non-natal tributaries (Perry *et al.* 2003; von Finster 2023). These movements can be extensive and include areas downstream of the WRGS (Moodie *et al.* 2000; Moodie and March 2000). Hryciuk (1973) studied the timing of outmigration in the tailrace and found that the outmigration of wild fry (0+) began June 22, peaked July 10, and was 95% complete by July 22 (Figure 5). Trapping also took place in 1960 which indicated the peak salmon fry outmigration occurs around July 10 (Figure 6). Trapping in Michie Creek from 2003-2012 found wild age-0 juveniles consistently from May to October (DeGraff 2012).

Age-1 wild Chinook Salmon

Many juvenile Chinook Salmon remain upstream of Whitehorse during their first year, obtaining a size of ~90 mm by the end of May (DeGraff 2012). In spring, these age-1 Chinook salmon leave overwintering and rearing habitats and pass the WRGS on their way to the Bering Sea where they will complete the marine stage of their lifecycle. The timing of outmigration of one year old (1+) juveniles from small streams appears to be related to annual thermal regimes and is delayed if the spring is cool or late (Moodie and March 2000). In areas with earlier peak flows (e.g., Dawson), very few 1+ juveniles are captured in the spring and summer which indicates they leave early in the spring (possibly mid-May; Bradford 2008). In Whitehorse, peak flows are later due to the high elevation and glacier melt, which potentially delays outmigration. Bradford *et al.* (2001) studied smolt outmigration in Croucher Creek (downstream of Whitehorse) and found that yearling smolt outmigration occurred primarily between mid-June and early July. Sampling in Michie Creek has found age-1 Chinook throughout most summer months, with peak captures the first week of July (potentially indicating outmigration from Michie Creek). Von Finster (1998) studied juvenile chinook migration, citing work from the 1960s and 1970s (Lister 1960; Hryciuk 1973). Lister (1960) found a low peak of juvenile salmon between May 26 and June 7 in the tailrace, but a high peak occurred on July 10 and no salmon were observed after July 30. Lister (1960) did not differentiate between life stages, though it seems possible the earlier peak was Age-1 while the later peak was Age-0 salmon. Hryciuk (1973) found that the outmigration of wild age-1 salmon began as early as June 10 and peaked June 20, tapering out July 22 (Figure 5). A CAFN Elder living downstream of the WRGS says that at the same time every year (June 20 or so), "birds go nuts feeding on what appears to be small fish" that are believed to be salmon (Mayes, pers. comm. 2023). Recent work by Von Finster (2023) suggests "few 1+ juveniles are captured in the Yukon River in Canada after July 15".

Age-0 hatchery Chinook Salmon

Hatchery Chinook Salmon are released into Michie Creek between June 1 and June 15 (2010 - 2021 data). Sampling in Michie Creek from 2004-2012 found hatchery juveniles in the creek until a minimum of about July 1 but juveniles may be absent as early as July 19 (though sampling intensity varied across years). In general, hatchery Chinook spend a minimum of 3 weeks and a maximum of 8 weeks in Michie Creek following release.

Figure 5. Captures of Chinook Salmon smolt (age-1) and fry (age-0) downstream of the Whitehorse Rapids Generating Station during the salmon outmigration in 1973 (Source: Brown *et al.* 1976). Data were used to infer migration timing of juvenile salmon through the WRGS.

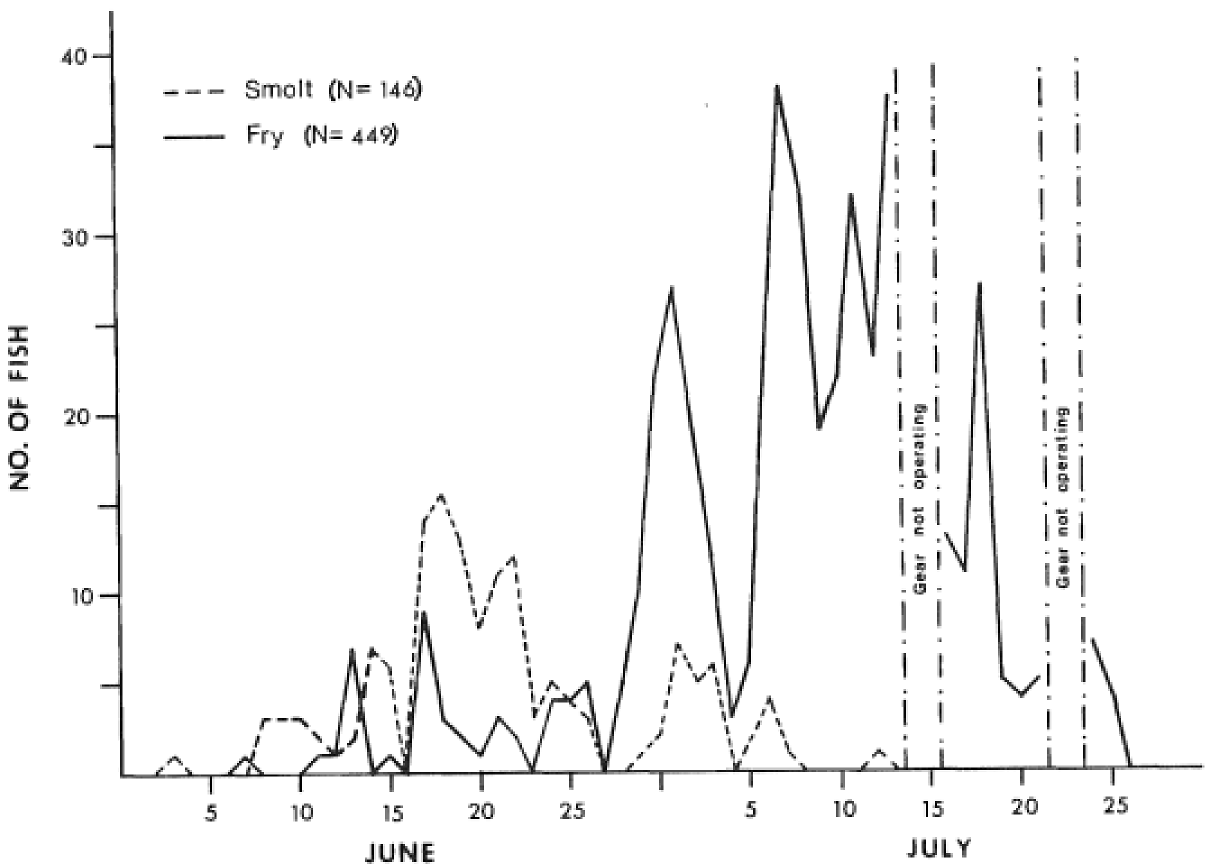


Fig. 13. Whitehorse Rapids chinook salmon smolt and fry migration in 1973 as depicted by gear catch.

Figure 6. Captures of Chinook Salmon juveniles (5-day intervals) downstream of the Whitehorse Rapids Generating Station during the salmon outmigration in 1960 (Source: Brown *et al.* 1976).

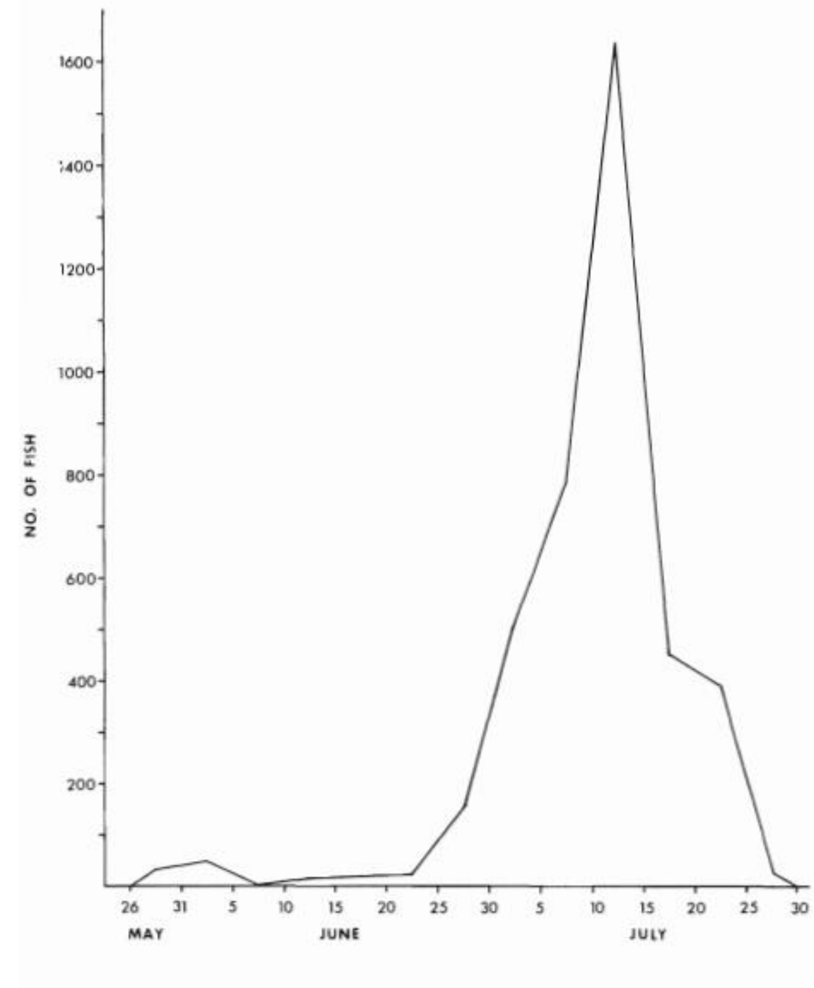


Figure 14. Daily migration of chinook salmon fry in 1960 as depicted by gear catch in 5 day intervals.

2.1.4.6. Entrainment Rates

Downstream passage can result in mortality for juvenile salmon, though the rates are highly context-specific and dependent on the proportion of fish that enter each passage route (i.e., entrainment) and the mortality associated with each route (Algera *et al.* 2020). Although limited information exists on passage route selection for downstream migrating juvenile Chinook Salmon in Whitehorse, previous work trapping juveniles downstream of each passage route suggests most juveniles pass through the turbines (Table 2). However, historic trapping occurred over a limited period prior to the construction of P127 and may not accurately account for interannual variability and passage route selections in recent years.

Table 2. Findings from a trapping study downstream of the Whitehorse Rapids Generating Station indicating the proportion of all age-0 and age-1 (i.e., wild fish) juvenile Chinook Salmon migrating through the various passage structures at the Whitehorse Rapids Generating Station (Sourced from Hryciuk 1973 as cited in von Finster 1998).

Group	Fishway	Spillway	Turbines
Age-0	37%	10%	55%
Age-1	1%	8%	91%

To estimate the current route-specific entrainment rates of juvenile Chinook Salmon, assumptions were made pertaining to the habitat use of different life stages approaching each intake. Salmon were assumed to be entrained in proportion to the discharge through each intake (reflective of salmon behaviour; Moser *et al.* 1991; Moore *et al.* 1995; Moore *et al.* 1998; Steel *et al.* 2013; Coutant and Whitney 2000), as well the location, and depth of each intake, recognizing that habitat use is likely to vary between age-0 and age-1 salmon (Figure 2). Given that the depth of each intake is relatively similar at the WRGS (Table 1), it was assumed differences in this variable were negligible. Age-0 salmon are typically found along shorelines (Tiffan and Connor 2012; Keefer *et al.* 2008). It was assumed that age-0 salmon would be equally divided between both shores of Schwatka Lake. Based on this assumption, it was estimated half of all age-0 salmon would be entrained along the river left shore (intake P125) and that the other half would be entrained on river right (intake P127 and the spillway). Within their respective sides of the river, it was assumed age-0 fish were entrained in proportion to discharge through each route. For age-1 salmon and hatchery juveniles, it was assumed they would occupy mid-channel habitats (Dauble *et al.* 1989; Tabor *et al.* 2011), and be entrained in proportion to the discharge through each intake (Coutant and Whitney 2000).

Based on the assumptions described above, daily entrainment was estimated using discharge data from 2013-2022, and information on outmigration timing (

Figure 7). Entrainment increased coincident with increased rates of presumed Chinook Salmon outmigration before tailing off at the end of the outmigration period. Given that most discharge from 2013-2022 occurred through the spillway, it was estimated that the majority of juvenile Chinook Salmon (of all life stages) pass through the spillway. For age-1 wild and hatchery juveniles it was estimated more individuals pass through Powerhouse P127 than P125. Based on the nearshore habitat use typical of age-0 juveniles, it was estimated that this life stage would be more susceptible to entrainment in P125 as they follow the river left shoreline. A summary of entrainment rate estimates for 2013-2022 is provided below (

Table 3). Notably, no juvenile Chinook Salmon were assumed to use the fishway given the insignificant amount of flow diverted through that structure and only infrequent juvenile Chinook Salmon observations from fish ladder and hatchery staff. However, work from Hryciuk (1973) suggests a considerable number of age-0 salmon may use the fishway. If age-0 salmon are following the shoreline, they would likely encounter the fishway before the spillway and turbines, which may disproportionately increase their use of the structure.

Figure 7. Estimated daily entrainment rates of juvenile Chinook Salmon (by life stage) at the Whitehorse Rapids Generating Station from 2013-2022 based on desktop assessment of available information (probability scale 0-1).

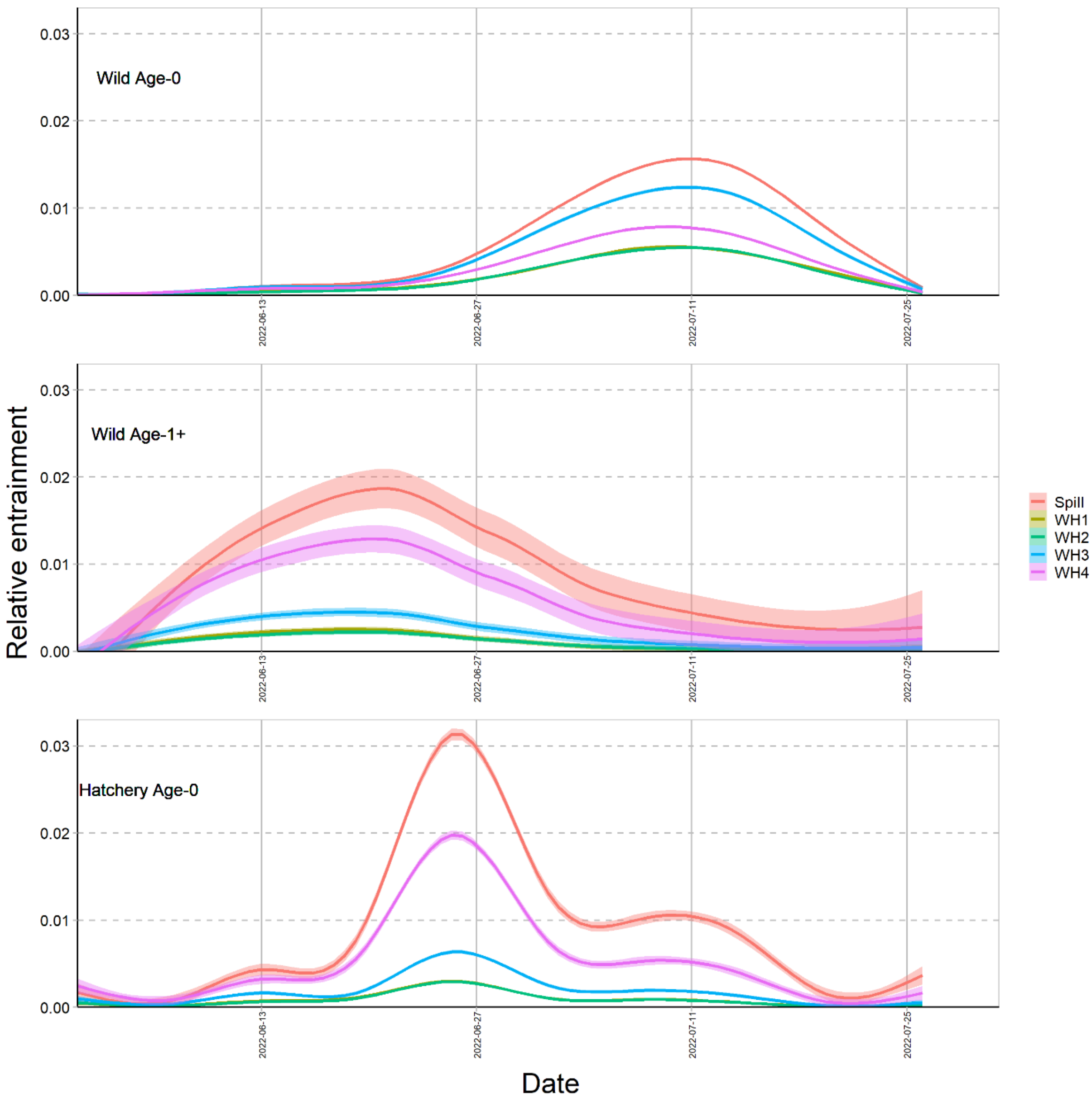


Table 3. Estimated overall entrainment rates of juvenile Chinook Salmon (by life stage) at the Whitehorse Rapids Generating Station from 2013-2022 based on desktop assessment of available information.

Group	Fishway	Spillway	P125	P127
Age-0 Wild	-	33%	50%	17%
Age-1 Wild	-	47%	22%	31%
Age-0 Hatchery	-	49%	21%	30%

2.1.4.7. Mortality Rates

Route-specific entrainment mortality estimates are provided for various life-stages of juvenile Chinook Salmon throughout the expected migration period using 2013-2022 operational data.

Turbines

Using the equations developed by Franke *et al.* (1997), the probability of blade strike was calculated for each intake and life-stage of salmon throughout the season (Figure 8). Wild 1+ juvenile Chinook Salmon entering the turbines had the highest turbine strike rate during the outmigration window (range 13% to 48% depending on the turbine and date), followed by hatchery 0+ (range 11% to 28%), and wild 0+ (6% to 28%). Differences across life-stages were primarily driven by differences in average total length, which were greatest for wild 1+ (113 mm), followed by hatchery 0+ (75 mm), and wild 0+ (58 mm). Mortality rates increased throughout the outmigration period, which is primarily related to the growth of juvenile salmon since larger body size increases the likelihood of being struck by the turbines. However, at some points throughout the season mortality rates decreased due to changes in discharge through each route. Mortality rates were highest for WH1 and WH2 which have similar design specifications (Kaplan turbines, four blades, 300 rpm, 2.2 m diameter runners). WH3 and WH4 are propeller turbines, which are similar to Kaplan turbines but have runner blades that are fixed to the hub. WH3 (four blades, 200 rpm, 2.8 m diameter runners) had higher mortality rates than WH4 (five blades, 150 rpm, 4.2 m diameter runners). In general, longer fish, more blades, shorter diameters of the runner blades, and higher rpm all increase fish mortality.

It should also be noted that fish may succumb to injury and mortality from other sources during turbine passage that remain difficult to quantify without field studies (discussed in Franke *et al.* 1997). These include other mechanical-related injuries such as wall strikes, gap grinding, and abrasion, pressure-related injuries, as well as fluid-related injuries such as fluid shear, cavitation, and draft tube backroll. Information on these other sources of mortality is lacking, though are generally expected to be less severe than those sources of mortality described above (Franke *et al.* 1997). These components of mortality (pressure and shear) are evaluated with the Sensor Fish (Section 2.3.4) and would be accounted for in the literature comparison below (Section 2.1.3).

Spillway

In general, mortality at spillways is very low but is likely to increase with greater spillway height (Algera *et al.* 2020). Using mortality estimates for similar sized dams found elsewhere (see Section 2.1.3), we have estimated mortality through the spillway to be 1%. Given the depth of spillway intakes, the plunging of water is limited, reducing the velocity of collisions compared to surface-release spillways.

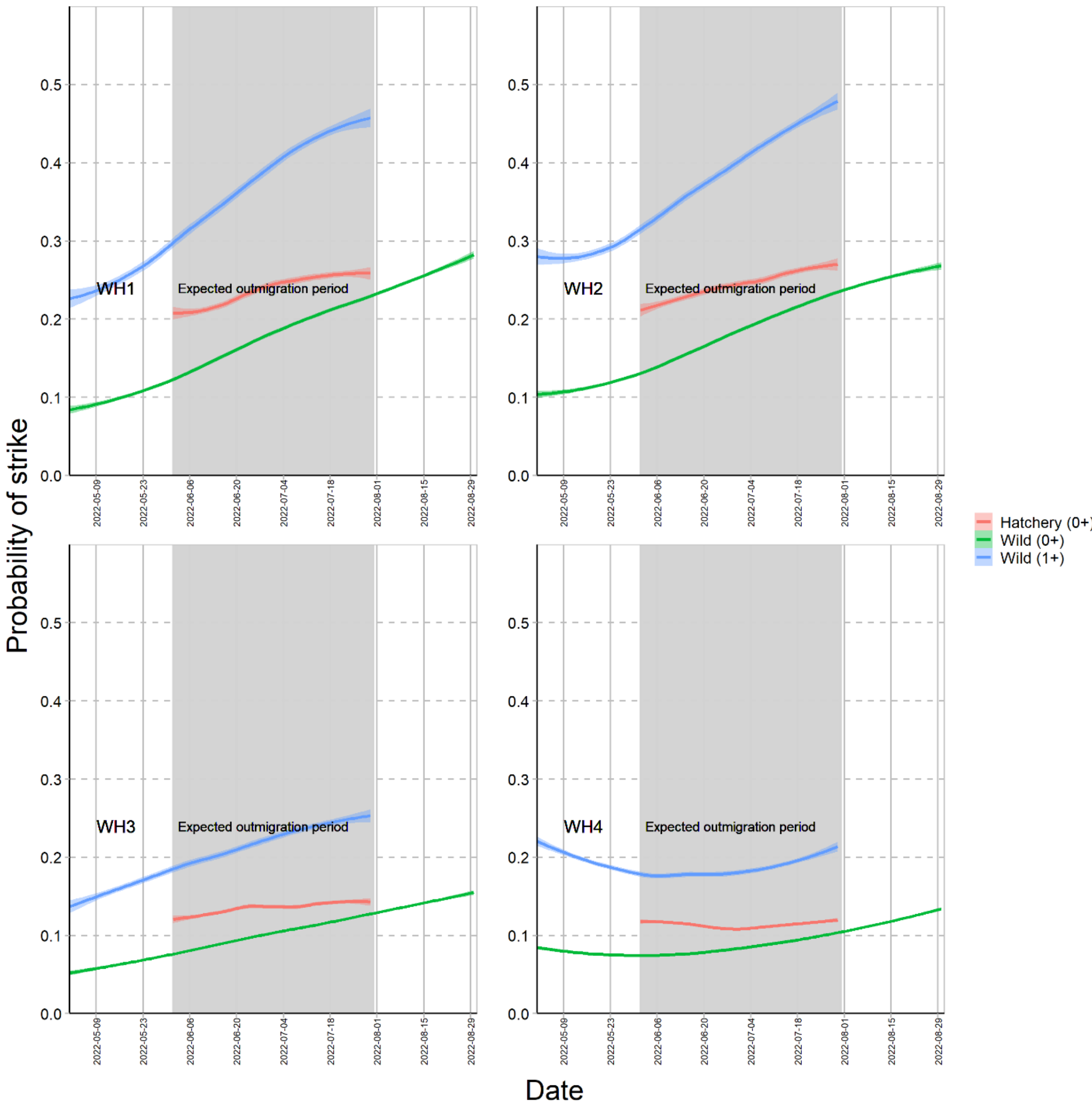
Fishway

As described in Section 2.1.1, the fishway is not assumed to result in any direct mortality of juvenile Chinook Salmon. The aggregation of juvenile Chinook Salmon exiting the fishway may increase their susceptibility to predation (Mclaughlin *et al.* 2013), however, this effect is likely much lower than downstream of the turbines and spillways.

2.1.1. Discussion

Overall, the desktop assessment estimated that mortality increases throughout the year (with increasing fish size) and that mortality is likely greatest for age-1 wild fish, followed by age-0 hatchery fish, and age-0 wild fish. These differences across life stage are due to differences in size, with small age-0 wild fish having the lowest likelihood of mortality. However, given their preference for nearshore habitats, we assumed that a greater proportion of age-0 wild salmon would pass through the turbines, increasing their overall mortality rate through the WRGS. However, for age-0 salmon travelling on river right, they may be more likely to enter the spillway and fishway as they encounter these structures prior to the turbines (as observed during historic sampling; Table 2). Our analysis also predicted that mortality would be greatest through WH1 and WH2 followed by WH3 and WH4. However, findings from the Sensor Fish study highlight that passage conditions through WH4 are considerably more severe than WH3 (see Section 2.3). It should be noted that the most relevant measure for downstream passage is the overall mortality rate through the WRGS which is calculated as the sum of each route-specific mortality rate x route-specific entrainment rate. In the synthesis (Section 3), we integrate findings from this desktop review with those from the Sensor Fish to provide this overall estimate of mortality through the WRGS based on available information.

Figure 8. Probability (scale 0-1) that juvenile Chinook Salmon of various life-stages entrained into turbine intakes would be struck by turbine blades throughout the expected outmigration period based on 2013-2022 operational data. It is assumed that all fish struck will die.



2.1.2. Limitations

The desktop assessment above provides an estimate of entrainment and blade strike mortality rates for juvenile Chinook Salmon through each intake taking into account seasonal changes and differences amongst life stages. In developing these estimates, clear information gaps were identified that limit certainty in our findings. First, desktop models are based on general findings observed across similar hydropower plants, but those general findings may not necessarily apply to the WRGS. Second, information relating to juvenile Chinook Salmon ecology upstream of the dam is limited (i.e., timing, behaviour, habitat use). Further efforts to understand juvenile Chinook salmon ecology will be important, but will be challenged by low salmon densities. It should also be noted that the estimates above are limited to blade strike mortality, and that additional sources of mortality exist that were explored through the Sensor Fish field study.

2.1.3. Comparison to Other Facilities

Although no mortality estimates exist for the fishway, spillway, and turbines in Whitehorse, estimates can be generated using the typical mortality rates for Chinook at similar structures located elsewhere. Algera *et al.* (2020) summarized all downstream mortality studies available prior to 2020. This dataset was filtered to include only those records pertaining to Chinook, Kaplan turbines, and dams with head heights greater than 18 m, resulting in 27 assessments of delayed mortality for juvenile Chinook. Mortality associated with turbine passage was corrected for control group mortality using Abbotts method (Abbot 1925). For hydropower plants of similar size and turbine type, delayed Chinook mortality through the turbines averaged 9.7% (range 1-21%). This is similar to the 8.6% estimate for Oncorhynchus through Kaplan turbines generated by Pracheil *et al.* (2016). The same process identified average mortality of <1% for spillway passage (range 0-35%) while no mortality is assumed for downstream passage through the Whitehorse Rapids Fish Ladder. However, turbine mortality can vary greatly with small changes in turbine specifications (Pracheil *et al.* 2016; Algera *et al.* 2016), highlighting the importance of site-specific studies.

2.2. Empirical Study - Hydroacoustic Scanning

2.2.1. Background

Hydroacoustic scanning (or sonar) is a commonly used tool to enumerate adult and juvenile fish in a variety of settings (Pollom and Rose 2016). Sonar uses a high-frequency acoustic beam (signal) through the water column and then listening for the echo that is formed when the signal bounces off objects in the water column. Sonar can provide information on the size, timing, and behaviours of fish, including their direction and depth of movements. Sonar technology is commonly deployed at hydroelectric dams to study entrainment of fish into intakes (Ransom and Steig, 2009). The sonar is typically mounted to the face of the dam and is set up in a downward or horizontal facing direction (Ransom and Steig, 2009). Notably, sonars are only able to identify fish within the beam transmitted by the sonar such that only a sub-section of the water column is typically scanned at a given time. Sonar has been widely used throughout the Yukon to count adult salmon returning to spawning grounds (Mercer 2016; YRP 2023).

2.2.2. Objective

The objective of this work is to characterize fish density and behaviour in proximity of the intakes to the turbine and spillway and to assess the efficacy of hydroacoustic scanning for the evaluation of juvenile Chinook salmon migratory behaviour at the WRGS.

2.2.3. Methods

Hydroacoustic scanning was undertaken during the expected peak of the fry/smolt outmigration period from June 28 – July 7, 2023 (see Section 2.1.4.5). Work was led by Metla Environmental Inc., a local contractor, with onsite support from Ecofish technicians. Over the 10-day period an ARIS model 1800 sonar, manufactured by Sound Metrics Corporation, was used for fish entrainment observation. Sound Metrics are currently the primary manufacturers of multi-beam sonars employed for detecting migrating salmon in lake and riverine environments.

The sonar continuously ensonified the water column over a 24-hr period. The sonar was adjusted, re-aimed and the data filed downloaded each morning (~9am). Sonar images were reviewed the following day, and sonar positioning was adjusted based on the knowledge gained from previous deployments. The sonar was installed on a rotational basis in front of each passage route (spillway, turbine intakes; Figure 9).

The sonar unit was mounted on an adjustable stand constructed of 2-inch aluminum pipe. The stand consisted of a horizontal member that was fixed to the guard rails at the turbine intakes as well as the spillways. A second vertical member, cantilevered over the water, was installed to submerge the sonar at a depth of approximately 1.0 meters. The sonar unit was bolted to a steel plate suspended from a cross bar that was connected to the stand with adjustable fittings. The adjustable clamps allowed the sonar pitch to be adjusted to accommodate variable views at the turbine intakes, hence allowing for ensonification of different depths of the water column (Figure 10).

The ARIS sonar with a standard lens produces an ensonified field 29 ° wide in the horizontal plane and 14 ° in the vertical plane. Daily adjustments to the sonar aiming configuration were performed in response to the assumed likelihood of capturing fish entrainment into the turbines/spillway. The window length of the ensonified area was typically set at 15 meters with minor adjustments depending on the location. The sonar system was powered by AC outlets, courtesy of Yukon Energy. The computer and sonar components were stored in a lockable watertight aluminum box on site. While no battery backup was supplied during this study period, no power outages were observed.

For optimal resolution of the ensonified targets within the migration corridor the following ARIS sonar settings were used: a) high frequency (1.8 Mhz), b) 96 sub-beam array, c) Frame rate of 4 frames/sec. and d) Samples per beam set at 1800. The computer equipment used to interface with the sonar consisted of a Eurocom ™ workstation laptop.

A total of 10 days of sonar recordings were performed over the period June 28 through July 7, 2023. The sonar data were collected continuously over the period and stored automatically in pre-programmed, 30-minute date-stamped files using the ARIScope software. This resulted in the accumulation of 48 files over a 24-hour period. The files were stored on the recording laptop computer and transferred each day to a 5 TB external hard drive. Each 30-minute file was approximately 300 Mb. It is MEI policy to maintain the ARIScope files on the external hard drive for a minimum of 3 years after the project is completed.

Figure 9. Hydroacoustic scanning locations at the Whitehorse Rapids Generating Station June 28 - July 7, 2023.

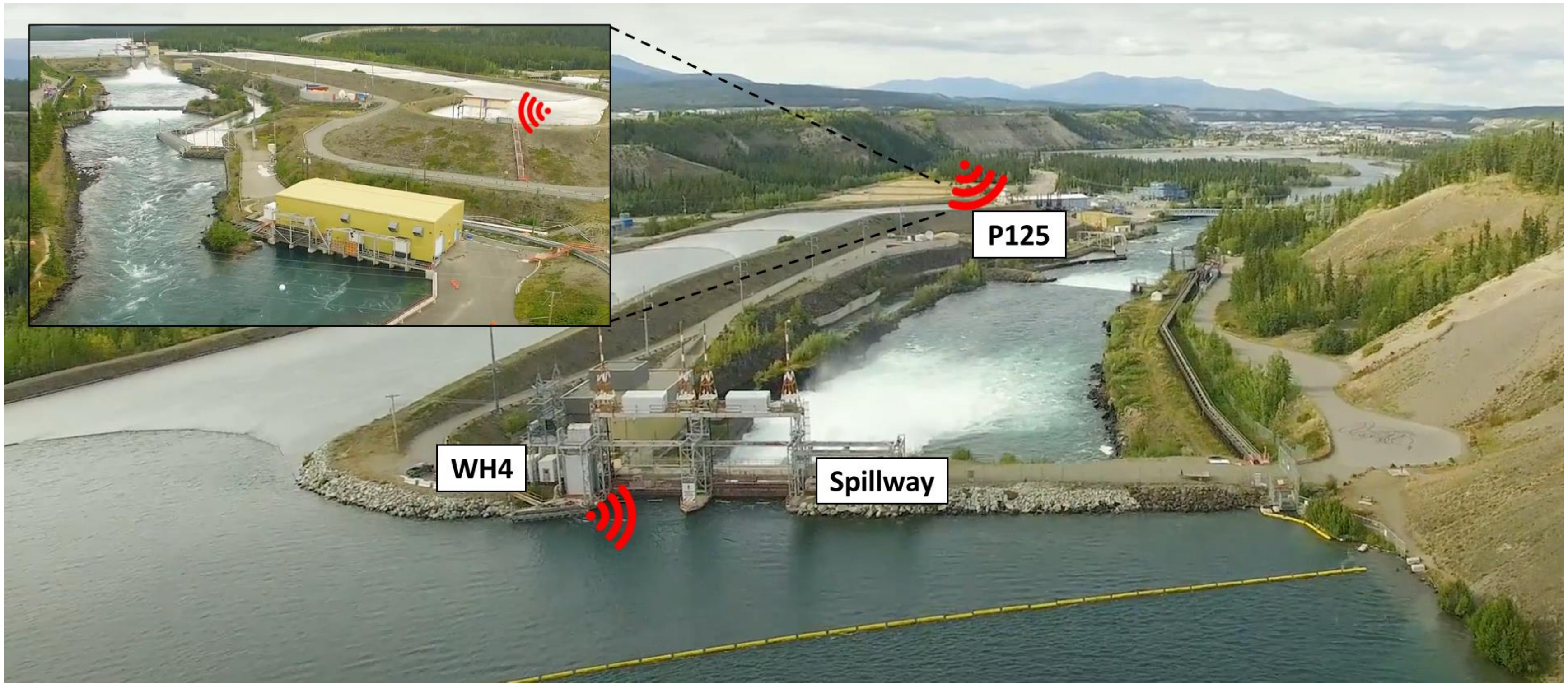


Figure 10. Acoustic sonar equipment deployed at the spillway on July 2, 2023.

2.2.3.1. Data and Statistical Analysis

The ARISFish software program was used for reading the recorded files and the inputting of data. File reading occurred the day following recording. All 48 files from each day were reviewed. Files were read using a combination of the sonar view platform and echogram view of each file. When the examiner identified a target on the echogram the sonar view was used to observe and measure the total length of the fish. The timing, depth, direction of movement, and range along the sonar were also recorded for each target. Potential Chinook Salmon targets were assigned for fish <140 mm based on the typical sizes of juvenile Chinook Salmon in Michie Creek at this time of year (DeGraff *et al.* 2022). To optimize target detection in both sonar and echogram view, the background subtraction feature was used to remove the static images such as the intake structure and lake bottom. ARISFish software inputs the targets selected by the reader into a comma-separated values (CSV) file. Data from the CSV file was inputted into an excel spreadsheet incorporating the counts from each file into hourly and daily counts as well as upstream and downstream movements. Only fish that entered the field of view from upstream that moved downstream (through the gate and become no longer visible) were marked as an entrained fish target using the ARIS software. Therefore, the counts only apply to the number of fish that are entrained into the spillway, and not fish that come into view and leave back to where they came from.

2.2.4. Results

Hydroacoustic sonar was used to observe fish entrainment at the various intakes from June 28 to July 7, 2023. Sonar conditions were reported to be "good" with low turbidity and laminar flows at the intakes. Daily effort and captures are summarized in Table 4.

Overall, 72 fish were observed becoming entrained during hydroacoustic scanning across all three intakes. The total length of fish ranged from 101 mm to 458 mm, with an average of 221 mm. The average depth of observed fish was 2.5 m, though scanning did not take place below 6.4 m. Further, the ensonified area inherently increases with greater depths given the vertical beam angle of the sonar, making it more likely to detect fish at greater depths. Three fish were identified with sizes expected for wild 1+ juvenile salmon (i.e., 101 mm, 119 mm, and 136 mm). These three fish were observed during the night/early morning, two of which were at P125 while the other was at WH4. Fish density was greatest at the spillway (15.5 fish/day), followed by WH4 (7.7 fish/day), and P125 (4.2 fish/day). Almost all fish were observed moving in the downstream direction (93%) while fish moving in the upstream direction were limited to the upper 2.0 m of the water column. Fish entrainment tended to be lowest during the middle of the day (i.e., 10am-5pm; Figure 11).

Table 4. Hydroacoustic scanning effort, maximum survey depths, and number of fish observed at each intake monitoring location from June 28 - July 7, 2023.

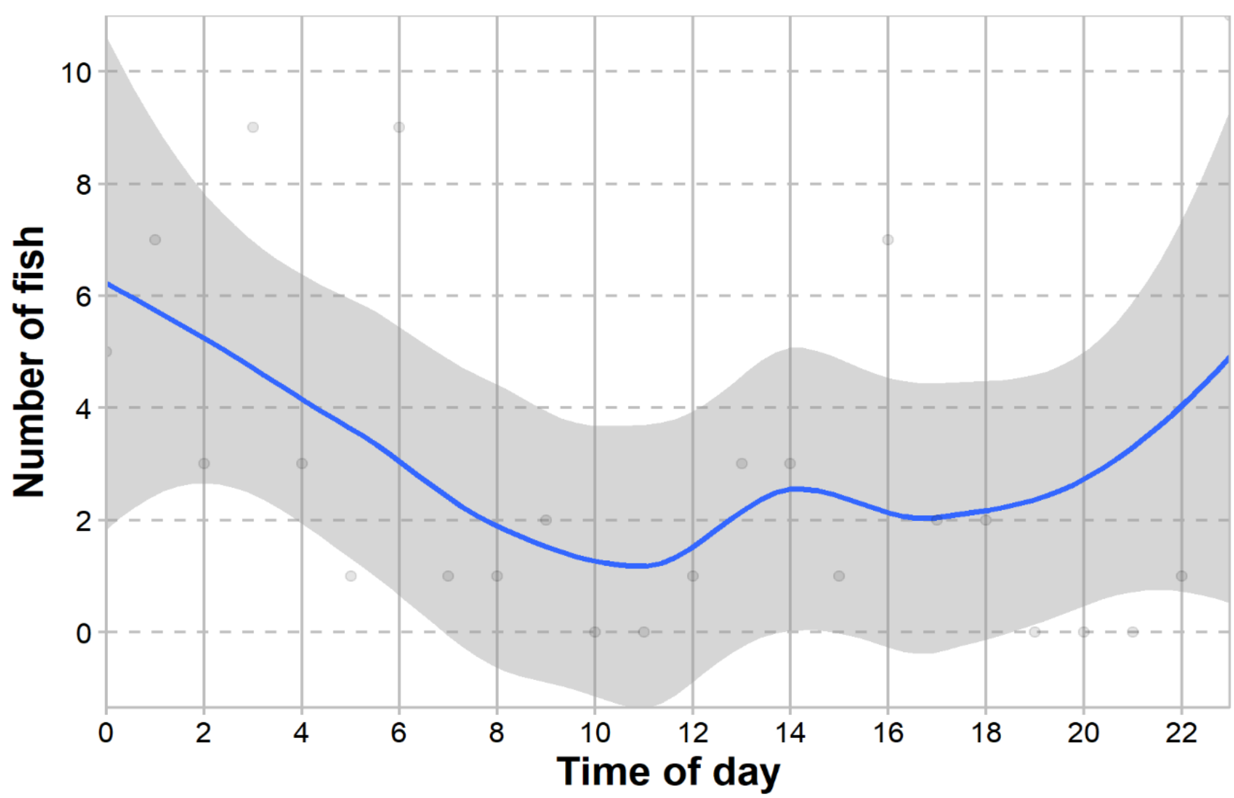
Date[1]	Intake Monitoring Location	Sonar Settings				Sonar Pitch (⁰)	Maximum Survey Depth[2] (m)	Fish Observations				
		Sensor Depth (m)	Beam Angle (⁰)	Sensor Pitch (⁰)	Beam Range (m)			n	Estimated Length (mm) Average	Min	Max	# Fish <140 mm
June 28, 2023	P125	1	14	-3.2	15	-3.2	3.7	4	214	187	240	0
June 29, 2023	P125	1	14	-10.1	15	-10.1	5.4	8	245	101	458	2
June 30, 2023	WH4	1	14	-6.7	15	-6.7	4.6	10	229	182	280	0
July 1, 2023	Spillway	1	14	-6.7	15	-6.7	4.6	31	227	147	338	0
July 2, 2023	Spillway	1	14	-14.2	15	-14.2	6.4	0	-	-	-	0
July 3, 2023	WH4	1	14	-9.2	15	-9.2	5.2	8	170	119	214	1
July 4, 2023	WH4	1	14	-9.2	15	-9.2	5.2	5	227	165	384	0
July 5, 2023	P125	1	14	-7.9	15	-7.9	4.9	5	230	192	263	0
July 6, 2023	P125	1	14	-7.9	15	-7.9	4.9	1	154	154	154	0
July 7, 2023	P125	1	14	-7.9	15	-7.9	4.9	0	-	-	-	0

[1] Sonar installed at 10:00 on June 28, 2023 and removed at 14:15 on July 7, 2023.

[2] Minimum survey depth = 1 m, maximum depth calculated using Equation 1. (Calculation of maximum survey depth)

Equation 1 → $\boldsymbol{Maximum\ Survey\ Depth = \ Sensor\ Depth + \sin\left(Sensor\ Pitch + \frac{1}{2} * Beam\ Angle\right)}$

Figure 11. Number of fish counted during each hour of the day during hydroacoustic monitoring of the various intakes at the Whitehorse Rapids Generating Station from June 28 – July 7, 2023.



2.2.5. Discussion

Hydroacoustic scanning was successfully completed at the three intakes at the WRGS between June 28 - July 7, 2023, the presumed peak of outmigration for juvenile Chinook Salmon beyond the dam. Overall, a maximum of three targets were observed within the size range of age-1 wild juvenile salmon. These fish were observed between midnight and 4am (when juvenile fish are presumed to migrate; (Chapman *et al*. 2012) and were moving in a downstream direction at depths between 2.4 - 4.8 m. Typical signs of juvenile salmon include large densities of salmon moving downstream at the same time which was not observed in this study and it is possible that these three targets were juvenile fish of another species. There are several possible explanations for the low number of salmon observations. First, salmon escapement has been very low over the last two years (~45 females each year), reducing the number of juveniles in the area. Second, although sonar performance was reported to be "fairly good", the sonar was not positioned to sample the deepest parts of the water column, an area where juvenile salmon may be found (Dauble *et al*. 1989; Li *et al*. 2018). If sonar is deployed in the future, it may be configured in a vertical (downward looking) orientation to scan the deepest components of the water column. It is also possible that run timing varied from that predicted based on available information (Section 2.1.4.5) such that we did not sample the peak of the outmigration. A total of 56,782 hatchery reared juvenile Chinook were released into Michie Creek on June 8, 2023 (Kapaniuk, pers. comm. 2023), and were expected to migrate past the facility during the monitoring period.

Although few juvenile salmon were observed, ~70 other fish were observed with the sonar around the various intakes, which provides some insight into the general behaviour of fish around the intakes, and the relative level of attraction of the various intakes. Most fish were observed around the spillway (57% of total fish density), with fewer fish observed at WH4 (28%) and P125 (15%). Interestingly, these proportions are fairly similar to the proportion of discharge through the various intakes (spillway = 61% of summer discharge, WH4 = 21% of summer discharge, and P125 = 18% of summer discharge, which is widely used to estimate salmon entrainment through intakes (see Section 2.1.4.6). Most fish were observed moving in a downstream direction, suggesting that they were likely entrained into the intake. Upstream movement was uncommon and was generally restricted to shallower depths where intake velocities are lower. Notably, we did not assess whether salmon were using the fishway, though previous discussions with the hatchery staff suggest very few juvenile salmon move through the fishway (Vano, pers. comm. 2023). Further, the fish ladder staff had not observed any juvenile salmon moving through the fishway since May 31 when they first started monitoring the viewing chamber. From June 15, 2023 onward (public-opening day), the viewing chamber was observed closely. On July 4 and July 17 (one each day), small salmonid fry of unknown species were observed. This also occurred on July 25, 2023 though the fry was later identified as a Mountain Whitefish.

Overall, the use of hydroacoustic scanning proved to be a viable approach for quantifying fish presence and movement around the various intakes at the WRGS. Scanning of the intakes required some troubleshooting to ensure proper functioning of the sonar at this specific location. Future sonar deployments at the intakes could likely be conducted with greater efficacy and over longer-term periods based on the work completed in 2023. This could provide important insight on route choice at the dam and migration timing, which would affect the size of fish and corresponding mortality rates. Sonar may also be a useful approach to gaining insight on the broader resident fish community interacting with hydropower infrastructure and can be done without handling fish (in contrast to fish sampling).

2.3. Empirical Study - Sensor Fish Deployment

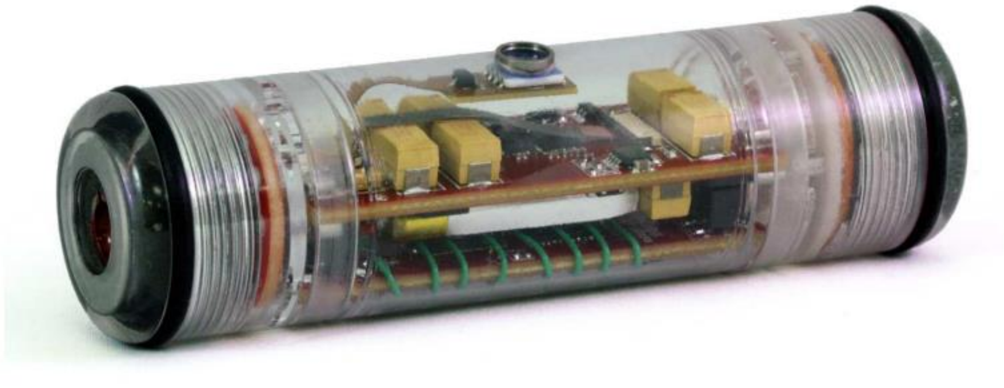
2.3.1. Background

Evaluating downstream passage success of fish through hydroelectric infrastructure has been the subject of considerable study over the past few decades (Algera *et al.* 2020). Much of this research has focused on Pacific salmon in the Columbia River, as salmon in this system must often pass several dams (during both upstream and downstream migration) to complete their lifecycle. There are multiple approaches available to assess downstream passage success, including application of telemetry (McMichael *et al.* 2010) or balloon tags (Benigni *et al.* 2021) on live fish, modelling (Ferguson *et al.* 2007; and see Section 3.1), and conventional fish sampling, among others. Many of these methods require significant fish handling, which may not be preferable for stocks of conservation concern (e.g., those of the upper Yukon River). Recent technological advances have provided means of evaluating mortality of fish traveling through hydropower facilities without the use of live fish (i.e., the Senor Fish).

The Sensor Fish is essentially a robotic fish (data logger) that records the conditions a fish endures while moving downstream through structures like turbines (Deng *et al.* 2014). These tags were developed to quantify salmon injury and mortality in the Columbia River (Duncan 2010) and provide many advantages relative to conventional tagging studies (including less fish handling, labour, and time). Further, the findings from Sensor Fish generally align with those for studies using live fish at the same facility, particularly when used for comparison across various design and operational regimes (Duncan 2011; Martinez *et al.* 2019).

The Sensor Fish has a size and density similar to those of a yearling salmon smolt and is neutrally buoyant in fresh water at deployment (i.e., 42.1 g, 24.5 mm in diameter, and 89.9 mm long; Deng *et al.* 2014; Figure 12). It contains three-dimensional (3D) rotation sensors (i.e., 3-axis gyroscope), 3D linear acceleration sensors (i.e., 3-axis accelerometers), a pressure sensor, a temperature sensor, a 3D orientation sensor (i.e., 3-axis magnetometer), a radiofrequency transmitter, a recovery module, and a communication module. It can store up to 5 minutes of data at a sampling frequency of 2,048 Hz, providing near continuous insight on passage conditions. Sensor Fish are meant for repeat deployments, allowing a single Sensor Fish to assess a passage route multiple times upon retrieval.

Figure 12. Photo of the Sensor Fish (Source: Martinez *et al.* 2019).



2.3.2. Objective

The objective of this study is to characterize the conditions experienced by juvenile Chinook Salmon during downstream passage through both turbine intakes and the spillway at the WRGS using Sensor Fish.

2.3.3. Methods

Three Sensor fish were deployed through WH3 of Powerhouse P125 and WH4 from July 2 to July 5, 2023. Sensor Fish were outfit with two balloon tags to facilitate the recovery of the tag in the tailrace. Balloons were filled with dissolvable capsules packed with baking soda and were injected with vinegar to begin inflation prior to deployment. Sensor Fish were attached to a quick release affixed to the end of an ~20 ft long pole intended for cleaning the trash rack. A nylon rope attached to the quick release and ran the length of the pole. The Sensor Fish and pole were lowered behind the trash rack screens (in the gate wells of P125, and through a gap downstream of the trash rack screens of WH4. The pole was lowered to a depth at which pull from the intake could be felt (~15 feet). Once lowered to depth, Sensor Fish were unclipped by pulling the rope and were entrained into the intake. Sensor Fish recorded acceleration, rotational velocity, and pressure during entrainment as per their standard procedure. Following entrainment, Sensor Fish floated to the surface using balloon tagging technology (and lead weights that are ejected from the Sensor Fish after a specified period of time) and were recovered downstream. Prior to Sensor Fish deployment, dozens of dummy tags were deployed through the turbines to refine deployment and recovery methods. Upon refinement of the methods, Sensor Fish were deployed repeatedly into the intakes. All three Sensor Fish were ultimately broken or lost during the study.

2.3.3.1. Statistical Analysis

The Hydropower Biological Evaluation Tool (HBET) software developed by the Pacific Northwest National Laboratory was used to analyse the data collected by the Sensor Fish and relate this to biological responses specific to juvenile Chinook Salmon. Sensor Fish data were downloaded to HBET and unique calibrations specific to each logger were applied as directed by the manufacturer.

Time marks were applied to physical condition curves following the HBET User Manual to identify the timing of severe events in relation to various passage phases (i.e., intake entrance, wicket gates, runner, draft tube, and tailrace). Biological responses were predicted based on the physical conditions recorded by Sensor Fish at the WRGS and models identifying mortality thresholds for live juvenile Chinook Salmon exposed to these conditions (all conducted in HBET). All biological predictions available in HBET were presented (though this varied across physical conditions depending on the models available in HBET). It should be noted that HBET does not currently have a model linking strikes/collisions to injury and mortality (models are currently being developed). To assign injury rates to strikes/collisions, we assumed that 'severe' events identified by HBET resulted in injury (likely a conservative approach; Deng, pers. comm. 2023). To assign mortality, we evaluated the magnitude of acceleration events (g-force; 1 g-force = 9.80665 m/s^2) experienced in the runner and attributed the most severe events to leading-edge blade strike (whereas the other events may involve collisions with the walls, runners, or the non-leading edges of blades). Events of similar magnitude in other regions were also deemed to be associated with mortality.

Biological outcomes were separately assessed for the various life stages of juvenile salmon in the area. This included selecting appropriate sizes and estimated acclimation depths for each life stage. Sizes were determined from trapping data in Michie Creek (see Section 2.1.4.5) and acclimation depths were estimated using the mean depths observed during a large-scale tracking study in the Snake River for age-0 and age-1 Chinook in 2012 (Li *et al.* 2018). It was assumed that hatchery fish had similar acclimation depths as age-1 juveniles as both are actively outmigrating. Given that blade strike is a function of fish size, and that Sensor Fish are approximately the size of an age-1 wild salmon, we scaled the strike/collisions mortality values by the smaller size of age-0 Chinook (61 mm) and hatchery chinook (81 mm) at the corresponding dates of deployments compared to age-1 Chinook (117 mm).

2.3.4. Results

From July 2 – July 5, 2023, Sensor Fish were deployed through both WH3 (n=4) and WH4 (n=11) of the WRGS to evaluate the conditions experienced by juvenile Chinook Salmon during downstream passage (Figure 13). Passage progressed from the intake entrance (~7 sec), through the wicket gate (~0.4 sec), runner (~0.5 sec), and the draft tube (~4 sec), with the entire process taking ~12 seconds. Three mechanisms for harm to fish occurred; pressure change (occurs in the runner region), sheer force, and strikes/collisions. Neither the intake or wicket gate regions were associated with significant sheer force or strikes/collisions. The runner region (i.e., turbines) were associated with pressure changes, sheer forces, and strikes/collisions harmful to fish. The draft tube was also generally not associated with severe events that would harm fish.

2.3.4.1. Hydraulic Conditions

The majority of Sensor Fish trials (trials) passing through WH4 recorded at least one severe event (i.e., acceleration events >95 g-force) during passage (6 of 11 trials), while a smaller proportion of trials passed through WH3 recorded severe events (1 of 4; Table 5). Only one trial experienced severe events across the entrance/wicket gate regions. This trial experienced two strike/collision events in the entrance region (max acceleration of 137 g-force). In the runner region of WH4, 6 of 11 trials experienced severe events, four trials experienced severe strike/collisions, one trial experienced both severe strike/collisions and shear, while one trial only experienced severe shear in the runner. In the runner region of WH3, 1 of 4 trials experienced severe events (all strike/collisions) during runner passage. These strike/collisions in the runner region are likely the result of making contact with the runner hub or blades, or alternatively the walls. One trial in each turbine experienced a strike event during draft tube passage (likely hitting the wall). In the runner region (where the most severe conditions to fish were recorded), the maximum magnitude of strikes/collisions (i.e., acceleration) was greater for WH4 (144.78 g-force) than WH3 (68.04). Similarly, decompression (i.e., nadir pressure) was lower and therefore more severe in WH4 (10.58 psia) than WH3 (16.60 psia). Rotational velocity (indicative of turbulence) was also greater for WH4 (2764 deg/sec) than WH3 (2374.63 deg/sec). Flow quality was assessed as 'poor' for all turbines based on the recorded rotational velocity. Across both turbines, poor flow quality was most common in the runner region (12 of 14 trials), followed by the draft tube (9 of 14 trials), intake entrance (4 of 14 trials), and wicket gate regions (none of 14 trials).

2.3.4.2. Biological Response

Acceleration measurements clustered into values between 19 to 60 g-force (most trials), 110-120 g-force (2 trials), and 200-325 g-force (5 trials). We assumed that the most severe values (i.e., >200 g-force were associated with leading-edge blade strike). Further, we had one confirmed blade strike on our Sensor Fish (the logger was recovered in two pieces), that indicated that particular blade strike was associated with acceleration of 325 g-force. Given that Sensor Fish are rarely broken, and that they are tested with thousands of g-force in the lab, it was hypothesized by the Sensor Fish producer that these turbines likely have sharp blades (common amongst older turbines). While not all leading-edge blade strikes may kill fish (e.g., if it grazes the tail), it was assumed all high acceleration blade strikes identified were likely lethal given the uncommon damage inflicted to the broken Sensor Fish. One high acceleration event also occurred in the draft tube (>250 g-force) which was also assumed to have resulted in mortality.

For sub-yearling Chinook Salmon (i.e., age-0 fish), it was estimated that 31.5% of individuals passing through WH4 may succumb to mortality (Table 6). This includes an estimated 9% of individuals dying due to barotrauma, 2% due to shear, and 24% due to strike/collisions. Minor injury rates (or worse) were estimated to be ~51% for age-0 salmon, though this does not include potential non-mortal injuries from barotrauma. For yearling Chinook Salmon (i.e., age-1 fish), it was estimated that 51.2% of individuals passing through WH4 may succumb to mortality (Table 6). This includes an estimated 6% of individuals dying due to barotrauma, 6% due to shear, and 45% due to strike/collisions. Minor to major injury rates were estimated to be ~73% for age-1 salmon, though this does not include potential non-mortal injuries from barotrauma. For hatchery Chinook Salmon, it was estimated that 36.2% of individuals passing through WH4 may succumb to mortality (Table 6). This includes an estimated 6% of individuals dying due to barotrauma, 2% due to shear, and 31% due to strike/collisions. Minor injury rates (or worse) were estimated to be ~56% for hatchery salmon, though this does not include potential non-mortal injuries from barotrauma.

For age-0 Chinook Salmon, it was estimated that 13.7% of individuals passing through WH3 may suffer direct mortality (Table 6). This includes an estimated <1% of individuals dying due to barotrauma, 0% due to shear, and 13% due to strike/collisions. Minor to major injury rates were estimated to be ~19% for age-0 salmon, though this does not include potential non-mortal injuries from barotrauma. For age-1 Chinook Salmon, it was estimated that 25.8% of individuals passing through WH4 may succumb to mortality (Table 6). This includes an estimated <1% of individuals dying due to barotrauma, <1% due to shear, and 25% due to strike/collisions. Minor injury rates (or worse) were estimated to be ~36% for age-1 salmon, though this does not include potential non-mortal injuries from barotrauma. For hatchery Chinook Salmon, it was estimated that 17.7% of individuals passing through WH4 may succumb to mortality (Table 6). This includes an estimated <1% of individuals dying due to barotrauma, 0% due to shear, and 17% due to strike/collisions. Minor injury rates (or worse) were estimated to be ~23% for hatchery salmon, though this does not include potential non-mortal injuries from barotrauma.

Figure 13. Pressure (psia), acceleration (g-force), and rotational velocity (degrees/s) profiles for individual Sensor Fish trials through WH3 (n=4) and WH4 (n=11) of the Whitehorse Rapids Generating Station from July 2 - July 5, 2023.

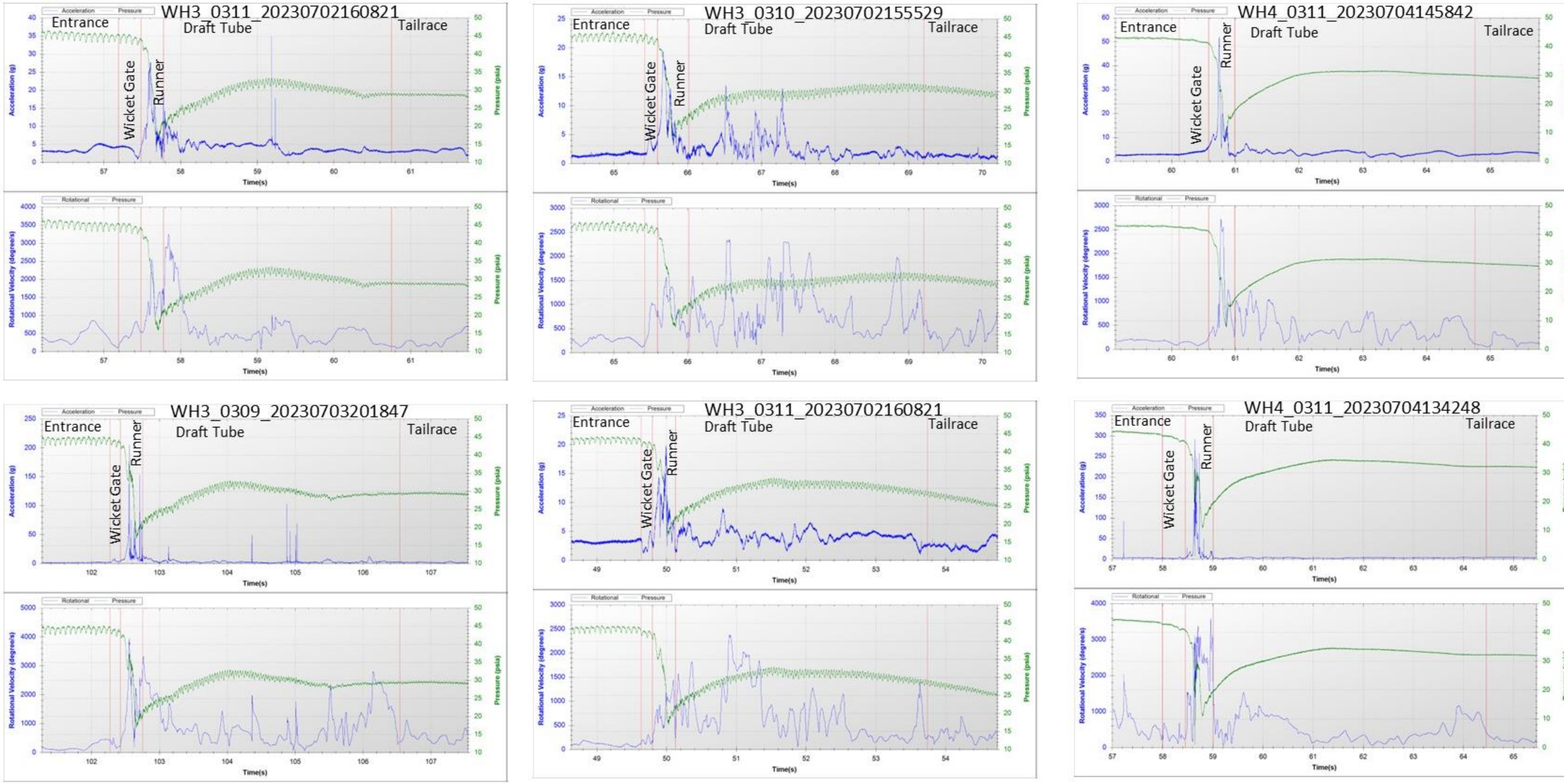


Figure 13. Continued (2 of 3).

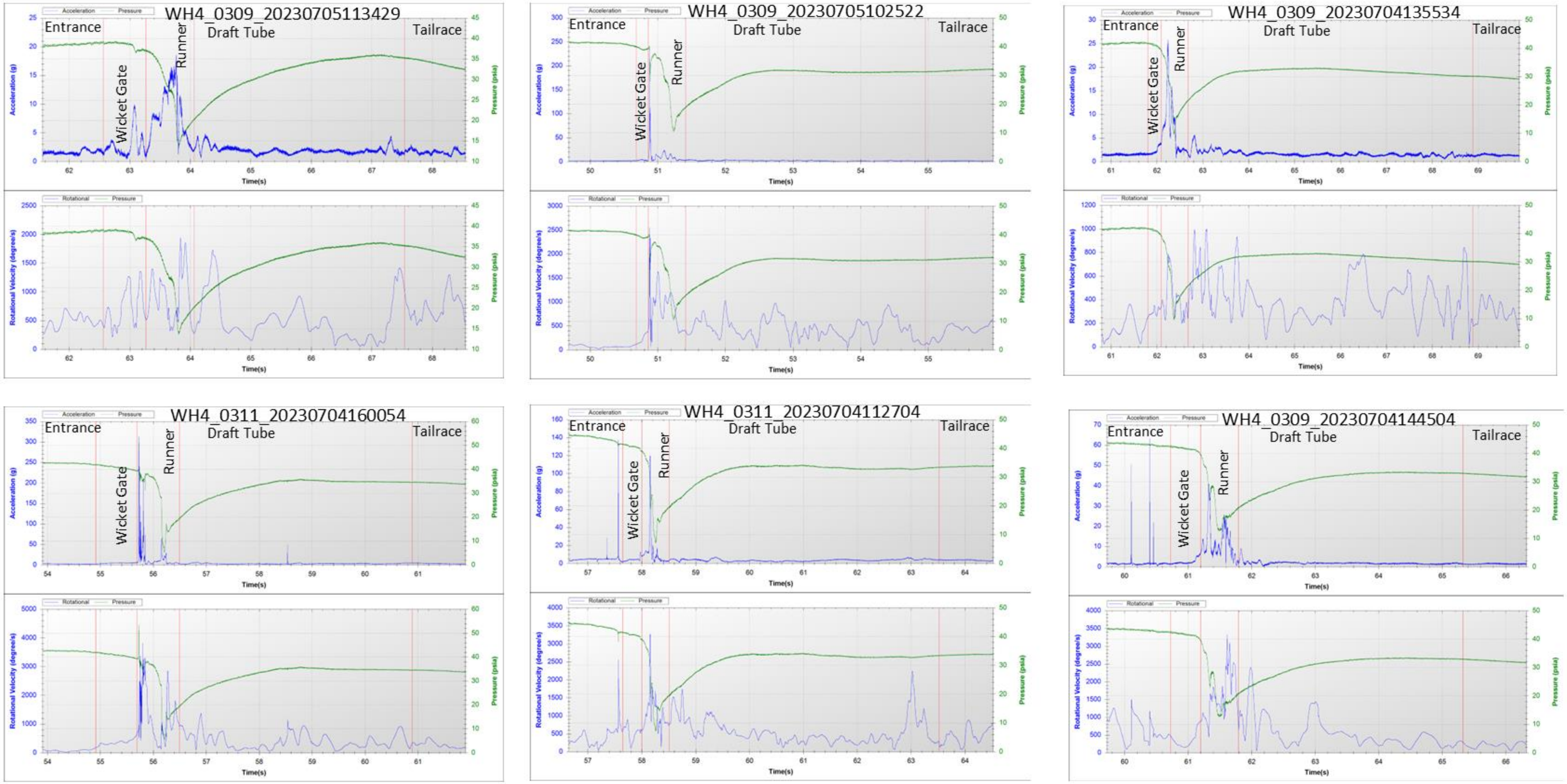


Figure 13. Continued (3 of 3).

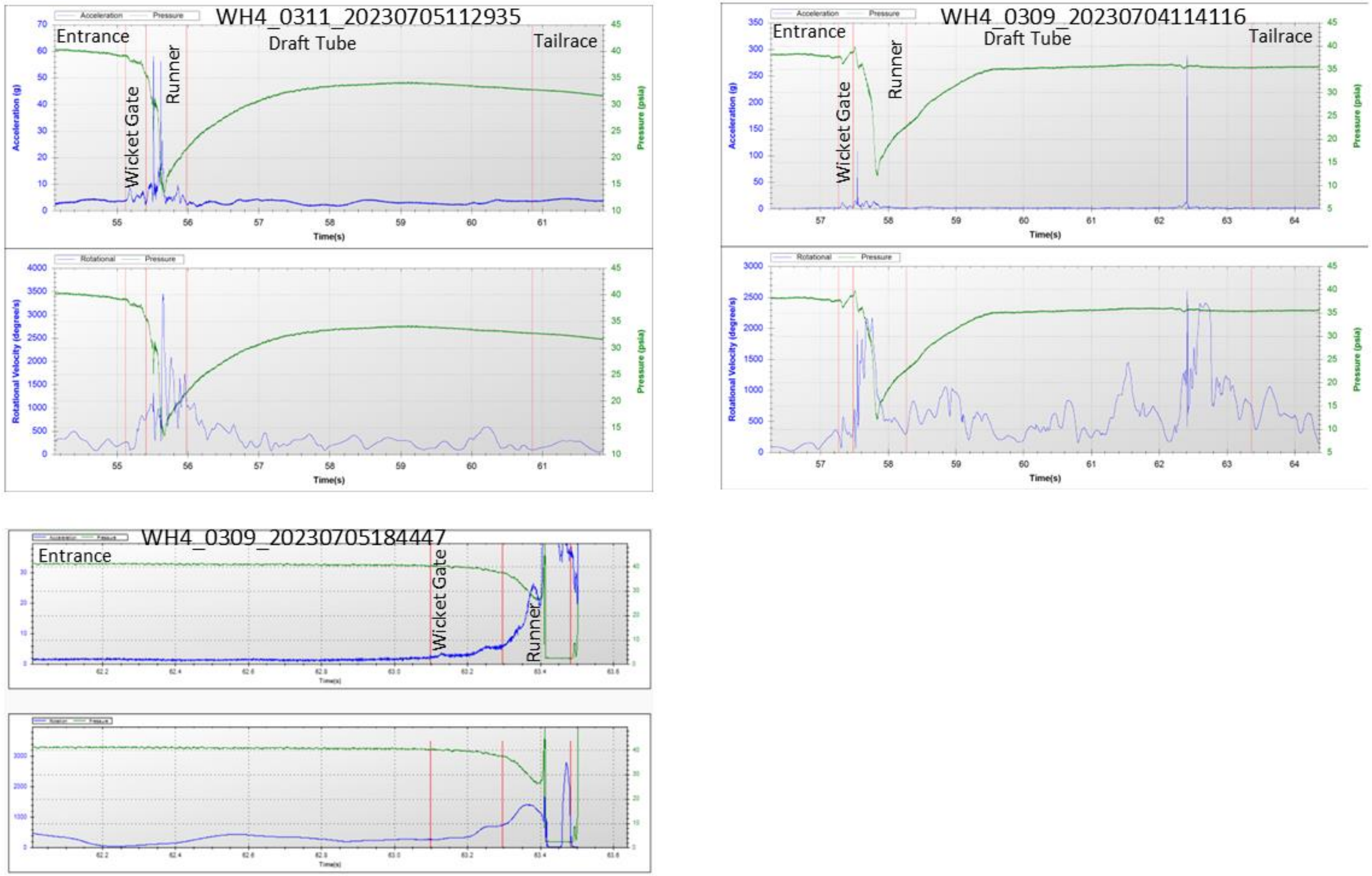


Table 5. Passage conditions experienced by Sensor Fish through WH3 (n=4) and WH4 (n=11) of the Whitehorse Rapids Generating Station from July 2 – July 5, 2023.

					Region										
						Entrance	Wicket Gate	Runner		Draft Tube	Runner			Overall	
Test date	Location	Filename	Sensor fish ID	Deployment time	Total duration (sec)	Severe strike events	Severe strike or shear events	Severe shear events	Severe strike event	Severe strike event	Max. acceleration (g)	Max. rotation (deg/s)	Nadir pressure (psia)	Severe events	Flow quality
2023-07-04	WH4	WH4_0309_20230704114116	309	10:57 AM	11.66	0	0	0	1	1	109.05	2165.12	11.96	2	poor
2023-07-04	WH4	WH4_0311_20230704112704	311	11:10 AM	13.98	2	0	1	0	0	119.93	3264.04	7.18	3	poor
2023-07-04	WH4	WH4_0311_20230704134248	311	1:09 PM	14.21	0	0	4	4	0	291.93	3586.43	11.28	8	poor
2023-07-04	WH4	WH4_0309_20230704135534	309	1:24 PM	12.96	0	0	0	0	0	25.77	788.00	9.35	0	poor
2023-07-04	WH4	WH4_0311_20230704145842	311	2:24 PM	14.72	0	0	0	0	0	52.10	2720.01	8.12	0	poor
2023-07-04	WH4	WH4_0309_20230704144504	309	2:34 PM	13.23	0	0	0	0	0	40.81	3329.56	12.53	0	poor
2023-07-04	WH4	WH4_0311_20230704160054	311	3:33 PM	12.12	0	0	0	5	0	313.11	3819.21	5.19	5	poor
2023-07-05	WH4	WH4_0309_20230705102522	309	9:59 AM	6.95	0	0	0	2	0	237.45	2554.49	10.35	2	poor
2023-07-05	WH4	WH4_0311_20230705112935	311	11:06 AM	11.55	0	0	0	0	0	58.12	3451.44	16.45	0	poor
2023-07-05	WH4	WH4_0309_20230705113429	309	11:14 AM	17.09	0	0	0	0	0	18.58	1942.88	13.45	0	poor
2023-07-05	WH4	WH4_0309_20230705184447	309	11:45 AM	-	0	0	-	≥1	-	325.77	2787.00	-	≥1	-
Average	**WH4**	**-**	**-**	**-**	**12.85**	**0.18**	**0.00**	**0.50**	**1.20**	**0.10**	**144.78**	**2764.38**	**10.58**	**2.00**	**poor**
2023-07-02	WH3	WH3_0311_20230702160821	311	10:59 AM	10.75	0	0	0	0	0	27.74	2541.08	15.82	0	poor
2023-07-02	WH3	WH3_0310_20230702155529	310	12:01 PM	12.31	0	0	0	0	0	19.45	1568.50	16.98	0	poor
2023-07-02	WH3	WH3_0309_20230703201847	309	2:04 PM	10.38	0	0	0	3	1	205.05	3950.28	16.83	4	poor
2023-07-02	WH3	WH3_0311_20230702185826	311	3:17 PM	10.95	0	0	0	0	0	19.94	1438.67	16.76	0	poor
Average	**WH3**	**-**	**-**	**-**	**11.10**	**0.00**	**0.00**	**0.00**	**0.75**	**0.25**	**68.04**	**2374.63**	**16.60**	**1.00**	**poor**

Table 6. Biological consequences (injury and mortality) to various life stages of Chinook Salmon associated with various hydraulic conditions associated with downstream passage through the Whitehorse Rapids Generating Station as determined by Sensor Fish trials during June and July, 2023.

WH4 (n=11)			Pressure-change	Shear			Strike/collisions		OVERALL (%)
Life stage	**Acclimation depth (m)**	**Discharge (m^3/s)**	**Mortality (%)**	**Minor injury (%)**	**Major injury (%)**	**Mortality (%)**	**Injury (%)**	**Mortality (%)**	**Mortality (%)**
Age-0+ wild (85-95mm)	3.57	126 (125-127)	**8.93 (8.26-9.63)**	26.51	7.07	**1.54**	28.36	**23.64**	**31.49**
Age 1+ wild (123-152mm)	1.54	126 (125-127)	**5.50 (5.05-5.98)**	40.5	14.95	**5.56**	54.55	**45.45**	**51.18**
Age-0+ hatchery (85-95mm)	1.54	126 (125-127)	**5.50 (5.05-5.98)**	26.51	7.07	**1.54**	37.76	**31.47**	**36.21**
WH3 (n=4)									
Life stage	**Acclimation depth (m)**	**Discharge (m^3/s)**	**Mortality (%)**	**Minor injury (%)**	**Major injury (%)**	**Mortality (%)**	**Injury (%)**	**Mortality (%)**	**Mortality (%)**
Age-0+ (85-95mm)	3.57	46 (45-47)	**0.78 (0.71-0.87)**	6.60	0.01	**0**	13.00	**13.00**	**13.68**
Age 1+ (123-152mm)	1.54	46 (45-47)	**0.43 (0.39-0.48)**	14.39	2.04	**0.7**	25.00	**25.00**	**25.84**
Age-0+ hatchery (85-95mm)	1.54	46 (45-47)	**0.43 (0.39-0.48)**	6.60	0.01	**0**	17.31	**17.31**	**17.66**

2.3.5. Discussion

Sensor Fish were deployed through both powerhouses at the WRGS from July 2 – July 5, 2023, providing insight into the physical conditions and corresponding biological outcomes associated with passage for juvenile Chinook Salmon. It should be noted that the mortality rates presented above need to be considered in the context of route choice and passage timing (which influences dam operations and the size of fish). For instance, if hypothetically all fish passed downstream through the spillway, mortality rates through the turbines would become irrelevant.

Despite a small sample size, the fine-scale data recorded by the Sensor Fish provided high confidence in biological outcomes. The confidence intervals associated with barotrauma mortality were small, (high certainty), and we have high confidence that shear stress mortality is low overall (as expected; Coutant and Whitney 2000). We have less confidence in how strike/collisions recorded by the Sensor Fish associate with mortality given that this prediction is not currently a function supported in HBET. To assign mortality, we evaluated the magnitude of acceleration events experienced in the runner and attributed the most severe events to leading-edge blade strike (whereas the other events may involve collisions with the walls, runners, or the non-leading edges of blades). The recovery of acceleration data from one Sensor Fish severed by the turbines provides validation for this approach. The Sensor Fish had an acceleration value >300 g-force in passing the turbine blades, which aligned with the comparatively high acceleration values observed for a handful of other Sensor Fish.

Overall, conditions were more severe during passage through WH4 than WH3. Maximum acceleration values and the average number of severe events were approximately double in WH4 than WH3. Rotational velocity (indicative of turbulence and low flow quality) was also greater in WH4. These physical conditions resulted in a predicted mortality rate that was approximately double for WH4 across all life stages.

Overall, we took a precautionary approach where data were lacking (e.g., assigning deeper acclimation depths which increases mortality slightly). We also assumed that all severe leading-edge blade strike events led to mortality, though it is hypothesized fish may be able to survive some leading-edge blade strikes (Deng, pers. comm. 2023). However, given the age of the turbines in Whitehorse and that a Sensor Fish was broken by the turbines (uncommon, Deng, pers. comm. 2023), it is presumed blade strikes are likely to be fatal for struck Chinook Salmon.

It should be noted that we did not assess the spillway using the Sensor Fish given that the three Sensor Fish were consumed during evaluation of the turbines (which was given highest priority for assessment given the greater consequences for fish associated with turbine passage). Further, we only assessed WH3 of powerhouse P125 (not WH1 and WH2) given the effort required to refine Sensor Fish deployments across different intakes. WH1 and WH2 have the same design specifications though these differ from WH3. WH1 and WH2 are Kaplan turbines (vs. propeller) and have higher RPM than WH3, which would likely result in higher mortality through these intakes.

Overall, Sensor Fish were challenging to deploy, but provided very fine-scale, useful data for insights into biological outcomes for juvenile Chinook Salmon passing through the WRGS. They appear to be a useful tool for studying entrainment and could be further applied at this system to improve evaluation of entrainment.

2.4. Empirical Study - Predator Surveys

2.4.1. Background

Hydropower infrastructure can increase the risk of mortality for fish migrating downstream, and lead to sublethal consequences for fish that do survive entrainment (e.g., stress, injury, disorientation, etc…). Previous research on juvenile salmon migrations through hydropower infrastructure has highlighted the potential for increased vulnerability to predation following downstream migration (Blackwell *et al.* 1998). Increased predation is likely a result of salmon being confined in high densities downstream of dams, as well as compromised anti-predator behaviour following disorienting, injurious, and potentially stressful downstream passage (Jepsen *et al.* 1998, Koed *et al.* 2002). Bird and fish predators have been known to aggregate and consume entrained fish, and evidence for this behavior is strongest regarding entrained salmonids (specifically juvenile Chinook) in Western USA (Ruggerone 1986; McLaughlin *et al.* 2013; Ferguson *et al.* 2007).

Observations from the Whitehorse Rapids Fish Ladder viewing chamber suggest Arctic Grayling (adults and juveniles) are the most numerous potential salmon predator, followed by Longnose Sucker (various life stages), and a small number of Rainbow Trout (sub-adults and adults), Lake Trout (sub-adults), Whitefish (sub-adults and adults), and Northern Pike (juveniles and sub-adults; Vano, pers. comm. 2023). It should be noted that the fish community within the ladder may be different than that in the tailrace, and that other species may be present as well (e.g., Inconnu) downstream of the dam. Observations from Nick DeGraff suggest Burbot are most often attracted to juveniles in traps (DeGraff, pers. comm. 2023). In addition to fish predators, there are relatively high densities of birds at the outflows of the WRGS (Jessup, pers. comm. 2023). There is potential for these fish and bird species to preferentially feed on entrained fish downstream of the dam.

2.4.2. Objective

The objective of this study is to characterize the vulnerability to and predation of juvenile Chinook Salmon to fish and avian predators following entrainment at the spillway and turbine outflows relative to control sites along the outmigration corridor.

2.4.3. Methods

2.4.3.1. Fish Predator Surveys

Angling was conducted to evaluate the presence of potential fish predators of juvenile Chinook Salmon downstream of outflows at the WRGS. To assess this objective, angling was conducted at the WRGS and at control sites located away from the WRGS. Angling was conducted in proportion to the amount of 'fishable' habitat at each site (typically 30 min per site). Angling sites around the WRGS included the spillway, eddy downstream of P125, the outflow channel of P127, and the riffle downstream of the fishway (river right; Map 1). Control sites were selected to be representative of the range of habitat types that juvenile Chinook Salmon experience in this stretch of the river. Control sites extended along the Yukon River from McIntyre Creek upstream to Wolf Creek. Various site, environmental, and sampling conditions were recorded at each sampling site (Table 7).

Anglers were instructed to sample all available habitat, with disproportionately higher effort in areas where potential predator prey interactions were suspected to be most likely. Angling was typically conducted by two people per site, with one angler using a size 1 (3/4 oz) spoon (targeting Northern Pike and other large predators) and the other angler using a size 0 or 1 (1/8 or 1/12 oz) inline spinner (targeting smaller predators like Arctic Grayling). Angling continued until both anglers had sampled all available habitat.

Upon capture, fish were identified to species, measured (fork length), weighed and photographed. Fish selected for lethal sampling were then dissected and had their stomach and stomach contents removed and weighed to the nearest gram. Prey items were identified in stomach contents where possible. Lethally sampled predators were stored in coolers and were distributed to First Nation partners following each day of sampling as requested. Vulnerability of juvenile Chinook Salmon to fish predators was assessed through catch-per-unit-effort (CPUE) of potential predators at control and impact sites. Fish considered too small to consume a juvenile Chinook Salmon were identified to species, measured for length and weight, and released at the location of capture.

Table 7. Site, environmental, and sampling variables recorded during angling for potential Chinook Salmon Predators.

Variables
Site name
Coordinates
River width (m)
Site length (m)
Max cast length (m)
Max depth (m)
Fishable area (%)
Habitat type
Substrate type
Water temperature
Number of anglers
Time in and out (per person)
Terminal tackle (per person)

2.4.3.2. Avian Predator Surveys

Avian surveys were conducted through a combination of both visual surveys and camera recordings. Visual surveys were conducted weekly by local biologists/bird watchers (Nick DeGraff, Bob Van Dijken, David Petkovich, Scott Keesey, and Jennifer Trapnell) from the beginning of May to the end of July (encompassing the entirety of the potential salmon outmigration period). Surveys were conducted at four zones between Robert Service Way and the WRGS; including two control zones along Robert Service Way (Zone 1 and 2) and the outflows of P125 (Zone 3) and P127 and the spillway (Zone 4; Figure 14). For each survey, observers were asked to record the date, time, zone, species abundances, and any comments on behaviour. Additionally, changes in the abundance of non-fish-eating birds was used as a control for seasonal changes in overall bird abundance that is unrelated to salmon presence.

Wildlife cameras were deployed at sites with elevated levels of predators identified via discussions with local partners and while conducting initial work around the hydropower plant. These sites included the outflows of the spillway, P125, and WH4 (Map 1; Figure 14). Cameras were set to take photos every 15 minutes. Photos from wildlife cameras were evaluated for abundance and composition of avian predators over time as well as the frequency of various behaviours (e.g., perching, flying, swimming, fishing). All data were plotted using the package 'ggplot2' in R statistical Software (R Core Team 2023). Smoothed lines of best fit were plotted to the data.

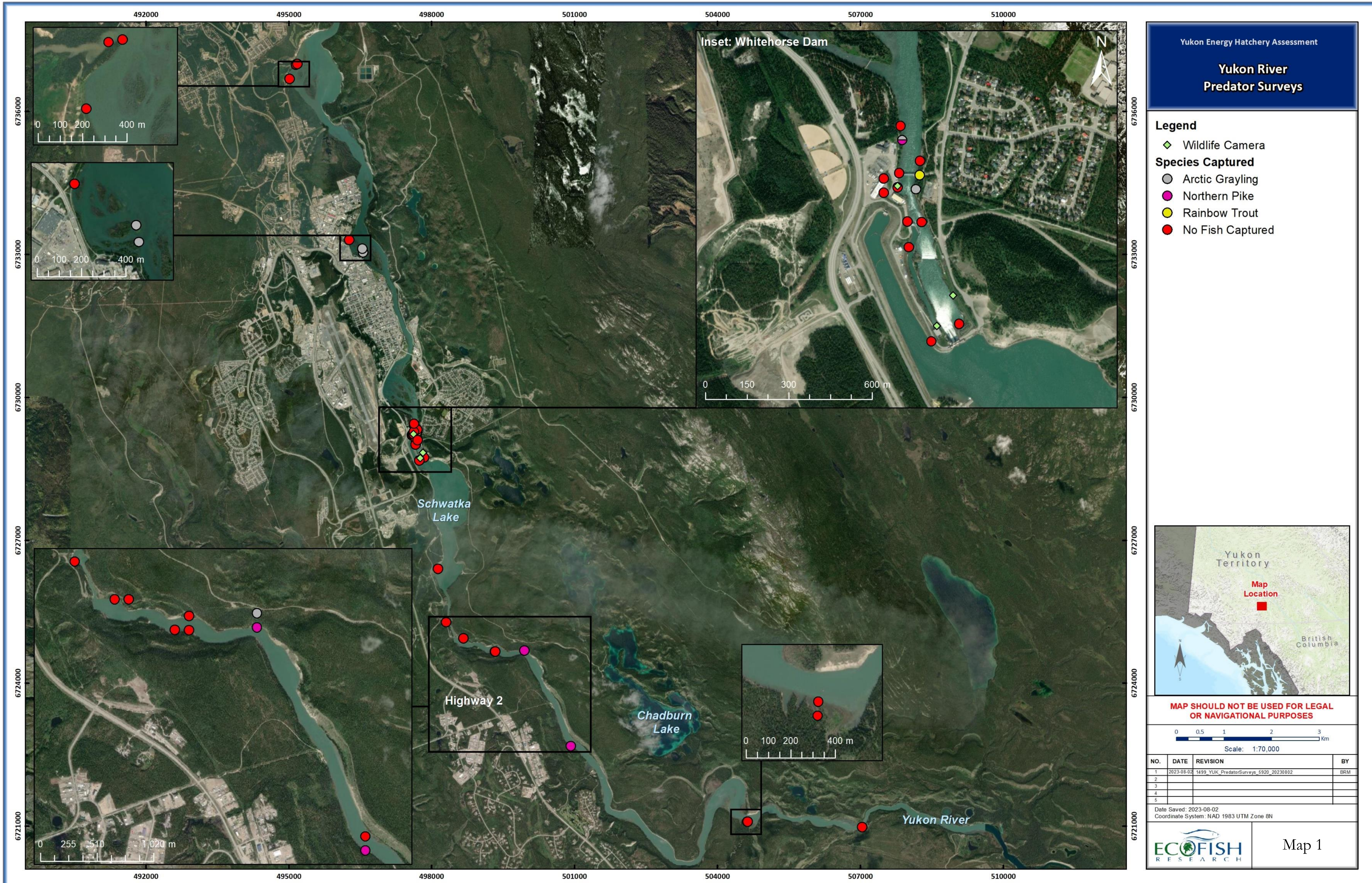


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Figure 14. Surveys zones for avian predator surveys conducted by bird watchers/biologists from the local community around the Whitehorse Rapids Generating Station from May to July 2023. Zones 1 and 2 were considered control sites away hydropower infrastructure.

2.4.4. Results

2.4.4.1. Fish Predator Surveys

Angling was completed at 23 control (13.0 rod hours) and 11 impact sites (10.4 rod hours) on the Yukon River. Correspondingly, ~12825 m^2 of area was angled for control sites and 7908 m^2 for impact sites. Turbidity was low and visibility was high during angling, providing good conditions for angling. A range of riffle, run, and pool habitat types were angled.

A total of 15 fish were captured across all sites, including 5 Arctic Grayling (*Thymallus arcticus*), 9 Northern Pike (*Esox lucius*), and 1 Rainbow Trout (*Oncorhynchus mykiss*; Table 8; Figure 15). Catch-per-unit-effort (fish/hour) was generally greater at control sites (~0.5 fish/hour) than around the WRGS where only one fish was captured (an Arctic Grayling in the tailrace; Table 9). No fish were captured in the spillway or outflows of WH4 or P125. However, CPUE was highest downstream of the tailrace (~1 fish/hour), though this was not assumed to be related to entrainment effects given that fewer predators (only one) were captured near the dam where entrainment effects are greatest.

All predators including Arctic Grayling (258 ± 85 mm), Northern Pike (579 ± 75 mm), and Rainbow Trout (175 mm) were of a sufficient size to consume juvenile salmon, though it is likely only Northern Pike could have consumed smolt (i.e., age-0 hatchery fish or age-1 wild fish). Captured fish included both male and females. All Arctic Grayling captured had prey items within their stomach upon inspection, as opposed to Northern Pike which typically had empty stomachs (7/9 pike). All Arctic Grayling had evidence of invertebrate prey consumption (e.g., stoneflies, mayflies), with two small, unidentifiable, digested fish skeletons found in one Arctic Grayling stomach upstream of the dam on the Yukon River (potentially the size of age-0 wild salmon fry). Two sculpins were found in one Northern Pike from upstream of the dam on the Yukon River, with an ~40 mm unidentifiable fish found in another Northern Pike downstream of the tailrace. Overall, there was little evidence of substantive juvenile salmon consumption by fish predators at any of the sampling sites.

Table 8. Effort and capture data associated with angling undertaken at and around the Whitehorse Rapids Generating Station from June 28 – July 7, 2023.

Site	Date	Location	Effort (h)	Area (m2)	Captures				CPUE (fish/hour)
					Grayling	Pike	Rainbow	Total	
YKN-DSAG01	2023-06-30	P125	0.5	337.5	0	0	0	0	0
YKN-DSAG02	2023-06-30	P125	0.83	200	0	0	0	0	0
YKN-DVAG01	2023-06-30	WH4	0.25	480	0	0	0	0	0
YKN-USAG01	2023-06-30	Upstream Control	0.57	1000	1	0	0	1	1.76
YKN-USAG02	2023-06-30	Upstream Control	0.5	300	0	1	0	1	2
YKN-USAG03	2023-06-30	Upstream Control	0.67	300	0	0	0	0	0
YKN-USAG04	2023-07-01	Upstream Control	0.33	300	0	0	0	0	0
YKN-USAG05	2023-07-03	Upstream Control	0.67	1600	0	0	0	0	0
YKN-USAG06	2023-07-03	Upstream Control	0.77	1050	0	0	0	0	0
YKN-USAG07	2023-07-03	Upstream Control	0.37	500	0	2	0	2	5.45
YKN-USAG08	2023-07-03	Upstream Control	0.5	400	0	0	0	0	0
YKN-USAG09	2023-07-03	Upstream Control	0.5	400	0	0	0	0	0
YKN-DSAG03	2023-07-04	Spillway	0.37	240	0	0	0	0	0
YKN-DVAG01	2023-07-04	WH4	0.13	500	0	0	0	0	0
YKN-DSAG04	2023-07-05	Tailrace	0.67	400	0	0	0	0	0
YKN-DSAG05	2023-07-05	Tailrace	1.67	600	1	0	0	1	0.6
YKN-DSAG06	2023-07-06	Upstream Control	0.43	240	0	0	0	0	0
YKN-DSAG07	2023-07-06	P125	0.17	360	0	0	0	0	0
YKN-DSAG08	2023-07-06	Downstream of Tailrace	1.25	1200	1	5	0	6	4.8
YKN-DSAG09	2023-07-06	Downstream of Tailrace	1	600	0	0	1	1	1
YKN-DSAG10	2023-07-06	Downstream of Tailrace	1	1200	0	0	0	0	0
YKN-DSAG11	2023-07-06	Downstream of Tailrace	0.5	150	0	0	0	0	0
YKN-DSAG12	2023-07-06	Downstream of Tailrace	0.6	400	0	0	0	0	0
YKN-USAG08	2023-07-06	Upstream Control	0.5	500	0	0	0	0	0
YKN-USAG10	2023-07-06	Upstream Control	0.5	500	0	0	0	0	0
YKN-USAG11	2023-07-06	Upstream Control	0.5	600	0	0	0	0	0
YKN-USAG12	2023-07-06	Upstream Control	0.5	400	0	0	0	0	0
YKN-USAG13	2023-07-06	Upstream Control	0.5	300	0	0	0	0	0
YKN-USAG14	2023-07-06	Upstream Control	0.33	400	0	0	0	0	0
YKN-USAG15	2023-07-06	Upstream Control	0.5	300	0	0	0	0	0
YKN-DSAG08	2023-07-07	Downstream of Tailrace	1.67	1600	0	1	0	1	0.6
YKN-DSAG13	2023-07-07	Downstream Control	0.25	500	0	0	0	0	0
YKN-DSAG14	2023-07-07	Downstream Control	0.67	600	0	0	0	0	0
YKN-DSAG15	2023-07-07	Downstream Control	0.67	800	0	0	0	0	0
YKN-DSAG16	2023-07-07	Downstream Control	1	750	0	0	0	0	0
YKN-DSAG17	2023-07-07	Downstream Control	1.17	500	1	0	0	1	0.86
YKN-DSAG18	2023-07-07	Downstream Control	0.5	225	1	0	0	1	2

Table 9. Summarized effort and capture data associated with angling undertaken at various sites at and around the Whitehorse Rapids Generating Station from June 28 – July 7, 2023.

Location	Effort	Captures	CPUE
Downstream Control	4.250	2	0.471
Downstream of Tailrace	6.017	8	1.330
P125	1.500	0	0
Spillway	0.367	0	0
Tailrace	2.333	1	0.429
Upstream Control	8.633	4	0.463
WH4	0.383	0	0

Figure 15. Examples of various fish predators captured during predator surveys from June 28 – July 7, 2023 in Whitehorse, YT.

2.4.4.2. Avian Predator Surveys

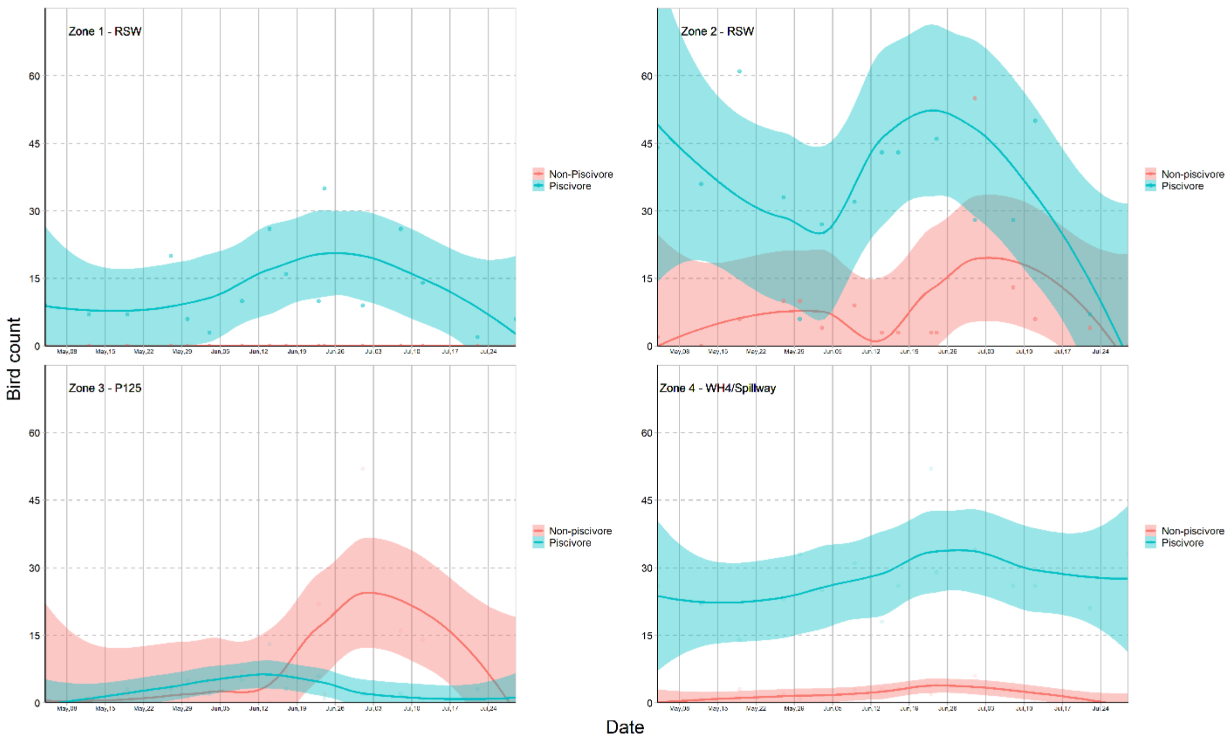
Bird surveys were completed 16 times between May 4 and July 29, 2023. A total of 1658 birds were observed across at least 40 species, which excludes hundreds of additional songbirds that were not enumerated. Observed birds included both fish-eating and non-fish-eating birds. Fish-eating-birds comprised 1263 observations across 7 species groups (Arctic Tern, Eagle, Merganser, Duck, Kingfisher, Osprey, and Gull).

Fish-eating-birds were commonly observed across all survey zones, including Zone 1 – RSW (206 birds), Zone 2 – RSW (570 birds), Zone 3 – P125 (48 birds), and Zone 4 – Spillway/WH4 (439 birds). These areas appear to be important bird habitat, particularly for gulls. Gulls were by far the most abundant species group, making up 91% of all fish-eating-bird observations (Figure 16). The islands along RSW and the canyon area around the spillway/WH4 are apparently rookeries for gulls. The roof of the powerhouse building for WH4 also maintained a high density of gulls.

The abundance of birds during each survey week was highly variable, though across all locations there appeared to be a peak around mid-late June for both fish-eating and non-fish-eating birds. Although this peak generally aligns with the expected peak of juvenile salmon outmigration at the dam based on previous study (Section 2.1.4.5), the similar patterns observed between fish-eating and non-fish-eating birds suggests that some other environmental variable is driving the seasonal abundance of birds across survey zones. Abundance patterns were similar between downstream (control) zones and zones at the dam where fish may be more susceptible to bird predation due to entrainment. Given that bird abundance is lower at the dam and that there does not appear to be a closer association between salmon outmigration timing and bird abundance at the dam, there is little evidence to suggest entrainment is driving bird presence at the dam based on these surveys. Overall, little fishing activity was observed across any week. Indeed, fishing only made up ~2% of all observed activities of fish-eating-birds, with perching and flying making up the majority of observations.

Figure 16. Pictures taken during a bird survey completed on July 8 (top) and July 12 (bottom) 2023. Top: Gulls perched at the outlet of turbines 1/2/3, Bottom: Gull perched near the shoreline in Zone 4 that was observed occasionally plunging into the water (Source: Nick DeGraff).

Figure 17. Piscivorous (fish-eating) and non-piscivorous (non-fish-eating) bird counts at various zones at and downstream of the Whitehorse Rapids Generating Station from May to July, 2023 as observed by bird watchers/biologists from the local community. Zone 1 and 2 along Robert Service Way (RSW) were considered control sites away hydropower infrastructure.



From June 28 to July 7, 4107 birds were enumerated on wildlife cameras aimed at the spillway, P125 outflow, and WH4 outflow (Figure 18). Almost all birds identified were gulls, though gulls were easiest to observe on the wildlife cameras. A small number of unidentifiable birds were also observed. Bird density was highest at the spillway (4.3±3.1 birds/100 m), and was similar at the P125 (0.8±1.7 birds/100 m) and WH4 (0.7±0.5 birds/100 m) outflows (Figure 19). However, the outflow channels with corresponding bird habitat are longer for WH4 (~350 m), followed by the spillway (~250 m), and P125 outflows (~10 m). As such, the total number of birds at any given time is estimated to be greatest at the spillway, followed by WH4, and then P125. Bird density tended to be greatest in the evening, lowest in the morning, with a second decrease in abundance midday (Figure 20).

Figure 18. Sample images from the wildlife cameras deployed at the WH4 outflow, P125 outflow, and spillway from June 28 – July 7, 2023.

Figure 19. Bird density (birds/100 m) at the P125, WH4, and spillway outflows at the Whitehorse Rapids Generating Station from June 28 – July 7, 2023 as observed in wildlife cameras.

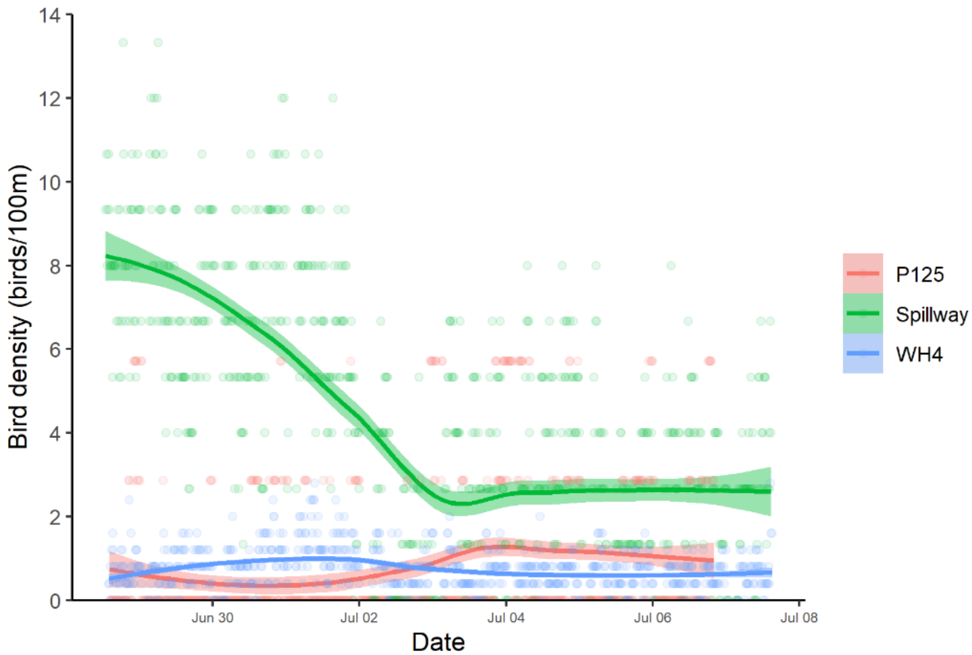
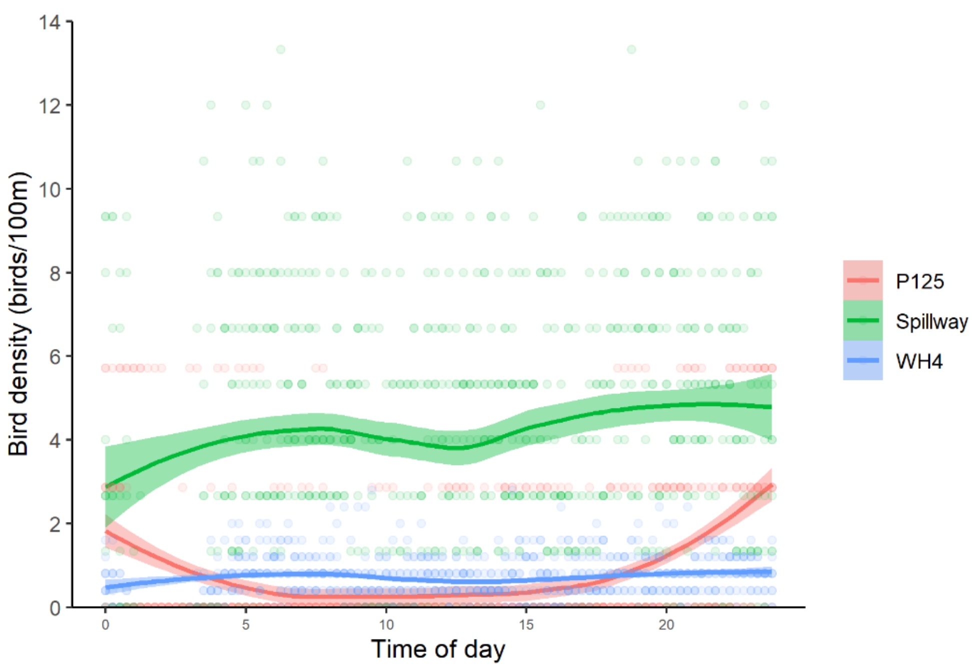


Figure 20. Bird density (birds/100 m) at the P125, WH4, and spillway outflows at the Whitehorse Rapids Generating Station over the diel period from June 28 - July 7, 2023 as observed in wildlife cameras.



2.4.5. Discussion

2.4.5.1. Fish Predators

Angling from June 28 – July 7, 2023 along the Yukon River suggests that there is a low abundance of fish predators in the outflow areas at the WRGS. Only one Arctic Grayling was captured across the outflows of the spillway, WH4, P125, and the combined tailrace across 4.6 rod hours. Ecofish technical staff observed fish surfacing downstream of the barrier weir, and in the outflow of WH4 upstream of the fish screens (including the sighting of one sub-adult Arctic Grayling). It should be noted that although few fish were captured in the outflow of WH4, sonar data suggests some larger predatory fish may be entrained into this outflow area. While mortality is likely for larger fish travelling through the turbines, some may survive and may occur in the WH4 outflow area given the small spacing of the fish screens located downstream which prohibit the movement of larger fish.

Predatory fish were more frequently captured downstream of the tailrace and in control areas up and downstream of the dam. This suggests that areas immediately downstream of the dam (where entrainment has the greatest effect on juvenile fish) support fewer predators than other areas in the Yukon River. The most common predators encountered during angling were Northern Pike and Arctic Grayling. Invertebrates were identified as the predominant food item for Arctic Grayling during our sampling, though one grayling had consumed a small, unidentifiable fish. Although only two Northern Pike had prey within their stomach, in both cases prey were small fish, suggesting that pike may be the predator of greatest relevance to salmon within the study area. Interestingly, most pike had empty stomachs, which suggests they had not fed within the last 48 hours (Seaburg and Moyle 1964). These results are not overly surprising given previous work conducted in interior rivers of Alaska that found Arctic grayling, burbot (*Lota lota*), and northern pike (*Esox lucius*) consumed small numbers of Chinook salmon (Schoen *et al.* 2022). In contrast, in the Chilko Watershed of B.C., it was not uncommon to find Bull trout (*Salvelinus confluentus*) with over 50 sockeye smolt (*Oncorhynchus nerka*) within their stomachs (Furey *et al.* 2015), highlighting what we may have expected had predation been very high in Whitehorse.

Overall, fish predator surveys suggest that entrainment is not resulting in elevated predation pressure in the tailrace relative to control areas, though our sample size remained low due to low fish densities in the study area. However, it is possible that fish predators only move into these habitats as prey cues becomes available. Given the low abundance of juvenile salmon in the study area, it may not be an advantageous feeding strategy to occupy the turbulent and higher velocity waters of the tailrace for low density of prey. Given the flow conditions experienced by fish passing through the turbines (Section 2.3.4.1), it is expected fish would have reduced capacity to respond to predators. Nonetheless, as hypothesized by Nick DeGraff, predation on salmon may be more of a factor in other areas of their journey (i.e., M'Clintock Bay and Lake Laberge) where fish predators would be more abundant. If further studies of the predatory fish community were conducted in the future, it may be valuable to deploy passive capture techniques such as gill netting, or active capture techniques such as seine netting or electrofishing that may have fewer biases than angling (which may tend to capture the hungriest fish with empty stomachs).

2.4.5.2. Avian Predators

Findings from both the community bird surveys and the wildlife cameras highlight that the outflows at the dam provide suitable habitat for numerous bird species, particularly gull *spp*. The canyon areas characterizing the outflow of WH4 and the spillway appear to host the greatest density of gulls around the dam. Further, the roof of the WH4 powerhouse typically had dozens of gulls roosting and raising young. Based on the community bird surveys, bird abundance in the study area was highly variable week to week, though there was a peak in abundance in mid-late June. Findings from the wildlife cameras also tended to align with higher density of birds near the end of June which then decreased into early July (generally when salmon are out-migrating). However, seasonal patterns in bird abundance were similar across all sites (whether at the dam or not), and for both fish-eating and non-fish-eating birds, suggesting some other environmental parameter was driving abundance along our survey zones rather than salmon abundance and entrainment. As reported by Bob van Dijken during a bird survey on July 22, 2023, "[we are in…] a summer lull of bird sightings, bird calls". It was observed during community bird surveys that bird presence in Zones 1 and 2 (i.e., Robert Service Way area) appeared to be impacted by flows in the river and the degree to which island habitat was available.

It should also be noted that bird density was greatest in the late evenings, which corresponded to a daily peak in fish activity on the sonar, though fish also tended to have higher activity during the night/early mornings when bird density remained lower. Feeding was only occasionally observed during community bird surveys, by wildlife cameras, and by Ecofish staff while on site. Given that gulls are not diving birds, they would likely only fish in the top 1 m or so of the water column, and would therefore likely pick off only very disoriented or injured fish. However, Brandy Mayes, KDFN, saw a feeding frenzy around the hatchery on July 10, 2023 (Mayes, pers. comm. 2023). Further, a CAFN Elder has consistently observed gulls and other birds feeding voraciously the same time each year (~June 20) on what appears to be small fish in the Yukon River along their property in Whitehorse (Mayes, pers. comm. 2023). Lars Jessup (local biologist) previously worked at the fish ladder and reported that that there was once many more birds (potentially several hundreds) around the dam and that they used to walk down to the river and watch them fish (Jessup, pers. comm. 2023).

Contemporary observations of birds around the WRGS during 2023 surveys suggest that feeding was uncommon and is unlikely to have biologically meaningful impacts to the population. However, although bird predation appears to be low right now and unrelated to salmon presence, there may be a functional response to salmon density in which birds feed disproportionately on salmon as they become more abundant (i.e., Type III response). This functional response is possible and likely for animals like gulls that are generalists, experience high conspecific competition, and are capable of quickly learning from conspecifics and responding to prey as their density increases (Greig *et al.* 1983). Despite no evidence of increased susceptibility to predation currently, the Sensor Fish provided a flow quality classification of "poor" for WH3 and WH4. Poor conditions indicate turbulent water where fish may be disoriented upon entering the tailrace such that they may be at higher risk of predation (Deng, pers. comm. 2023). We hypothesize this heightened risk of predation could be of greater importance during high abundance years. Current bird surveys have established an important baseline that could be referred to in the future if further surveys were warranted and undertaken.

2.5. Empirical Study - TDG Monitoring

2.5.1. Background

Total dissolved gas (TDG) supersaturation is a physical phenomenon whereby the amount of atmospheric gases dissolved in water is greater than the amount of gas dissolved in water that is in equilibrium with the barometric pressure at the water surface. TDG supersaturation can be generated downstream of hydropower dams due to various hydropower related activities, but particularly the spilling of excess water and the subsequent plunging of water in a plunge pool, where entrained air may become dissolved in water at elevated hydrostatic pressure (Weitkamp *et al.* 1980), leading to TDG supersaturation in the downstream river water (Li *et al.* 2009). In specific circumstances, turbine operations can contribute to TDG supersaturation that can arise from certain operations that are occasionally used (air injection and synchronous condensing). Regardless of the source, the corresponding TDG supersaturation can have adverse impacts on fish, leading to Gas Bubble Trauma (GBT), though the severity of impacts is dependent on the species, life stage, fish depth, supersaturation level, and duration of exposure (discussed in Algera *et al.* 2020). In surface waters such as the study area where fish have access to habitats >1 m deep, TGP >110% presents a risk of GBT and mortality to fish (lower levels of TGP may pose a risk in shallower habitats, e.g., hatchery environments) (Pleizier *et al.* et al. 2020). The potential for TDG supersaturation to influence fish downstream of the WRGS was assessed in 1997 and 1998 (Antcliffe and Von Finster 1999).

2.5.2. Objective

The objective of this work was to evaluate total gas pressure (TGP) downstream of the WRGS during the expected juvenile Chinook Salmon outmigration period. Field measurements are compared to biological TDG thresholds known to cause adverse impacts on fish species (with emphasis on juvenile Chinook Salmon). Measurements focused on the spillway.

2.5.3. Methods

Total Gas Pressure loggers were deployed upstream and downstream of presumed sources of potential TDG supersaturation (i.e., spillway and turbines) using a control-impact study design. Loggers were deployed concurrently for several hours (the duration of the battery life), taking measurements every 15 mins (one in the reservoir Schwatka Lake, and one adjacent to the spillway). Logging was undertaken multiple times at the spillway throughout the study period to confirm logger measurements. To evaluate TGP further downstream, a logger was deployed ~ 475 m downstream in the tailrace and spot measurements were taken at various locations downstream of key project infrastructure (see Map 2). For further comparison, spot measurements were taken on the Yukon River at various locations several km away from the dam.

2.5.3.1. Data and Statistical Analysis

Data were summarized and presented using R Statistical Software and ArcGIS. Plots were developed in ggplot2 and present the default LOESS smooth line. At the time of draft completion, data from one of the loggers could not be downloaded. Efforts are being made to obtain the data before final report completion. It is not expected that these additional data would change the conclusions.

Total Gas Pressure measurements recorded at the WRGS were compared to injury and mortality models developed for Chinook Salmon exposed to supersaturated TDG in laboratory studies (i.e., Pleizer *et al.* 2020). The following equations were used to estimate the total durations (hours) of exposure required to reach the expected time to external GBT symptoms for a given TDG level; $\text{eGBT}=\exp^{(12.86-0.11(\%\text{TDG})+\text{species})}$

Where *TDG* in the equation above is TDG measured in percent saturation and *species* is a species-specific constant (3.35 was used as per Pleizer *et al.* (2020), corresponding to Chinook Salmon).

2.5.4. Results

Total Gas Pressure was monitored over 26 times across 20 different locations, extending from the Wolf Creek area to McIntyre Creek. In addition, data were collected downstream of the dam over multiple periods of several hours. Total Gas Pressure varied by site (Map 2), with the highest values observed immediately downstream of the spillway. Total Gas Pressure varied from 108% to 116% immediately downstream of the spillway, with a mean of 112%. In contrast, in the reservoir immediately upstream of the dam (sites unimpacted by the spillway), values were lower on average (105%). Values tended to be lower on the Yukon River upstream of the dam, though a value of 110% was recorded in the Yukon River upstream of Schwatka Lake. Spot measurements did not reveal elevated TDG downstream of either turbine outflow.

Spot measurements in the tailrace suggest that TGP values are higher on river right compared to river left (Map 2). For example, on July 6, 2023, various sites were compared that were directly across from each other adjacent to opposite banks, downstream of the Millennium Trail footbridge. In each case, sites on river right had higher TGP levels. This is likely due to variable mixing of spillway water (higher TDG) and turbine water (lower TDG) across the river channel. Spot measurements around the Walmart area (108%) and at McIntyre Creek (107%) were higher than background levels observed upstream of the dam. TGP logged at the spillway appears to be positively correlated with discharge through the spillway (Figure 21). TGP measurements were undertaken downstream of the spillway from 124 to 204 m^3/s through the spillway.

To evaluate the potential biological impacts of TDG supersaturation on Chinook Salmon, we incorporated the highest measurement recorded at the spillway (116%) into species-specific injury and mortality models following exposure to TDG (Pleizer *et al.* 2020). Based on these models, it was estimated that it would take 31.5 hours of continuous exposure to 116% TDG to yield external symptoms of GBT for Chinook Salmon. It was also estimated it would take ~100 hours of exposure to 116% TDG to yield 10% mortality.

Yukon Energy Hatchery Assessment

Total Gas Pressure Monitoring Stations

Legend

TGP (%)

- 105
- 106
- 107
- 108 - 109
- 110 - 115

MAP SHOULD NOT BE USED FOR LEGAL OR NAVIGATIONAL PURPOSES

0 0.5 1 2 3 Km

Scale: 1:70,000

NO.	DATE	REVISION	BY
1	2023-07-19	1499_YUK_TGP_5920_20230719	BRM
2			
3			
4			
5			

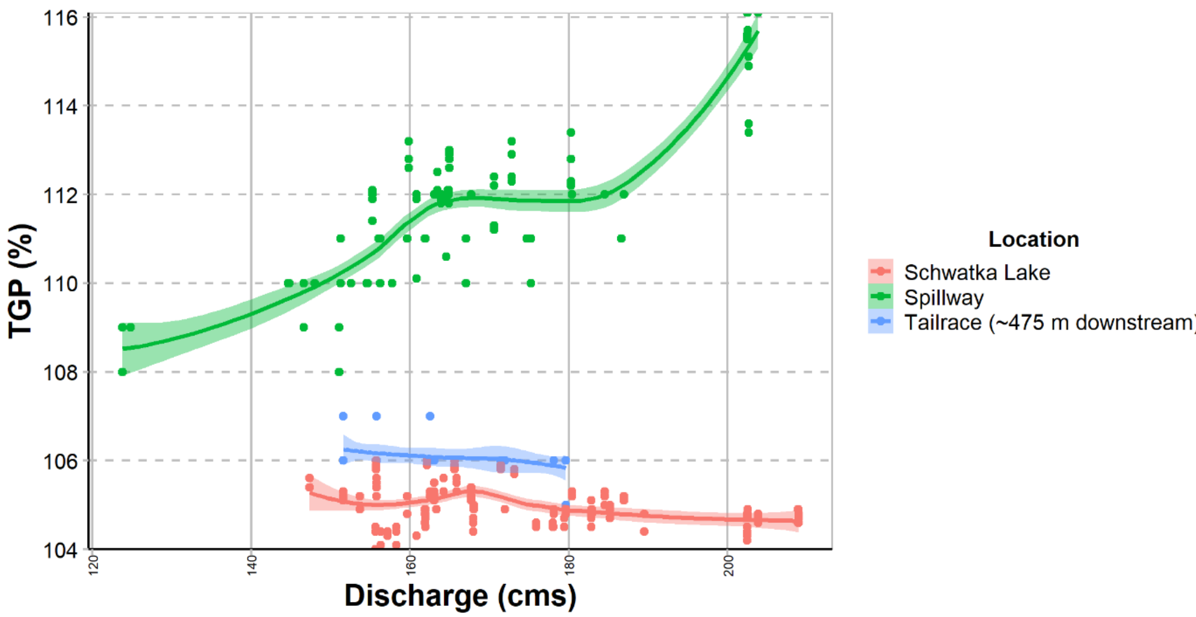
Date Saved: 2023-07-19
Coordinate System: NAD 1983 UTM Zone 8N

ECOFISH RESEARCH

Map 2

Path: M:\Projects-Active\1499 Yukon Energy\MXD\Fisheries\1499_YUK_TGP_5920_20230719.mxd

Figure 21. Total Gas Pressure (%) measured immediately downstream of the spillway (see Map 2) and in the tailrace ~475 m downstream of the spillway (river left) in relation to hourly discharge.



2.5.5. Discussion

Total Gas Pressure loggers were deployed at the WRGS while the plant was actively spilling water during the period when Chinook Salmon are expected to be actively outmigrating. Total Gas Pressure was found to be highest immediately downstream of the spillway, decreased with distance from the spillway, and was positively correlated with discharge immediately downstream of the spillway. We compared TGP levels observed at the WRGS to the Canadian Council of Ministers of the Environment guidelines (CCME 1999), the BC Water Quality Guidelines (Fidler and Miller 1997) and the U.S. EPA water quality criteria (NAS/NAE 1973) for TGP, which each recommend that TGP should be < 110% to protect fish (e.g., avoid GBT) in natural waters ≥1 m deep. Immediately downstream, of the spillway, TGP averaged 112%, highlighting the potential for impacts to fish in that area. Although values further downstream of the spillway were elevated above background levels, only 1 of 16 measurements were >110%. In general, the low height of the dam and the deep intakes of the spillway reduce the likelihood of water plunging to depth, leading to gas supersaturation.

The TDG measurements collected in 1997 and 1998 downstream of the WRGS provide a valuable point of comparison to contemporary measurements taken in 2023 (Antcliffe and Von Finster 1999). Measurements were taken during the last week of August when spill tends to be highest throughout the year, and the sampling areas generally overlapped with the sampling areas studied by Ecofish in 2023 (i.e., from the dam to McIntyre Creek). Antcliffe and Von Finster (1999) recorded higher TDG levels at the spillway in 1997 (113.5%) but lower levels in 1998 (103.6%) than we observed in 2023.

However, Yukon River discharge was higher during measurements taken in 1997 (471-497 m^3/s) and 1998 (~400 m^3/s) than 2023 (365-398 m^3/s). There were several similar patterns in the data between the two sets of studies. Both studies did not find any evidence of elevated TDG associated with the turbine outflows, and both studies found that water from the spillways and turbines did not mix completely for some distance downstream. For instance, in 1997 and 1998 it was found that TDG remained low along Robert Service Way. This is a potentially important finding given that there is Chinook Salmon spawning habitat along Robert Service Way. Similar patterns in TDG levels were observed by EDI during three days of sampling in the same area on August 4th, 6th, and 11th, 2023 (Schonewille, pers. comm. 2023). Measurements around the spillway did not exceed 110% during their sampling.

Physiological effects of supersaturated gas are generally only observed at levels above the acute threshold (i.e., >110%; CCME 1999). As fish pass through the spillway, they are likely temporarily exposed to supersaturated water beyond this threshold. However, given that supersaturated TGP (>110%) was localized to immediately downstream of the spillway, and that fish likely pass through that localized area quickly, it is unlikely they would be exposed to elevated TDG (~116%) for the ~32 hour exposure period that would be required to develop external symptoms of GBT (Pleizer *et al.* 2020). Fish can rapidly recover from physiological effects of TGP supersaturation when TGP levels decrease, allowing them to be intermittently exposed to elevated TGP without developing long-term symptoms of GBT (Lutz *et al.* 1993). Further, the impacts of TDG supersaturation decrease with increasing water depth (by providing compensating pressures), allowing fish to recover quickly from GBT if they can swim to sufficient depth. It should also be noted that resident fish in the Whitehorse area may have chronic exposure to elevated levels of TDG that remain <110%. Values less than 110% can be detrimental over very long exposure periods (i.e., thousands of hours; Pleizer *et al.* 2020), though impacts would only occur if fish consistently remained in these chronic exposure areas. As described above, it is likely fish would move to compensatory depths or areas of lower TGP frequently enough to avoid any chronic impacts of exposure.

The positive correlation between spillway discharge and TGP levels (Figure 21) immediately downstream of the spillway highlights the need for monitoring at the highest discharge levels of ecological relevance to juvenile Chinook Salmon and resident fish in the study area. Our study conducted most measurements at the spillway during spillway discharges of 124–204 m^3/s. Notably, on July 6 onwards, discharge increased to ~300 m^3/s and remained at an average of 256 m^3/s until July 18. The average spillway discharge during the expected salmon outmigration (i.e., June 28 - July 7) since 2006 has been 209 m^3/s and has been as high as 530 m^3/s (recorded on July 11, 2021). Given the close relationship between discharge and TGP (Figure 21), it seems likely that TGP levels measured during the 2023 field study may be slightly lower than would typically be experienced during the salmon outmigration period, though higher spillway discharges would have been captured during the 1997 and 1998 measurement period. Although our study did not continuously log TGP during peak spillway discharge, spot measurements were collected at several locations downstream while discharge was >275 m^3/s. One of these measurements was 110% close to the Millennium footbridge, which is greater than the guideline values recommended for fish.

As part of the predator surveys, eight angled fish (pike and grayling) were captured at this location at the time the elevated measurement was made and elevated discharge occurred at the spillway. Anglers did not observe any sub-dermal gas bubbles in captured fish upon internal and external examination (a common sign of GBT). Further, acoustic tagging and carcass surveys of Chinook Salmon occurred downstream of the dam from 2018–2022, and although evaluation of GBT was not the intent of these studies, researchers did not observe symptoms of GBT in the >200 salmon handled. Given that there is high angling pressure downstream of the dam in the Whitehorse area, it seems likely the fishing community would have noticed external symptoms of GBT (i.e., gas bubbles under the skin) if it were a prevalent issue.

Overall, our measurements and those of Antcliffe and Von Finster (1998) suggest that elevated TGP values (i.e., >110%) are primarily restricted to the spillway area and the tailrace downstream (within ~750 m of the spillway). Further, elevated values in the tailrace are uncommon, and are likely restricted to river right when present. Values further downstream have remained below the acute threshold level during measurements across years. As such, we do not predict long-term consequences of TDG on juvenile salmon migrating through the WRGS. Risks to resident fish are also likely to be low given that shallow, rearing habitat is poor in the tailrace area where TDG can be elevated. As such, we would not expect fish to be occupying the most sensitive habitat with the highest TGP. Further, resident fish likely swim to greater depths throughout the day (e.g., >1 m), which would compensate for any exposure to TDG <110% but greater than background levels. Although the data provided by Antcliffe and Von Finster (1999) and Ecofish have provided key insights into TDG supersaturation, monitoring has not occurred at the highest spillway discharges (>500 m^3/s) such as those observed in 2021. It remains possible that, during such high discharge conditions, impacts to fish from TDG supersaturation could be greater than indicated by the measurements recorded to date at lower discharge.

3. SYNTHESIS - OVERALL MORTALITY ESTIMATE

Three estimates of mortality were provided for Chinook Salmon migrating through the WRGS; a desktop review model (Franke *et al.* 1997), a literature review, and a Sensor Fish estimate. The desktop model only accounted for blade strike mortality, while the Sensor Fish and literature review considered all/most sources of mortality. Blade strike is typically the leading cause of mortality during passage at lower head dams such as the WRGS, though the blade strike estimates differed between the model and the Sensor Fish (Table 10). Sensor Fish estimates of blade strike mortality were substantially higher than that predicted by the model (Franke *et al.* 1997), particularly for WH4. The higher strike estimates produced by Sensor Fish at the WRGS is consistent with that observed previously at other hydropower stations (Deng *et al.* 2011). Given that the Sensor Fish collected data specific to the Whitehorse Rapids Generating Station, we consider that data to provide a more representative estimate of fish mortality in comparison to the desktop assessment. However, the desktop assessment provides a useful indication on how mortality rates change throughout the season (due to changes in fish size and operation). As such, our mortality estimate incorporates the general seasonal trends from the desktop assessment, using the Sensor Fish data to scale the mortality rates given that the desktop assessment underestimated mortality.

Table 10. Comparison of blade strike mortality estimates from the desktop review strike model (Franke *et al.* 1997) and that estimated from Sensor Fish strike/collision events in the runner region of each turbine using the conditions experienced by Chinook Salmon during Sensor Fish deployments on July 2, July 4, and July 5, 2023.

Date	Turbine	Discharge (m^3/s)	Head (m)	Blade strike mortality (%) – 90 mm Chinook (% of individuals entering turbine)	
				Strike model	Sensor Fish
July 2, 2023	WH3	46	18.3	15.2	25
July 4/5, 2023	WH4	126	17.4	12.5	36

Overall mortality estimates are provided that combine the modelled daily entrainment rates (

Figure 7) and corresponding daily mortality rates associated with each downstream passage (using 2022 operational data). Daily mortality rates were calculated by adjusting the daily strike mortality rate curves developed during the desktop review (Figure 8) by the ratio between the Sensor Fish mortality estimate and strike model mortality estimate from Table 10. Essentially, the mortality curves in Figure 8 were increased ~1.6 fold for WH1, WH2, and WH3 and ~2.9 fold for WH4 for blade strike. Given the similar design of turbines WH1-WH3, the adjustment applied to WH3 was similarly applied to those turbines. Additionally, the other sources of mortality calculated by the Sensor Fish (barotrauma and shear) were added to daily mortality rates. Accounting for differences in strike mortality throughout the season is important given the influence of fish size on strike likelihood and that migration timing influences the size of fish at passage (Section 2.1.4.5).

Mortality of route = Proportion of population entering route × route-specific mortality rate.

Based on the assumptions and analyses completed above (and those described in Section 2.1), it was estimated that 26.0% of age-0 and 33.6% of age-1 wild juveniles are killed during passage through the project across all routes (spillway, turbines). Although larger age-1 juveniles have higher mortality during passage, it was estimated that more age-1 juveniles would use the spillway given their propensity for mid-channel habitat. It was estimated that 23.0% of hatchery juveniles would succumb to mortality during passage through the project. This estimate reflects the intermediate size of hatchery juveniles, and assumption that they would behave like age-1 juveniles (i.e., move in proportion to the amount of discharge and therefore use the spillway more often). Little information exists to evaluate the proportion of juveniles moving past the dam as either age-0 or age-1. However, using the trapping data at the dam from Brown *et al.* (1976), and the corresponding spawner counts from the preceding two years, it can be estimated that 13% of wild juveniles migrate downstream as age-1 fish, as such, the overall mortality rate for the wild juvenile population would be closer to that of age-0 wild fish (i.e., 27.0% overall). Mortality associated with impingement (i.e., the trapping of fish against screens/trash racks; Barnthouse 2013) was not quantified here but was expected to be low given the small size of juvenile salmon relative to screen dimensions. In addition to mortality, a substantial additional proportion of the population would succumb to non-lethal injuries.

Brown *et al.* (1976) reported a 2% fry loss was observed in 1960 due to the turbines and that 16% of smolts were lost in 1973. While the details of these studies are unavailable, it is likely they involved a netting program in the tailrace based on limited details in Brown *et al.* (1976). Primary differences between our estimate and the historic estimates likely relate to the construction of WH4 (increasing turbine mortalities) and assessment methods. Based on our literature review of similar-size facilities, juvenile Chinook Salmon mortality appears to be higher in Whitehorse than the typical values observed elsewhere (Algera *et al.* 2020). While the literature review is general and not specific to Whitehorse, it would have produced an estimated mortality rate for juvenile Chinook Salmon in Whitehorse of 4.4%. Each independent mortality estimate is provided in Appendix A.

4. MITIGATION CONSIDERATIONS

Various approaches exist to reduce entrainment and mortality during downstream passage, including physical modifications, operational changes, and behavioural guidance. Below we describe a few examples as to how this can be achieved. To reduce entrainment, operational changes could include adjusting discharge during the salmon outmigration period to increase the likelihood of salmon passing through the least harmful routes. In general, more discharge will increase the proportion of fish using the route. Fish behaviour can also be influenced to try and guide fish away from potentially harmful passage routes. This has been attempted using screens, flow deflectors, lights, electricity, and bubble curtains with some success. Construction of “fish friendly” bypass systems has also aided downstream migration of juvenile fish at many facilities (Johnson and Dauble 2006). Additional details on juvenile Chinook Salmon ecology in the reservoir would help better inform these mitigation strategies.

Cada *et al.* (1997) listed the following criteria for minimizing strike-related injury: minimizing the number of blades or amount of blade leading edge, maximizing the open space between blades and other structures, using blunt leading edges instead of sharp ones, minimizing blade speed, and minimizing gaps between fixed and moving parts. Various “fish-friendly” turbine options exist including Alden turbines and minimal gap runner turbines (Cade 2001; Purece and Corlan 2021).

5. CONCLUSIONS AND CONSIDERATIONS FOR FUTURE WORK

The entrainment study provided overall estimates of mortality for juvenile Chinook Salmon during downstream passage through the WRGS, bringing together findings from a desktop study and on-site pilot field studies. Exact mortality estimates were provided, but these were based on a combination of strong and weak quantitative evidence, and subjective decisions made using reasonable realism erring on the side of caution where no information was available. Subjective decisions/assumptions are outlined in the various sections, but primarily pertain to juvenile Chinook Salmon ecology (and the corresponding influence on entrainment route and timing) and entrainment through intakes not assessed by the Sensor Fish. These assumptions introduce uncertainties in our mortality estimates. A sensitivity analysis (alternate models representing the range of values for each parameter) could be completed to help communicate the range of possible mortality rates based on the limited available data. It would be beneficial to reduce data gaps before attempting a sensitivity analysis.

Despite uncertainties in our quantitative estimates, key patterns arose from individual study components and through the integration of information across study components. For instance, juvenile Chinook Salmon density was low during our study period. This is apparent from the lack of juvenile salmon in the diets of fish predators, lack of bird feeding behaviours, lack of salmon detections on the sonar, and lack of juvenile salmon observations through the fishway by ladder staff (Sayer, pers. comm. 2023). The desktop assessment (relying on flow data) and the sonar data suggested that fish downstream movements are highest at the spillway, followed by WH4, and P125, though historic sampling found most juvenile salmon used the turbines (Hryciuk 1973). Further sampling (e.g., sonar) would help refine entrainment route estimates which would influence the overall mortality estimate. The Sensor Fish study revealed that passage conditions are more harmful to Chinook Salmon in WH4 than WH3 and both routes lead to mortality of ≥25% of passing individuals. We have less knowledge on passage conditions through WH1 and WH2, though it seems likely conditions are worse than WH3 based on the desktop assessment. We were unable to assess the spillway with the Sensor Fish because the loggers were broken or lost during the turbine trials prior to attempting assessment at the spillway. Our desktop assessment, and the deep intakes at the spillway suggest mortality associated with the spillway route is likely minimal (<1%), though this remains uncertain and further assessment is warranted. Additionally, although the spillway was associated with some concerning TDG levels (i.e., >110%), based on the localized area impacted, depth of the Yukon River, and ecology of local fish populations, TDG supersaturation likely has negligible effects on the local fish community. Finally, entrainment does not appear to be increasing susceptibility of juvenile salmon to predation, though this may be a function of low density, as predators may not key in on low density prey items.

Although the relative importance of the limiting factors affecting the recovery of the population are uncertain, it is clear that entrainment is just one of many factors affecting this population. Given the widespread declines of Chinook Salmon throughout the Yukon River (and across the range of Chinook Salmon), it seems likely broader ecosystem processes are the principal driver of declines (e.g., marine ecosystem processes; Cunningham *et al.* 2018). Nonetheless, given the low abundance of the population, it seems likely that mitigating any excess mortality through the WRGS would be beneficial to recovery of the population.

Based on the findings of our study and existing data gaps, we suggest the following be considered for future work:

- Increase knowledge of juvenile Chinook Salmon ecology passing through the WRGS, including confirming the timing of salmon outmigration and route choice. Longer-term sonar deployments would be useful for providing this information. Sonar could be deployed continuously or intermittently from May 1 to July 31 to ensure the periods of highest likelihood are assessed. Information on migration timing could also be gleaned from camera observations in the fish ladder, though this would require earlier deployment of the camera and scoring of the videos which may be hard to automate. Minnow trapping could be attempted, though low fish densities would likely make this approach ineffective. Understanding current entrainment routes may be important for future evaluation of any mitigation measures aimed at guiding fish towards safer passage routes.
- The useful application of Sensor Fish was confirmed for the WRGS at WH3 and WH4. To provide better mortality estimates, additional Sensor Fish could be deployed through each intake (particularly those intakes not assessed in 2023). Sensor Fish are also particularly useful for evaluating relative harm, and could be used to assess the effectiveness of potential design and operational changes.
- Predator surveys are likely not needed moving forward unless a substantial Chinook Salmon run occurs and increases juvenile salmon densities.
- Additional TGP monitoring could be useful during spill periods that exceed 500 m^3/s. These conditions may not occur every year but have been observed in recent years. Monitoring should be undertaken on both sides of the river and should extend to at least McIntyre Creek (or further if TDG remains elevated).
- The entrainment assessment could be expanded to consider impacts to the resident fish community.

6. CLOSURE

This report includes information on the entrainment of juvenile Chinook Salmon through the Whitehorse Rapids Generating Station based on desktop review and pilot field studies. This information is critical for evaluation of entrainment effects to the Chinook Salmon population and will provide important guidance for future study of entrainment at the WRGS. We thank the many individuals who provided expertise and field support during the completion of this project.

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APPENDICES

Appendix A. Various Estimates for Overall Mortality Based on Different Sources and Approaches of Deriving the Estimate. Although Uncertainty Exists For All Estimates, The Desktop Model + Sensor Fish Estimate Provides The Most Recent Site-Specific Estimate

Source	General Approach	Life Stage	Overall Mortality Estimate
Desktop Model + Sensor Fish	As presented in this report prepared by Ecofish Research.	Age-0 Wild	26.0%
		Age-1 Wild	33.6%
		Age-0 Hatchery	23.0%
Literature Review	Reviewed a recent systematic review (Algera *et al*. 2020) to identify similar facilities to the WRGS and compare juvenile Chinook Salmon mortality rates for those facilities. We similarly used the entrainment rates based on discharge to estimate overall mortality for this data source.	Juvenile Chinook	4.4%
Brown *et al*. 1976	Historic estimates of turbine mortality from two assessments completed in 1960 (fry) and 1973 (smolt) prior to construction of WH4.	Age-0 Wild	2%
		Age-1 Wild	16%