Assessing the Fate of Returning upper Yukon River Chinook Salmon - 2020

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Highlights

- Fall back (or over shoot) after passing the Whitehorse Hydro Plant was substantial (31%) compared to previous years of study
- Many fish migrating into Michie Creek ventured to the uppermost reaches of the creek and even Michie Lake
- Recovery of a tagged female carcass revealed successful egg deposition in the Yukon River mainstem above the WHP

Abstract

A 62-receiver acoustic telemetry array was deployed throughout the upper Yukon River and supporting tributaries to identify spawning locations of Chinook Salmon (*Oncorhynchus tshawytscha*) upstream of Lake Laberge, YT. Fish of both wild and hatchery origin were gastrically implanted with acoustic/radio transmitters at the Whitehorse Rapids Fishladder viewing chamber or downstream via gill net capture to evaluate passage success and subsequent spawning locations. A total of 26 tagged fish passed upstream of the Whitehorse Hydro Plant with 65% terminating in the Michie Creek - M'Clintock River system, and 31% traveling back through the WHP spillway and remaining downstream. Two of these salmon that returned back downstream (one wild male and female) then migrated up the Takhini River. In the Yukon River, 5 gill-netted fish approached the Whitehorse Hydro Plant, none of which successfully passed the facility. Of four fish that reached the fish ladder entrance, two actually entered, and one reached the viewing chamber before returning downstream. Findings from 2020 highlight interesting differences in terminal locations of tagged fish compared to previous years of tagging and highlight the need for research on inter-annual differences in behaviour.

Introduction

Upper Yukon River Chinook Salmon (*Oncorhynchus tshawytscha*) populations (defined for the purpose of this study as fish that terminate in the mainstem Yukon River or its tributaries upstream of the Teslin River) have experienced similar declines to other Yukon River populations over the past 25 years. Greater declines probably occurred much earlier in the past century, possibly due to overfishing associated with human population increases in the region in the wake of the Klondike Gold Rush (Gilbert and O'Malley 1921; von Finster pers. comm.). Commercial fishing early in the 20th century in the lower reaches of the Yukon River and near the river mouth are thought to have contributed greatly to declines (Gilbert and O'Malley 1921). Traditional knowledge and historical accounts indicate that many Chinook Salmon were harvested annually in the Michie Creek - M'Clintock River system (Cox 1997, Herkes, 2015). It was alleged that Indigenous families would harvest 500 fish a season (Brown et al. 1976). Families would dry and smoke salmon along the banks of the M'Clintock River, and some caches of dried salmon were large enough to last through winter (Herkes, 2015). In 1957, the Chief Biologist for the Pacific Area wrote to the Deputy Minister of Fisheries that "as many as 10,000 spring salmon were taken in the M'Clintock River some years ago" (Cox 1997). Similarly, a fishery officer recorded that as many as 25 families once harvested 300-400 fish each there, based on an interview with Johnny Joe (Cox 1997). However, by the mid-1950s, annual harvests appear to have declined to a few hundred fish or less per year, and there was much debate about whether previous versions of the Lewes Dam had contributed to this decline by acting as a barrier to migration (Cox 1997).

The current spawning and rearing capacity of the primary spawning grounds upstream of Whitehorse, the Michie Creek – M'Clintock River system, is unknown, though it is expected rearing capacity is not limited as juveniles can migrate downstream to access abundant rearing habitat in the Yukon River (von Finster pers. comm). Returns counted at the Whitehorse Rapids Fishladder (ladder) have averaged ~950 since the ladder was constructed in 1959. Initial returns were ~1100 for the first four years, then declined until the late 1980's when returning hatchery-reared fish began to supplement wild returns (W. R. Ricks Consulting and DNA Enterprises 1996). In 2019 and 2020, returns to the ladder were the lowest on record since the hatchery began over three decades prior. The fate of a small proportion of Chinook Salmon after they pass the ladder is uncertain. Previous radio telemetry studies (Cleugh and Russel 1980; Matthews 1999a) showed that 77% to 88% of these Chinook Salmon traveled to the Michie Creek - M'Clintock River system, though sample sizes were small. Contemporarily, the majority of Chinook Salmon migrating upstream of the WHP are believed to spawn in Michie Creek, particularly between Michie Lake and Byng Creek (de Graff 2015); although, the M'Clintock River upstream of Michie Creek has been identified as a historically important spawning location as well (Cox 1997; Herkes 2015). Confirming where Chinook Salmon spawn in the Michie Creek - M'Clintock River system will inform further efforts to recover the stock. The fate of Chinook Salmon that pass the ladder but do not terminate in the Michie Creek - M'Clintock River system is only partially known. Fish spawn in Wolf Creek and may spawn in other unknown locations between the Whitehorse Hydro Plant (WHP) and the Southern Lakes, or they may expire before reaching any spawning ground. Determining the terminal location of all

Chinook Salmon migrating upstream of the WHP will help identify management actions for restoring the habitat and vitality of this stock.

The role of the WHP as a barrier to Chinook Salmon migration is largely unknown. No formal reports of run size exist prior to the construction of the WHP in 1958, making it difficult to assess how the population was affected by its construction. The population has been partially maintained by the Whitehorse Rapids Fish Hatchery, built in 1984 in an effort to mitigate increased Chinook Salmon fry loss as a result of a fourth turbine being constructed at the WHP (Yukon Energy Corporation 2011). In contrast with the exact records of Chinook Salmon migrating through the WHP, the portion that spawn or expire downstream of the WHP is less well studied. However, an average of 26 redds was observed near Robert Service Way from 1998-2002 (Access Consulting Group & Yukon Engineering Services 2002).

The Whitehorse Rapids Fishladder is a 366 m vertical slot ladder that rises 18 m. Other studies on vertical slot ladders have shown low passage efficiency (ability to swim through the ladder) but high attraction efficiency (ability to find the ladder) across all species (Roscoe et al. 2010; Bunt et al. 2012). Little is currently known about the attraction efficiency of the Whitehorse Rapids Fishladder, though operators have control over regulating attraction flows and could adjust this to improve passage. Cleugh and Russel (1980) assessed passage success and delays at the WHP using radio telemetry. Of the 12 fish captured or released downstream of the WHP, 7 passed after delays ranging from 10 hours to 10 days (average 3 days). Similarly, little is known about delays, stress, or energetic costs of fish passage at the WHP. More than five decades of passage and subsequent spawning in the Michie Creek - M'Clintock River system provide clear evidence of individual passage success. However, sub-lethal and population-level consequences of passage are unclear. No definitive studies on this specific site have been conducted but the broader literature on this topic is extensive. Fish ladders over dams can lead to passage delays, increased disease incidence, and higher pre-spawning mortality (Hinch et al. 2012) as well as acute energetic stress (Roscoe et al. 2010) resulting in suppression of reproductive hormones (Kubokawa et al. 2001) and mortality (Burnett et al. 2017). These studies show that most salmon recover relatively quickly from acute energetic stress associated with approaching and ascending fish ladders (Roscoe et al. 2010), yet post-passage mortality has still been observed (Burnett et al. 2017), indicating potential long-term effects of ladder passage.

In 2017, we initiated a research program that would begin to evaluate the effectiveness of the Whitehorse Rapids Fishladder and identify terminal locations of spawning fish. Fish were tagged at the ladder viewing chamber to evaluate passage efficiency of the upper ladder and post-passage migration behaviour. We also began capturing fish by gill net downstream of the WHP to assess movement as fish approach the fishway.

This project has two primary goals. The first is to identify depleted stocks that are candidates for restoration, along with potential spawning restoration sites. Specific objectives associated with this goal are to assess:

1) Where salmon spawn in the Michie Creek - M'Clintock River system;

2) What other terminal locations exist upstream of Lake Laberge aside from the Takhini River, McIntyre Creek, the Yukon River downstream of the WHP, Wolf Creek, and the M'Clintock River.
3) Whether some fish that pass the WHP fail to reach Marsh Lake
4) What proportion of the run spawns in each terminal location.

The second goal is to assess whether challenges associated with passage at the WHP are limiting production of upper Yukon River Chinook Salmon stocks. Specific objectives associated with this goal in 2020 are listed below.

5) What proportion of tagged fish approach and pass the WHP.
6) What sections of the ladder are difficult for fish to navigate.
7) What proportion of fish return downstream after passing the WHP.

Methods

Study Site and Receiver Locations

The 2020 study site consisted of the Yukon River and its tributaries upstream of Lake Laberge, near Whitehorse, YT. Thirty-nine Vemco VR2W receivers were deployed between the confluence of the Yukon and Takhini Rivers and the spawning grounds in the Michie Creek - M'Clintock River system and the Takhini River (Figure 1 and 2; Table 1). Acoustic receivers were generally anchored with a cement block or sandbag and were tethered to a rope extending up to a sub-surface buoy. Receivers were tested prior to deployment and range testing was conducted for a subset of receiver sites in 2018 and 2020 (Appendix 1). Range testing was completed at each site by placing a V16 range test transmitter at set distances from each receiver for a set time interval (generally 12 minutes or 100 potential detections). Around the WHP, three radio receivers were deployed instead of acoustic receivers given their higher performance in acoustically complex environments. Range testing was completed on these receivers to confirm their function. Additionally, Chinook Salmon movement was monitored beyond Marsh Lake and into the Southern Lakes by a 20-receiver array maintained by Environment Yukon for a Lake Trout (*Salvelinus namaycush*) study in the Southern Lakes.

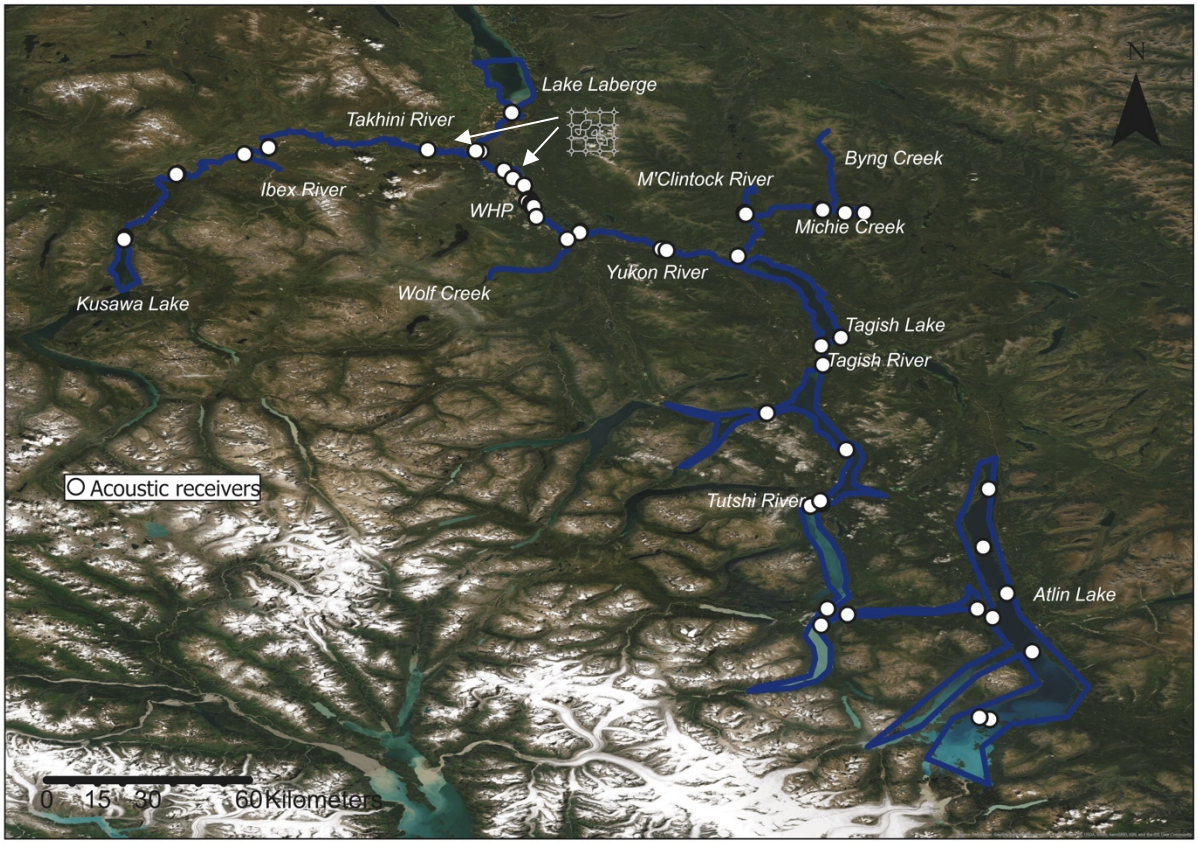

Figure 1: Locations of acoustic and radio receivers deployed in 2020 and the two gill net fishing sites.

Figure 2: Locations of acoustic and radio receivers deployed around the WHP in 2020.

Table 1: Description of 2020 acoustic and radio receiver locations and rationale.

Location	Long, Lat	Rationale
6-11 km upstream of Takhini River fishing sites	60.844790, -135.31953	Similar distances upstream of the Takhini River tagging sites as Schwatka Lake is to the Yukon River tagging site. Confirms that fish travel as far as the WHP after capture and handling in the control river.
Alaska Highway Bridge on the Takhini (km 57)	60.85261, -135.74275	Adult salmon have been seen surfacing between the Alaska Highway bridge and the Ibex River mouth late in the spawning season
Alaska Highway Bridge on the Takhini (km 57)	60.85096, -135.74363	To confirm upstream movement to the most downstream known potential spawning areas and evaluate whether there are effects of capture and handling
Ibex River	60.83314, -135.80833	To detect movement into the Ibex River, a tributary of the Takhini River
Yukon River upstream of Takhini River confluence	60.84043, -135.17846	To detect post-gill-netting fallback at the confluence of the Takhini River and Yukon River
Yukon River downstream of Takhini River confluence	60.845413, -135.185913	To detect post-gill-netting fallback at the confluence of the Takhini River and Yukon River
Takhini River mainstem upstream of Stoney Creek (km 87)	60.779476, -135.9892	Lowermost extent of major spawning areas in the Takhini River downstream of Kusawa Lake
Takhini River mainstem upstream of Stoney Creek (km 87)	60.780947, -135.986029	To detect movement upstream of known primary Takhini River spawning areas
Takhini River at Kusawa Lake	60.61173001, -136.127206	To detect movement into Kusawa Lake
Kusawa Lake	60.606238, -136.128715	To detect movement into Kusawa Lake

Tagging site on the Yukon River	60.790074, -135.11613	To confirm tags are emitting frequencies at the time of tagging
McIntyre Creek	60.768124, -135.092107	To detect movement into a potential spawning area
Industrial boat launch (6 km upstream of tagging site on Yukon River)	60.749805, -135.062065	To detect movement upstream from Yukon River gill netting locations, confirming initial post-tagging recovery
Rotary Park (11 km from tagging site on Yukon River)	60.7126700, -135.049475	To detect movement upstream towards the WHP. Locations further upstream were unsuitable because of river noise or braided channels.
Robert Service Way flats lower (11 km from fishing site on Yukon River)	60.7067819, -135.053803	To detect fish that hold or terminate on the spawning grounds near Robert Service Way
Robert Service Way flats upper (11 km from fishing site on Yukon River)	60.7067819, -135.053803	To detect fish that hold or terminate on the spawning grounds near Robert Service Way
Rotary Centennial Foot Bridge ~300 m downstream of ladder (right)	60.6994300, -135.0419859	To detect fish that approach the WHP
Rotary Centennial Foot Bridge ~350 m downstream of ladder (right)	60.70202, -135.0421	To detect fish that approach the WHP
Rotary Centennial Foot Bridge ~300 m downstream of ladder (left)	60.7003119, -135.043479	To detect fish that approach the WHP
Ladder entrance (radio)	60.696356, -135.041109	To detect fish holding at the ladder entrance (attraction efficiency)
Lower ladder (radio)	60.696877, -135.041014	To detect fish in the lower ladder and to separate attraction/entrance/passage elements of ladder efficiency

Ladder turning basin (radio)	60.696418, -135.040685	To detect progress between the ladder entrance and viewing chamber, and identify a potential holding location
Viewing chamber	60.696418, -135.040685	To confirm detections in or adjacent to the viewing chamber
Schwatka Lake	60.69395, -135.038143	To confirm ladder passage success and timing
Schwatka Lake 2	60.69395, -135.038143	To confirm ladder passage success and timing (duplicate receiver to ensure detection)
Miles Canyon	60.66606, -135.0296	To quantify reservoir passage times
Yukon River mainstem at Wolf Creek	60.6268539, -134.913185	To detect movement in and out of Wolf Creek
Wolf creek entrance	60.62448400, -134.914222	A known spawning tributary
Downstream of Lewes Dam	60.58048, -134.69665	To detect passage at the Lewes Dam
Upstream of Lewes Dam	60.577723, -134.683858	To detect passage at the Lewes Dam
Mouth of the M'Clintock River	60.56174998, -134.492166	To identify entrance to the Michie Creek - M'Clintock River system
M'Clintock River, downstream of confluence with Michie Creek	60.67360, -134.4732	To identify movement direction at the confluence of the M'Clintock River and Michie Creek
M'Clintock River, upstream of confluence with Michie Creek	60.676778, -134.475	To identify movement direction at the confluence of the M'Clintock River and Michie Creek
Michie Creek, upstream of confluence with M'Clintock River	60.67375, -134.471361	To identify movement direction at the confluence of the M'Clintock River and Michie Creek

Michie Creek, downstream of confluence with Byng Creek	60.685083, -134.270167	To identify movement direction at the confluence of Michie and Byng creeks
Byng Creek	59.999984, -135.9999	To identify movement direction at the confluence of Michie and Byng creeks
Michie Creek, upstream of confluence with Byng Creek	60.684528, -134.2665	To identify movement direction at the confluence of Michie and Byng creeks
Michie Creek, at outlet of Michie Lake	60.67718, -134.2063	To identify movements upstream of Michie Creek
Michie Creek, upstream of Michie Lake	60.67747, -134.1554	To identify movements upstream of Michie Lake
Tagish River	60.27275, -134.2657	To identify fish entering Southern Lakes
Atlin River	59.62241, -133.8540	To identify fish entering Atlin Lake
Tutshi River	59.91029, -134.2726	To identify movement into a potential spawning site off Tagish Lake

Tagging methods

Chinook Salmon were gastrically implanted with a V13 transmitter (6 g; diameter = 13 mm x length = 36 mm) attached to a Sigma Eight TX-PSC-I-80 radio transmitter (4.2 g; diameter = 10 mm x length = 27 mm). These transmitters were affixed together with a marine-grade adhesive for ease of application in the salmon (combined weight = 10.2 g, diameter = 13 mm, length = 63 mm). This combined tag has comparable specifications as the Vemco V16 (10.3 g; diameter = 16 mm x length = 68 mm) acoustic transmitters that were used in 2017, 2018, and 2019 for this project. The antenna of a transmitter was slid down a thin PVC pipe, and the pipe was used to guide the tag into the mouth of the fish for release into the stomach. A wooden dowel was then inserted into the pipe to release the transmitter, and the pipe and dowel were withdrawn from the stomach. Subjects were then marked with a hole punch through the caudal fin (genetic sample). External tags and markings allowed visual identification of treatment groups to avoid double tagging with acoustic transmitters. Sex, origin (hatchery or wild), and fork length (cm) were recorded. Fish were kept in the water during sampling except during gastric tagging.

Tagging in the Whitehorse Rapids Fishladder Viewing Chamber

Chinook Salmon were tagged at the Whitehorse Rapids Fishladder by ladder and hatchery staff with combined acoustic/radio transmitters. Fish were selected for tagging based on size, sex,

origin, and arrival date at the viewing chamber, to mimic the characteristics of an average run (though proportionally less females were tagged; Table 2). Hatchery staff used their discretion to determine the number of transmitters applied daily in the viewing chamber, while also ensuring that a sufficient number of fish were kept as broodstock. Most tagged fish were of medium size, male, and wild. Fish that were selected for tagging were dip netted from the viewing chamber. Total handling time was ~2 min and air exposure was generally <20 s. Fish were released beyond the upstream gate of the viewing chamber. All tagging was completed by August 30th, 2020 to ensure that fish condition, which degrades rapidly toward the end of the run, was suitable to support tagging.

Tagging downstream of the WHP

A gill net was used to capture fish downstream of the WHP approximately 9-12 km upstream of the confluence of the Yukon and Takhini rivers. The cable-laid gill net measured 30.5 m (100 ft) long, 3.05 m (10 ft) tall, and had a 3:1 hang ratio and 16.5 cm mesh size. The hang ratio encouraged entanglement over gilling to minimize harm and facilitate removal. Nets were set along eddy lines and were constantly watched over a 30-min soak period. Nets were checked immediately if the float line indicated a fish capture, and were otherwise checked at the end of the soak period. Fish were lifted on board and were quickly unrolled. Scissors were used to cut the net (typically 1-2 panels per fish) to decrease the amount of time spent entangled. One fish was captured while drifting the net, rather than the set net approached described above. Entanglement time averaged 112 s and air exposures averaged 39 s. Fish were immediately placed into a tote filled with river water and an oxygen pump set at 25 mg/L. Fish were sampled as described above (with the combined acoustic/radio transmitters) while a boat driver moved upstream approximately 500 m to a release site. Fish were released upstream to reduce the likelihood of recapture in the gill net. The total tagging period from entry in the gill net to release upstream was approximately 8.4 min, with the majority of this time spent in an aerated tote. No captured fish were released without transmitters (i.e., there was no bycatch).

Similar tagging was completed in the Takhini River in 2018 and 2019. The Takhini River is unimpounded (no physical barriers to migration), so an inability of Chinook Salmon to complete their migration could be attributed to a combination of natural pre-spawn mortality and instantaneous or latent mortality from gill netting and handling. Conversely, if fish complete their migration in the Takhini River after gill net capture, tagging, and handling, then we would expect salmon in the Yukon River to have similar success completing their migration if there are no effects of the hydro plant on migration. Tagged salmon were successful migrating to spawning areas on the Takhini River (93%; n=15) so it was assumed capture and tagging did not prevent completion of upstream migration. Similarly, Eiler et al. (2014) observed a 98% post-tagging recovery rate using similar methods in the lower Yukon River.

Radio tracking

Fish were tracked using a Lotek SRX800 radio receiver attached by coaxial cable to a three or four prong Yagi antenna. Tracking was conducted approximately every three days from McIntyre Flats to the WHP tail race between August 25th and September 8th by jet boat. The stretch of river between McIntyre Flats and the Takhini River was tracked once on September 8th. Tracking was completed between Schwatka Lake and the Lewes Dam on September 9th. A

tracking survey was completed on September 4th over the M'Clintock River, Michie Creek, the Yukon River mainstem, and Wolf Creek using a Cessna 206.

Data analysis

Terminal reaches were assigned based on the last receiver that fish were detected at by September 5th, 2020. However, if a fish spent five or more days in an upstream reach, followed by downstream movement late in the season, the upstream reach was designated as the terminal reach. Single downstream movements were observed for a few fish after September 5th, but these movements likely represented downstream carcass or post-spawning drift and were not included in analyses. Mobile tracking was used to assign finer scale terminal locations. Final terminal locations were calculated as the average location of multiple detections, weighted by detection signal strength. Survival of fish that moved back through the WHP was based on detection patterns. Fish that moved upstream were designated as alive, as were fish that were detected consistently over multiple discrete periods at a receiver over the span of several hours (indicating active movement in and out of a receiver's detection range). Detection probability was calculated as the number of fish successfully detected by a receiver divided by the number of fish detected upstream of this receiver (Appendix 2). The short-term migration rates of Chinook Salmon in the Takhini and Yukon rivers were compared to evaluate migration delays associated with passage at the fish ladder.

Results

Chinook Salmon were tagged at the ladder viewing chamber (n=26) and by gill net in the Yukon River (n=7) (Table 1). The last upstream movement of any fish was detected on September 4th, though downstream movement occurred after this date.

Table 2. Origin, sex, and length of fish implanted with acoustic transmitters in 2020 for two tagging groups. Small Chinook Salmon were defined as having a fork length <70 cm, medium as between 70 and 100 cm, and large as >100 cm.

Fish type	Viewing chamber	Gill net - Yukon
Large wild male	-	-
Medium wild male	16	2
Medium wild female	4	4
Small wild male	3	-
Medium hatchery male	3	1
Medium hatchery female	-	-
Small hatchery male	-	-
Mean fork length (cm±SD)	79±9	89±5

Fish migrating beyond the WHP

A total of 26 tagged Chinook Salmon migrated beyond the WHP via the ladder in 2020. Most fish (65%) terminated in the Michie Creek - M'Clintock River system (Table 3). Most of these

fish terminated in Michie Creek upstream of Byng Creek (71%) whereas 29% terminated in Michie Creek between Byng Creek and the M'Clintock River, though many of these salmon first reached the confluence of Byng Creek and Michie Creek. Two male fish that spent multiple days upstream of Byng Creek and moved downstream late in the spawning season were assigned terminal locations of Michie Creek upstream of Byng Creek. Finer scale terminal locations of fish in Michie Creek were determined by manual radio tracking on foot and in a Cessna 206 (Figure 3).

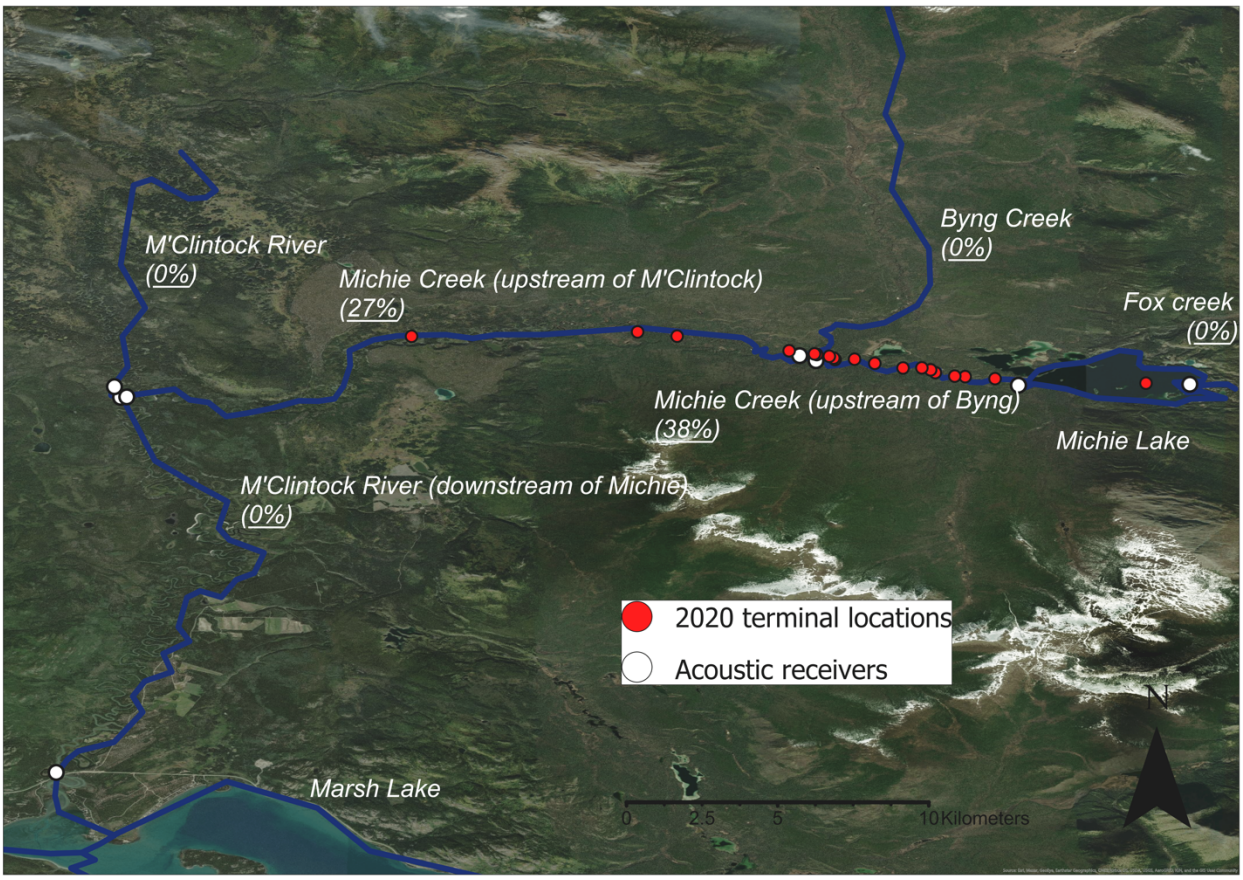

Figure 3. Terminal locations of Chinook Salmon (red) and acoustic receivers (white) in the Michie Creek - M'Clintock River system in 2020 (n=26 fish). Percentages refer to the proportion of all tagged salmon passing the WHP that terminated in each reach. Note that some areas have a high density of terminal locations (i.e., at the confluence of Michie and Byng Creek), such that it is difficult to discern individual locations (see appendix 3 for GPS locations).

Eight fish (31%; 7 males and one female) returned downstream after passing the WHP, presumably through the spillway and it appears all fish survived spillway passage. These salmon spent a substantial amount of time upstream of the WHP, typically migrating dozens of kilometres upstream before returning. In one case, a wild male salmon first visited Michie Creek before returning downstream of the WHP, and in another case a salmon first traveled to the south end of the Six Mile River. Salmon returning downstream of the WHP typically terminated between M'Cintyre Flats and Rotary Park, often spending some time on Robert Service Way

(and potentially spawning in this area). Two fish tagged at the Fish Ladder viewing chamber returned back to the Takhini River, and migrated over 60 km upstream toward Kusawa Lake. It is unclear whether these fish spawned, and if so, where spawning took place.

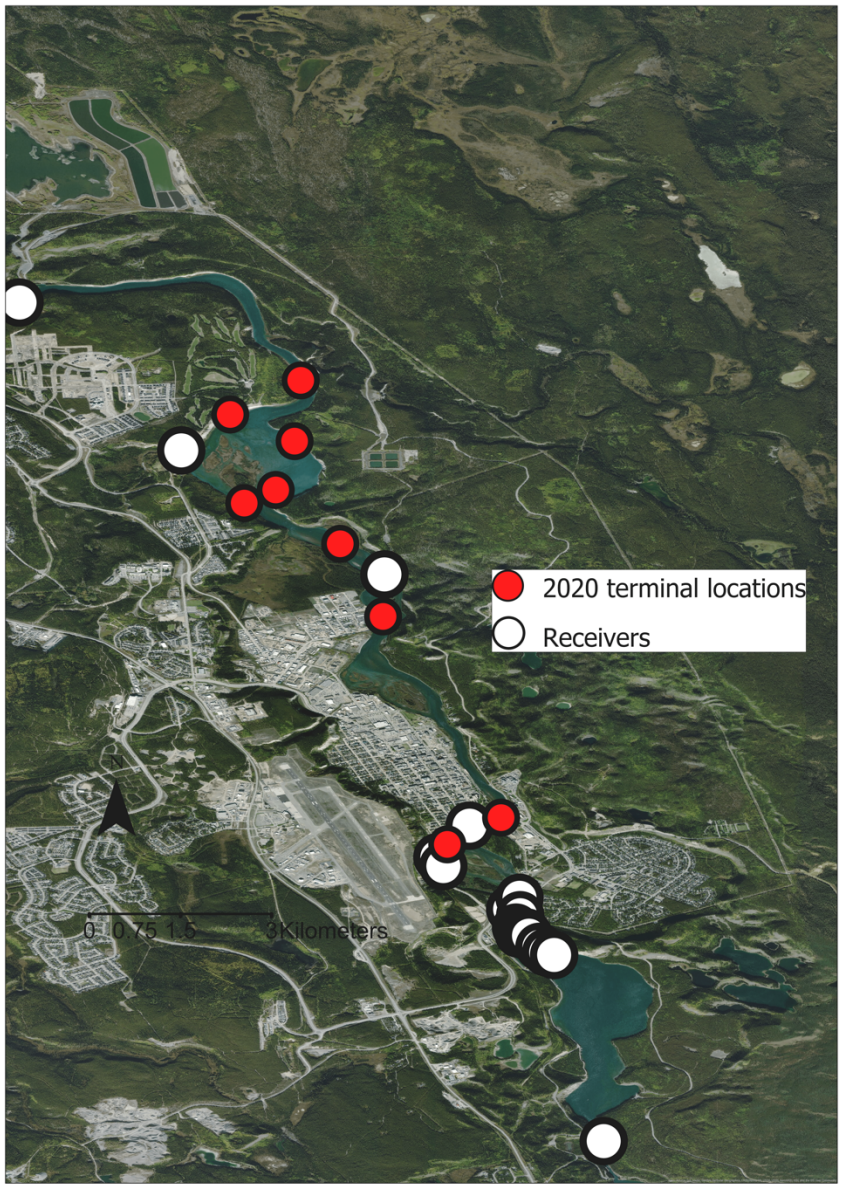

Figure 4. Terminal locations of Chinook Salmon (red) and acoustic and radio receivers (white) downstream of the Whitehorse Hydro Plant in 2020. Note that nine receivers are clustered at the Whitehorse Hydro Plant. Locations were assigned based on detections from manual radio tracking by boat between August 29th – September 8th, 2020. Given that carcasses have the potential to drift several kilometres in this reach of the river, these sites may not be the terminal locations of these fish.

Similar to 2019, no fish terminated in Wolf Creek nor in the M'Clintock River upstream of Michie Creek. Fish were observed entering these reaches, but only for brief forays. One female wild fish was recovered as a carcass in the mainstem Yukon River downstream of Wolf Creek. This fish had spawned completely (i.e., no eggs left in cavity; Figure 5). After passing the ladder, this fish remained between Schwatka lake and the Yukon River at Wolf Creek. For the first time during this four-year study no salmon terminated in the Southern Lakes, though one fish traveled to the south end of the Six Mile River before returning downstream of the WHP.

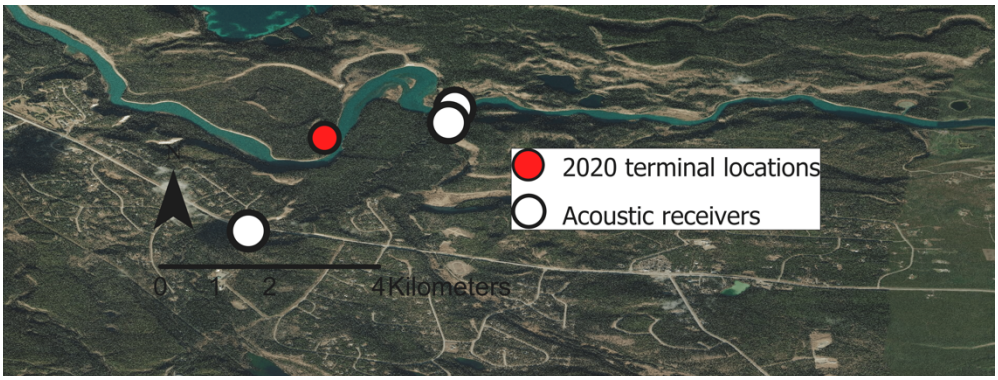

Figure 5. Terminal location of a wild Chinook Salmon female that was recovered as a completely spawned carcass in the Yukon River downstream of Wolf Creek in 2020.

Table 3. The proportion of Chinook Salmon migrating upstream of the WHP that terminated at various locations in the upper Yukon River in 2020 (n=26).

Fate	Count	%
Robert Service Way	1	4%
Wolf Creek	0	0%
M'Clintock River upstream of Michie Creek	0	0%
Michie Creek between the M'Clintock River and Byng Creek	5	19%
Byng Creek	0	0%
Michie Creek upstream of Byng Creek	12	46%
Michie Creek upstream of Michie Lake	0	0%
Southern Lakes	0	0%
Mainstem Yukon River upstream of the WHP	1	4%
Mainstem Yukon River between Robert Service Way and the industrial area launch	4	19%
Takhini River upstream of Stoney Creek	2	8%

Tagging by gillnet

All fish captured by gill net in the Yukon River moved upstream after capture (n=7). Most captured salmon were wild (n=6), with one hatchery salmon captured. Two of these fish did not approach the dam. These fish terminated in the mainstem Yukon River between McIntyre Flats

and Rotary Park. None of the five fish that approached the dam passed through the fish ladder. Three salmon approached the ladder entrance, spending multiple hours there, two of which moved into the ladder. One of these two salmon reached the fish ladder viewing chamber but returned downstream after spending several hours within that section of the ladder. Across all years of this study 36 tagged salmon approached the WHP, the majority of which were wild salmon (86%). Passage success in 2020 (0%) was lower than that recorded in 2018 and 2019 (Table 4).

Table 4. Overall passage of tagged Chinook Salmon at the Whitehorse Rapids Fishladder from 2017-2020, including attraction, entrance, and passage efficiencies. Radio receivers were deployed in 2019 and 2020, allowing passage efficiency to be quantified for various segments of the fish ladder.

	Downstream sample	Entered tail race	Attraction	Entrance	Passage			Overall passage
2020	7	5	80% (4/5)	50% (2/4)	0% (0/2)			
				2	Turning Basin	Viewing chamber	Ladder exit	0% (0/5)
					1	1	0	
2019	29	16*	81% (13/16)	77% (10/13)	60% (6/10)			31% (6/16)
					Turning Basin	Viewing chamber	Ladder exit	
					91% (10/11)	80% (8/10)	75% (6/8)	
2018	10	9	>78% (n=9)	>78% (n=9)	>78% (n=9)			66% (6/9)
2017	10	≥6						0% (0/6)
ALL	56	36	86% (18/21)	77% (14/17)	42% (5/12)			33% (12/36)

*It was estimated one fish in 2019 swam into the tail race undetected based on the detection probability of receivers just downstream of this area.

No salmon were captured by gill net in 2020 on the Takhini River though they were captured in the Takhini River in 2018 and 2019 (n=15; all wild). Most salmon (93%; n=15) were successful in migrating >10 km upstream of the tagging site (a similar distance as the WHP is from the Yukon River tagging site) and all fish that traveled 10 km upstream also traveled 55 km upstream. These fish took an average of 27.2 ± 18.8 hours to reach this location (n=14), compared to the 142.8 ± 180.8 hours to pass the dam (n=8). This suggests that capture and tagging does not restrict upstream migration.

Discussion

Spawning sites

The distribution of terminal locations from 2017-2020 confirms traditional knowledge and other biological studies stating that the majority of Chinook Salmon that pass upstream of Whitehorse spawn throughout the Michie Creek - M'Clintock River system (Cox 1997; Table 5). Cleugh and Russel (1980) found that 87% of the run terminates in Michie Creek, whereas in 1993 and 1994, 56% and 44% of the run counted at the ladder were counted entering Michie Creek. Our results from 2017-2020 suggest that 79% of fish that pass the WHP terminate in Michie Creek. Within Michie Creek, Cleugh and Russell (1980) observed that 100% of radio tagged fish migrating into the Michie Creek - M'Clintock River system terminated in Michie Creek upstream of Byng Creek. In 1998, 0% of 35 radio tagged Chinook Salmon reached Byng Creek (Matthews 1999a). Corresponding foot and aerial surveys indicated that a beaver dam (~7 km downstream of Byng Creek) was likely blocking fish migration (Matthews 1999b). Our results from 2017-2019 suggest that 55% of fish entering the Michie Creek - M'Clintock River system terminate in Michie Creek upstream of Byng Creek.

In 2017, 2018, 2019, and 2020 11%, 7%, 0%, and 0% of tagged fish migrating upstream of the WHP terminated in the M'Clintock River upstream of Michie Creek, compared to 20% in 1998 (Matthews 1999a). A substantial number of Chinook Salmon terminated in Michie Creek between Byng Creek and the M'Clintock River (36% of those that passed the WHP in 2017, 33% in 2018, 33% in 2019, and 38% in 2020). Manual radio tracking by plane in 2020 highlighted several locations that Chinook Salmon may be spawning in this stretch of river (Figure 3). Over four years of this study, just one tagged Chinook Salmon terminated in the M'Clintock River downstream of Michie Creek and no fish terminated in Byng Creek or in Fox Creek upstream of Michie Lake. Further investigations such as spawning ground surveys may be warranted in the lower reaches of Michie Creek where we identified terminal locations in 2019 and 2020.

In contrast to 2017 and 2018, no tagged fish terminated in Wolf Creek, which has been the site of fry stocking by the Whitehorse Rapids Fish Hatchery every year since its founding in 1986 (Joint Technical Committee of the Yukon River U.S./Canada Panel 2017). In 2020, one wild female fish explored the creek but left and then travelled to the Takhini River. Previous studies based on stream counts estimated that 1.9%, 3%, and 11.5% of fish passing the WHP terminated in Wolf Creek (Matthews 1999b). In 2017 and 2018, 4% and 9% of tagged fish passing the WHP terminated in Wolf Creek (Sebes and Lapointe 2018; Twardek and Lapointe 2019). The return of wild fish in 2017 (2% of all tagged fish that passed the WHP) and 2018 (7% of all tagged fish that passed the WHP) suggests there is natural recruitment within this system, though it is unclear whether the creek contains a self-sustaining population or acts as an ecological sink (i.e., if these are only the direct descendants of returning hatchery-origin fish). In 2018, one fish entering Wolf Creek was detected upstream of the fishway installed in Wolf Creek at the Alaska Highway, approximately 2.5 km upstream of the mouth of the creek.

Of fish that passed the WHP in 2020, 31% returned downstream of the WHP, presumably through the spillway, and did not return upstream via the ladder. Migrating fish are rheotactic (face oncoming current) and can be attracted to the water passing through a spillway upon entering reservoirs (discussed in Boggs et al. 2004); however, most fallback events that we observed occurred after fish had moved upstream away from the spillway. Fallback may also occur for fish that 'over shoot' downstream spawning grounds (Ricker 1972). In fact, in 2020, two salmon returned back downstream through the spillway, moved to the Takhini River, and terminated near Kusawa Lake. In the Columbia River basin, overshoot averaged 15% for Chinook Salmon populations, and typically lasted less than 5 days (Keefer et al., 2008). Fallback was higher in 2020 than in 2019 (15%), 2018 (9%), and 2017 (4%), while in 1998, 12% of fish fell back downstream of the WHP, all of which terminated on the Robert Service Way spawning grounds (Matthews 1999a). Rates of fall back were nearly identical from 2017-2020 for hatchery and wild salmon, despite evidence that straying is generally more common in hatchery salmon (Quinn 1993).

Regardless of the mechanism, fallback through spillways can decrease survival to spawning grounds in Chinook Salmon and lead to injuries such as bruising (Wagner and Hilsen 1992; Bjornn et al. 1998). All tagged salmon that moved back through the spillway appeared to survive the event based on their detection patterns downstream of the WHP. It is unclear whether these fish suffered injuries, or whether they spawned successfully downstream of the dam. Spawning success of fish terminating downstream of the WHP appears variable based on carcass surveys from 2018-2020 (Twardek and Lapointe 2019, 2020). These carcasses likely included fish that did not approach the WHP, fish that approached the WHP and did not pass, and fish that passed then fell back. Of 27 carcasses found downstream of the WHP in 2020, 23 were female, and 24 were wild. For female carcasses, 48% had completely spawned; Twardek and Lapointe, 2020). Fish found downstream of the WHP were estimated to have exuded ~77% of their eggs based on comparisons to a fecundity model based on broodstock egg counts at the Whitehorse Rapids Fish Hatchery in 2017-2019 (full details in Twardek and Lapointe, 2019; 2020). In the Teslin River, 78% of females had completely spawned, while it was estimated that ~93% of eggs in Teslin River fish were released by females (Twardek and Lapointe 2020).

Table 5. The proportion of tagged Chinook Salmon that terminated at various locations in the upper Yukon River for each year in which telemetry projects were completed in Whitehorse, YT.

Location	1979 (N=15)	1998 (N=33)	2017 (N=50)	2018 (N=55)	2019 (N=40)	2020 (N=26)
Michie/M'Clintock system	87%	82%	86%	80%	75%	65%
Wolf Creek	0%	3%	8%	9%	0%	0%
Fell back downstream of the WHP	0%	12%	4%	9%	15%	31%
Mainstem Yukon River	0%	3%	0%	0%	3%	4%
Southern Lakes	13%	0%	2%	2%	7%	0%

* Returns at this time (1998) included releases into the Fishway of 50k per year between 1989 and 1994 (BY 1988 to 1993). Note that fish that returned to the fishway, were sport fished, or were considered unknown in Matthews 1999a were excluded in the above calculations.

Gill netting synopsis

Salmon were captured and tagged downstream of the dam to evaluate the effectiveness of the ladder at facilitating fish movement upstream. Despite 35 boat days of netting, only 7 fish were captured. Gill net capture success was low in 2020 given the small return to Whitehorse (N=216 counted at the fish ladder viewing chamber) and high water levels.

Movement through the ladder

None of the 5 tagged salmon that approached the WHP successfully passed the facility in 2020. This passage rate is lower than that observed in 2018 (66%), 2019 (38%) and across years (33%), and is also much lower than the average upstream passage rate observed for salmonids in fishways around the world (62%; Noonan et al. 2011). It is also likely that overall passage was slightly lower than that reported, given that detection probability for salmon entering the tail race was lower in 2019. Salmon ceased upstream migration at multiple different stages of the fish ladder. One fish reached the viewing chamber but did not pass despite spending several hours nearby. This behaviour was observed in tagged salmon in both 2018 and 2019. In some cases fish approached at night when passage was not possible due to the upstream gate of the chamber being closed. This gate was also closed at times during the day. Fish often spend time in the viewing chamber even when the gate is open, and our data suggest that fish will move in and out of the chamber over an extended period of time. This reach of the ladder may warrant further investigation for improved design and operation given that multiple fish have turned back after reaching this point over multiple years. A portion of fish that approached and entered the fish ladder may have 'over shot' intended spawning areas near Robert Service Way, eventually returning downstream (Keefer et al. 2008), though for the most part this behaviour is interpreted as an inability to pass the ladder to reach intended upstream spawning sites. Bett et al. (2017) reviewed the causes of straying in salmon populations, including delays/failed passage downstream from dams, but concluded that there was no literature available to assess this potential relationship. They hypothesized that disrupted flow patterns at dams can make olfactory navigation difficult, and that fish may track the conspecific cues of salmon aggregations downstream of a dam (Bett and Hinch 2015; Quinn et al. 1989). In Whitehorse, conspecific cues from the spawning population downstream of the WHP and effluent from the Whitehorse Rapids Fish Hatchery, located 1 km downstream of the WHP, may further impact salmon olfactory navigation.

Across all years, salmon often made downstream movements within the ladder during passage, increasing total passage times. Fish ladders can be energetically costly because fish undertake burst swimming to navigate areas of high water velocity (Burnett et al. 2014). Depleted energy reserves following dam passage may lead to pre-spawn mortality and reduced spawning success in Chinook Salmon (Geist et al. 2000). Over the three years of our study there has been little indication that salmon have failed to reach spawning areas after passage, though spawning success was not assessed.

Passage success varied greatly across years. This may be due to sampling bias (small sample sizes each year), improved handling practices following 2017, or environmental differences (e.g.

temperature, flow). Challenging conditions during 2019 and 2020 may have reduced ladder passage success. Both years involved the lowest returns on record since hatchery operation began in the late 1980s. Salmon were delayed in reaching spawning locations, perhaps due to warm temperatures in the Yukon River in 2019, and high water levels in 2020, both of which have been implicated with delayed migrations in other Chinook Salmon populations (Keefer et al. 2004; Salinger and Anderson 2011). Water temperatures and flow are expected to increase in the Yukon, as is the frequency of extreme climate conditions (Goulding 2011), which will undoubtedly affect Chinook Salmon migrations in the terminal reaches of the upper Yukon River.

Conclusions

Acoustic tagging of Chinook Salmon in the upper Yukon River in 2020 highlighted the importance of multiple spawning areas within Michie Creek, consistent with our previous findings. Unlike previous years, no salmon terminated in Wolf Creek, M'Clintock River, or the Southern Lakes, though one female fish terminated in the mainstem Yukon River upstream of the hydro plant (and fully deposited her eggs). These spawning locations should be considered for future stock and habitat restoration. Although sample sizes remain modest, evidence from three years of sampling indicates that passage efficiency in the Whitehorse Rapids Fish Ladder is low. Findings from this work may help to inform design and operational changes of the facility to improve salmon passage.

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References

Access Consulting Group & Yukon Engineering Services. 2002. Robert Service Way Reconstruction Project fish habitat compensation plan 2002 annual monitoring report -with a five year summary. Discussion Draft for the City of Whitehorse, Whitehorse, YT. 27 p.

Bett, N.N., Hinch, S.G., Burnett, N.J., Donaldson, M.R., and Naman, S.M. 2017. Causes and consequences of straying into small populations of pacific salmon. Fisheries 42(4): 220–230.

Bernard, D.R., Hasbrouck, J.J., and J. Fleischman, S. 1999. Handling-induced delay and downstream movement of adult chinook salmon in rivers. Fish. Res. 44(1): 37–46.

Bett, N.N., and Hinch, S.G. 2015. Attraction of migrating adult sockeye salmon to conspecifics in the absence of natal chemical cues. Behav. Ecol. 26(4): 1180–1187.

Bjornn, T.C., Hunt, J.P., Tolotti, K.R., Keniry, P.J., and Ringe, R.R. 1998. Migration of adult chinook salmon and steelhead past dams and through reservoirs in the lower Snake River and into tributaries. 1998. Report to the U.S. Army Corps of Engineers, Walla Walla District, Walla Walla, WA, and Bonneville Power Administration, Portland, OR 237 p.

Boggs, C.T., Keefer, M.L., Peery, C.A., Bjornn, T.C., and Stuehrenberg, L.C. 2004. Fallback, reascension, and adjusted fishway escapement estimates for adult chinook salmon and steelhead at Columbia and Snake River Dams. Trans. Am. Fish. Soc. 133(4): 932–949.

Brown, R.F., Elson, M.S., and Steingenberger, L.W. 1976. Catalogue of aquatic resources of the upper Yukon River drainage (Whitehorse Area). Environment Canada Report PAC/T-76-4. 172 p.

Bunt, C.M., Castro-Santos, T. and Haro, A., 2012. Performance of fish passage structures at upstream barriers to migration. Riv. Res. Appl. 28(4): 457-478.

Burnett, N.J., Hinch, S.G., Braun, D.C., Casselman, M.T., Middleton, C.T., Wilson, S.M. and Cooke, S.J. 2014. Burst swimming in areas of high flow: delayed consequences of anaerobiosis in wild adult sockeye salmon. Physiol. Biochem. Zool. 87(5): 587-598.

Salinger, D.H. and Anderson, J.J., 2006. Effects of water temperature and flow on adult salmon migration swim speed and delay. *Transactions of the American Fisheries Society*, *135*(1), pp.188-199.

Burnett, N.J., Hinch, S.G., Bett, N.N., Braun, D.C., Casselman, M.T., Cooke, S.J., Gelchu, A., Lingard, S., Middleton, C.T., Minke-Martin, V., and White, C.F.H. 2017. Reducing carryover effects on the migrations and spawning success of sockeye salmon though a management experiment of dam flows. Riv. Res. App. 33: 3–15.

Cleugh, T.R. and Russell, L.R. 1980. Radio tracking Chinook Salmon to determine migration delay at Whitehorse Rapids dam. Canadian Department of Fisheries and Oceans, Fisheries and Marine Services Manuscript Report No. 1459, Vancouver, BC. 52 p.

Cox, J. 1997. Archival research - salmon in the Upper Lakes region, Yukon Territory. Yukon Conservation Society, Whitehorse, YT. 75 p.

de Graff, N.M. 2015. KDFN Michie Creek monitoring project. Yukon River Panel Report. Kwanlin Dün Government, Whitehorse, YT. 15 p + 12 appendices.

Eiler, J.H., Masuda, M.M., Spencer, T.R., Driscoll, R.J., and Schreck, C.B. 2014. Distribution, stock composition and timing, and tagging response of wild Chinook Salmon returning to a large, free-flowing river basin. Trans. Am. Fish. Soc. 143(6): 1476–1507.

Fisheries and Oceans Canada. 2018. Takhini River Chinook Salmon restoration investigation – 2017 final report part 1 : conservation (sonar enumeration) part 2 : restoration (habitat investigation). Fisheries and Oceans Canada, Whitehorse, YT. 62 p.

Gilbert, C.H. and O'Malley, H. 1921. Investigation of the salmon fisheries of the Yukon River. Bureau of Fisheries Document. United States Department of Commerce, Washington, DC. 33 p.

Geist, D.R., Abernethy, C.S., Blanton, S.L. and Cullinan, V.I., 2000. The use of electromyogram telemetry to estimate energy expenditure of adult fall Chinook salmon. Trans. Am. Fish. Soc. 129(1): 126-135.

Goulding, H. 2011. Yukon water: An assessment of climate change vulnerabilities. Pp 98. http://www.env.gov.yk.ca/publications-maps/documents/yukonwater_climatechange_report.pdf

Herkes, J. 2015. Carcross/Tagish traditional knowledge of salmon in the upper Yukon River, Ecofor Consulting Ltd, Whitehorse, YT. 21 p.

Hinch, S.G., Cooke, S.J., Farrell, A.P., Miller, K.M., Lapointe, M., and Patterson, D.A. 2012. Dead fish swimming: a review of research on the early migration and high premature mortality in adult Fraser River sockeye salmon *Oncorhynchus nerka*. J. Fish Biol. 81(2): 576–599.

Joint Technical Committee of the Yukon River U.S./Canada Panel. 2017. Yukon River salmon 2016 season summary and 2017 season outlook. Alaska Department of Fish and Game, Division of Commercial Fisheries, Regional Information Report 3A17-01, Anchorage, AK. 219 p.

Keefer, M.L., Caudill, C.C., Peery, C.A., and Boggs, C.T. 2008. Non-direct homing behaviours by adult Chinook salmon in a large, multi-stock river system. J. Fish Biol. 72(1): 27–44.

Keefer, M.L., Peery, C.A., Bjornn, T.C., Jepson, M.A., and Stuehrenberg, L.C. 2004. Hydrosystem, dam, and reservoir passage rates of adult Chinook Salmon and Steelhead in the Columbia and Snake rivers. Trans. Am. Fish. Soc. 133(6): 1413–1439.

Kubokawa, K., Yoshioka, M., and Iwata, M. 2001. Sex-specific cortisol and sex steroids responses in stressed sockeye salmon during spawning period. Zool. Sci. 18(7): 947–954.

Matthews, I.P. 1999a. Radio tagging adult Chinook Salmon (*Oncorhynchus tshawytscha*) returning to the Whitehorse Fishway 1998. Yukon Fish and Game Association, Whitehorse, YT. 28 p.

Keefer, M.L., Peery, C.A., Jepson, M.A. and Stuehrenberg, L.C., 2004. Upstream migration rates of radio-tagged adult Chinook salmon in riverine habitats of the Columbia River basin. *Journal of Fish Biology*, *65*(4), pp.1126-1141.

Matthews, I.P. 1999b. Wolf and Michie Creek enumeration weirs, 1998. Unpublished report. Yukon River Restoration and Enhancement project No. CRE-27-98. Whitehorse, YT. 25 p.

Quinn, T.P., Brannon, E.L., and Dittman, A.H. 1989. Spatial aspects of imprinting and homing in Coho Salmon (*Oncorhynchus kisutch*). Fish. Bull. 87: 769–774.

Quinn, T.P., 1993. A review of homing and straying of wild and hatchery-produced salmon. *Fisheries research*, *18*(1-2), pp.29-44.

W.R. Ricks Consulting and DNA Enterprises. 1996. A review of the Whitehorse Rapids Fish Hatchery. Canadian Department of Fisheries and Oceans, Whitehorse, YT. 144 p.

Ricker, W.E. 1972. Hereditary and environmental factors affecting certain salmonid populations. pp. 27–160 *in*: The Stock Concept in Pacific Salmon (Simon, R. C. & Larkin, P. A., eds), University of British Columbia, Vancouver, BC. 134 p.

Roscoe, D.W., Hinch, S.G., Cooke, S.J., and Patterson, D. A. 2010. Fishway passage and post-passage mortality of up-river migrating Sockeye Salmon in the Seton River, British Columbia. Riv. Res. App. 27(6): 693-705.

Sebes, J., and Lapointe, N.W. 2017. Assessing the fate of returning upper Yukon River Chinook Salmon. Unpublished report. Yukon River Restoration and Enhancement project No. CRE-149-17N. Ottawa, ON. 50 p.

Twardek, W.M., and Lapointe, N.W. 2018. Assessing the fate of returning upper Yukon River Chinook Salmon - 2018. Canadian Wildlife Federation, Ottawa, ON. 34 p.

Twardek, W.M., Reid, C.H., and Lapointe, N.W. 2018. Survey of Chinook Salmon (Oncorhynchus tshawytscha) carcasses in Whitehorse, Yukon - 2018. Canadian Wildlife Federation, Ottawa, ON. 6 p.

Twardek, W.M., and Lapointe, N.W. 2020. Survey of Chinook Salmon (Oncorhynchus tshawytscha) carcasses in Whitehorse, Yukon - 2019. Canadian Wildlife Federation, Ottawa, ON. 10 p.

Wagner, P., and Hilsen, T. 1992. 1991 evaluation of adult fallback through the McNary Dam juvenile bypass system. Washington Department of Fisheries Habitat Management Division, Olympia, WA. 92 p.

Yukon Energy Corporation. 2011. Marsh Lake Storage Project – Fact Sheet. 8 p.

Appendices

Appendix 1. Detection rate of a range test tag placed near each receiver for a fixed period of time (100 potential detections) in 2018 (V16 tag) and 2020 (V13 tag).

Receiver location	Test tag location	Dist. (m)	Detection rate
2018			
Confluence of the Yukon and Takhini rivers	Directly across from receiver on opposite bank	150	24%
Takhini River km 11	Directly across from receiver on opposite bank	87	74%
Industrial boat launch	Upstream of receiver on opposite bank	280	0%
Rotary Park	Directly across from receiver on opposite bank	150	0
~500m downstream of ladder	Directly across from receiver on opposite bank	71	7%
Viewing chamber	At lower end of the chamber	5	70%
Viewing chamber	First step below	7	44%
Viewing chamber	Second step below	10	0%
Spillway	Near receiver	3	0%
Spillway	Lower end of eddy	30	0%
Upper Wolf Creek	Near receiver	1	~25%
Upper Wolf Creek	Near receiver	1.5	~25%
Upper Wolf Creek	Near receiver	2	~25%
Upper Wolf Creek	Downstream run	10	0%
Upper Wolf Creek	Downstream run	12	0%
Lewes Dam	Upstream of receiver, just downstream of the Lewes Dam	450	48%
Mouth of the M'Clintock River	Directly across from receiver on opposite bank	55	75%
Michie Creek, upstream of Michie Lake	Same bank	5	42%
2020			
Ladder entrance	Lower ladder (first step)	4	0%
Ladder entrance	Lower ladder (bend below first step)	3	0%
Ladder entrance	Ladder entrance (in outflow)	2	93%
Ladder entrance	Ladder entrance (8 m away)	8	77%
Lower ladder (first step)	Ladder entrance (in outflow)	4	0%
Lower ladder (first step)	Lower ladder (bend below first step)	3	48%

Lower ladder (first step)	Lower ladder (first step)	1	92%
Lower ladder (first step)	Lower ladder (second step)	3	0%
Ladder turning basin	One step below turning basin	3	6%
Ladder turning basin	Lower turning basin	1	87%
Ladder turning basin	Upper turning basin	1	78%
Ladder turning basin	One step above turning basin	3	25%
Viewing chamber	One step below viewing chamber	5	0%
Viewing chamber	Viewing chamber	2	70%
Viewing chamber	Immediately before bend upstream	100	11%
Viewing chamber	Immediately after bend upstream	105	0%

Appendix 2. The detection efficiency of fish passing each receiver based on subsequent detection at upstream receiver sites in 2020. Fish were counted as having been detected at a receiver if one or more transmissions were detected there, followed by one or more detections at any receivers upstream of that site. Only the first pass by a receiver was considered in calculations.

Receiver	Detection efficiency (%)
Industrial Boat Launch	100% (n=5)
Rotary Park	100% (n=5)
Rotary Centennial Bridge	100% (n=4)
Ladder entrance	100% (n=2)
Ladder first step	100% (n=1)
Ladder turning basin	100% (n=1)
Viewing chamber	92% (n=26)
Schwatka Lake	88% (n=26)
Below Lewes Dam	100% (n=24)
Above Lewes Dam	100% (n=18)
Yukon @ Wolf Creek	100% (n=24)
Mouth of M'Clintock River	Not retrieved in 2020
Michie Creek at the M'Clintock River	100% (n=18)
Michie Creek at Byng Creek	100% (n=13)

Appendix 3. The terminal locations of each Chinook Salmon implanted with an acoustic transmitter in 2020. Fish were captured and tagged at the Whitehorse Rapids Fishladder viewing chamber (n=29) or by gill net downstream of the WHP in the Yukon River (n=7). For each fish, the acoustic ID#, date, sex, length (FL; cm), and origin are listed. For each fish with an additional radio tag, specific terminal locations are provided with error estimates (UTM). 'Exact location' refers to GPS points taken after the tag was physically retrieved (3 m error), 'minimal error' refers to GPS points taken while walking or boating in the immediate vicinity of a tagged

fish (3-100 m error), 'low error' was assigned to fish that had several GPS points taken while flying overhead, with final location based off the detection with the highest recorded signal strength (<500 m error). Where provided, ±location errors were assigned based on the approximate distance between the two furthest detections for a single transmitter.

Tagging Location	ID #	Date tagged	Sex	FL; cm	Origin	Terminal Location
Ladder	54539	06/08/2020	m	76	w	Yukon River between Rotary Park and McIntyre Creek
Ladder	54540	07/08/2020	f	83	w	Takhini River upstream of Stoney Creek
Ladder	54536	10/08/2020	f	93	w	Yukon River upstream of Whitehorse 60.6219786, -134.9346036 (exact location)
Ladder	54534	10/08/2020	m	69	w	Michie Creek upstream of M'Clintock River 60.6863349375, -134.266256675 (low error)
Ladder	54533	12/08/2020	m	81	h	Michie Creek upstream of M'Clintock River 60.683543, -134.238094 (low error)
Ladder	54542	12/08/2020	m	60	w	Michie Creek upstream of M'Clintock River 60.68528035, -134.2612303625 (low error)
Ladder	17815	13/08/2020	m	74	w	Michie Creek upstream of Byng Creek 60.68370738, -134.24902846 (low error)
Ladder	17835	14/08/2020	m	72	w	Yukon River between Rotary Park and McIntyre Creek 60.773427, -135.084853
Ladder	17848	14/08/2020	m	77	w	Takhini River upstream of Stoney Creek
Ladder	17828	15/08/2020	m	87	w	Michie Creek upstream of M'Clintock River 60.6858104666667, -134.262539811111 (low error)
Ladder	17826	18/08/2020	m	63	w	Michie Creek upstream of Byng Creek 60.6874497375, -134.2744885375 (low error)
Ladder	17872	18/08/2020	m	73	w	Yukon River between Rotary Park and McIntyre Creek 60.754321, -135.068583 (minimal error)
Ladder	17838	19/08/2020	f	87	w	Michie Creek upstream of Byng Creek 60.67992445, -134.22526395 (low error)
Ladder	17879	20/08/2020	m	75	w	Michie Creek upstream of Byng Creek 60.6917236166667, -134.38669195 (low error)
Ladder	17832	21/08/2020	m	72	h	Michie Creek upstream of Byng Creek 60.680940375, -134.2310161875 (low error)
Ladder	17836	21/08/2020	m	73	w	Michie Creek upstream of Byng Creek 60.682354525, -134.2350320375 (low error)
Ladder	17817	21/08/2020	m	82	w	Michie Creek upstream of Byng Creek 60.6817821555556, -134.232399211111 (low error)
Ladder	17852	23/08/2020	m	80	w	Michie Creek upstream of M'Clintock River 60.6917816125, -134.307766225 (low error)
Ladder	17820 *	23/08/2020	m	93	w	Yukon River upstream of Whitehorse 60.6791661333333, -134.213285833333 (minimal error)

Ladder	17843	24/08/2020	m	80	w	Robert Service Way spawning grounds 60.709895, -135.05275 (minimal error)
Ladder	17819	24/08/2020	m	93	w	Michie Creek upstream of Byng Creek 60.6791661333333, -134.213285833333 (low error)
Ladder	17871	25/08/2020	m	91	w	Michie Creek upstream of Byng Creek 60.6848225111111, -134.2608059 (low error)
Ladder	17850	26/08/2020	f	82	w	Michie Creek upstream of M'Clintock River 60.6930573714286, -134.3195114 (low error)
Ladder	17865	27/08/2020	m	84	w	Michie Creek upstream of Byng Creek 60.68231765, -134.240620975 (low error)
Ladder	17846	29/08/2020	m	71	w	Michie Creek upstream of M'Clintock River 60.6849286875, -134.25504735 (low error)
Ladder	17858	30/08/2020	m	78	h	Yukon River between Rotary Park and McIntyre Creek
Downstream gill net	54551	21/08/2020	F	86	w	Yukon River between Rotary Park and McIntyre Creek 60.760329, -135.082781 (exact location)
Downstream gill net	54549	21/08/2020	F	90	w	Yukon River between Rotary Park and McIntyre Creek 60.762271, -135.078125 (minimal error)
Downstream gill net	54554	22/08/2020	F	82	w	Yukon River between Rotary Park and McIntyre Creek 60.743577, -135.062251 (minimal error)
Downstream gill net	54552	23/08/2020	M	91	w	Yukon River between Rotary Park and McIntyre Creek 60.743577, -135.062251 (minimal error)
Downstream gill net	54548	24/08/2020	M	92	w	Yukon River between Rotary Park and McIntyre Creek 60.769482, -135.075334 (exact location)
Downstream gill net	54538	19/08/2020	M	98	h	Yukon River between Rotary Park and McIntyre Creek 60.77847, -135.074419 (exact location)
Downstream gill net	54544	25/08/2020	F	87	w	Yukon River between Rotary Park and McIntyre Creek 60.713848, -135.044785 (minimal error)

*Fish 17820 terminated downstream of the WHP but first spent several days in the Yukon River mainstem above the WHP

+UTM coordinates provided for fish that terminated in the Yukon River mainstem downstream of the dam indicate locations that carcasses drifted to, which are likely multiple kilometres downstream of where fish died/spawned. Fish were detected at many locations temporarily, but generally settled on McIntyre Flats. In some instances, transmitters were retrieved from the riverbank after the tagged fish was preyed/scavenged upon.