Assessing the Fate of Returning upper Yukon River Chinook Salmon - 2019

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Table of Contents

Highlights

- This is the first of the three years of this study that fish have neither terminated in the Upper M'Clintock River above the confluence with Michie Creek nor in Wolf Creek.
- Two fish terminated in the Southern Lakes (Marsh Lake and Tagish Lake south of Tutshi) with a potential third fish having terminated in Marsh Lake
- Unique terminal locations were identified in Michie Creek using manual tracking

Abstract

A 52-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 transmitters at the Whitehorse Rapids Fishladder viewing chamber or downstream via gill net capture to evaluate passage success and subsequent spawning locations. Fish were captured and acoustically tagged in the Takhini River (a barrier-free river) as a control group for the potential consequences of gill net capture on migration. A total of 40 tagged fish passed upstream of the Whitehorse Hydro Plant with 75% terminating in the Michie Creek - M'Clintock River system, 15% traveling back through the WHP spillway and remaining downstream, two wild male fish terminating in the Southern Lakes (Marsh Lake and Tagish Lake), and one additional wild male fish having last been detected upstream of the Lewes Dam. In the Yukon River, 16 gill-netted fish approached the Whitehorse Hydro Plant, five of which successfully passed the facility. Many fish entered the fish ladder and, in some cases, reached the viewing chamber before returning downstream. Findings from 2019 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 ecological 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 ~1200 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). 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. 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 vertical slot ladder. 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 fish 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 2019 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 2019 study site consisted of the Yukon River and its tributaries upstream of Lake Laberge, near Whitehorse, YT. Thirty two 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 sand bag and were tethered to a rope extending up to a sub-surface buoy. Receivers were tested prior to deployment and a subset of receivers were range tested. Range testing was completed in 2018 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). Range test results are presented in Appendix 1. Around the WHP, 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 the 20-receiver array maintained by Environment Yukon for their Lake Trout (*Salvelinus namaycush*) study in the Southern Lakes. These receivers will be retrieved in spring 2020, providing data on any tagged Chinook Salmon that visited these areas.

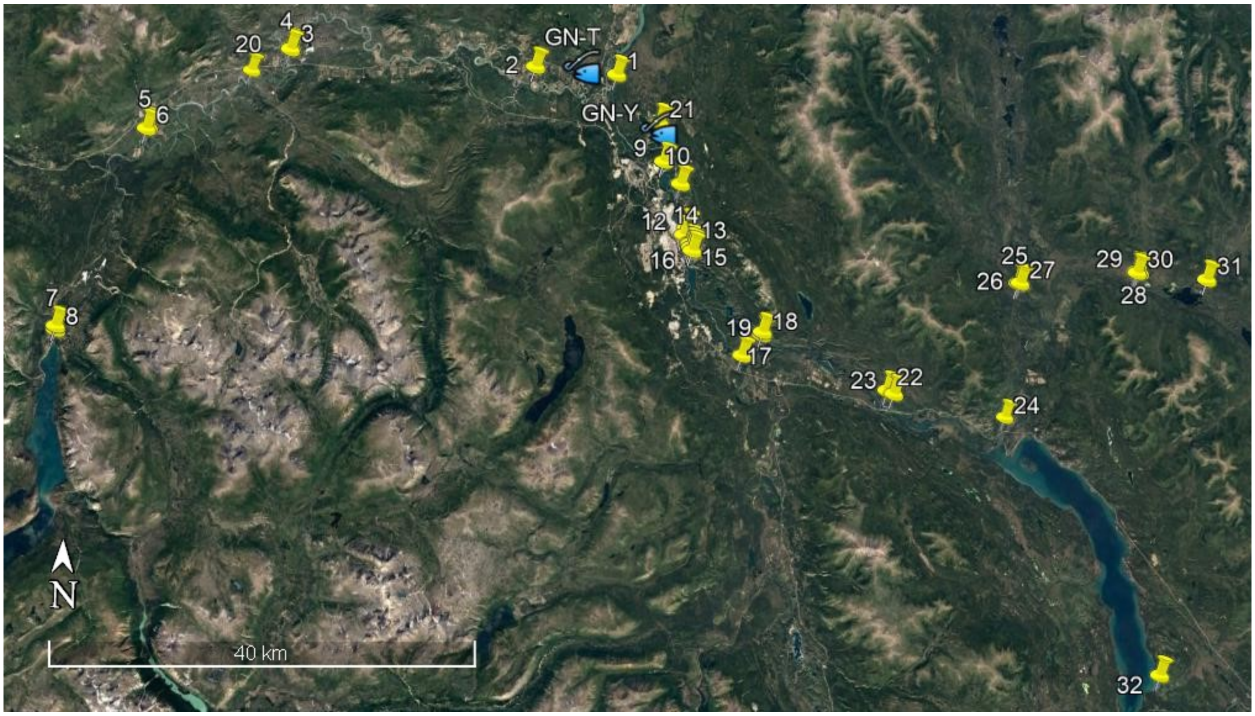

Figure 1: Locations of acoustic and radio receivers deployed in 2019 and the two gill net fishing sites. Yellow pins represent receivers and blue fish heads represent gill net fishing sites.

Figure 2: Locations of acoustic and radio receivers deployed around the WHP in 2019. Yellow pins represent acoustic receivers and green pins represent radio receivers.

Table 1: Description of 2019 acoustic receiver locations and rationale.

Receiver #	Location	UTM (8V)	Rationale
1	Fallback site at mouth of Takhini River	6739408.96, 493677.39	To detect post-gill-netting fallback at the confluence of the Takhini River and Yukon River
2	6-11 km upstream of Takhini River fishing sites	6745540.01, 482633.25	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.
3	Alaska Highway Bridge on the Takhini (km 57)	6746597.30, 459642.35	Adult salmon have been seen surfacing between the Alaska Highway bridge and the Ibex River mouth late in the spawning season
4	Alaska Highway Bridge on the Takhini (km 57)	6746414.52, 459592.13	To confirm upstream movement to the most downstream known potential spawning areas and evaluate whether there are effects of capture and handling
5	Takhini River mainstem upstream of Stoney Creek (km 87)	6738790.16, 446304.29	Lowermost extent of major spawning areas in the Takhini River downstream of Kusawa Lake.
6	Takhini River mainstem upstream of Stoney Creek (km 87)	6738628.85, 446127.62	To detect movement upstream of known primary Takhini River spawning areas
7	Takhini River at Kusawa Lake	6720068.41, 438293.42	To detect movement into Kusawa Lake
8	Kusawa Lake	6719458.20, 438200.32	To detect movement into Kusawa Lake
9	McIntyre Creek	6736962.08, 494981.99	To detect movement into a potential spawning area
10	Industrial boat launch (6 km upstream of tagging site on Yukon River)	6734919.78, 496616.74	To detect fish that moved upstream from Yukon River gill netting locations, confirming initial post-tagging recovery.
11	Rotary Park (11 km from tagging site on Yukon River)	6730783.10, 497299.96	To detect fish that moved upstream from gill netting locations to approach the WHP. Locations further upstream were unsuitable

			because of river noise or braided channels.
12	Robert Service Way flats (11 km from fishing site on Yukon River)	6730127.48, 497063.23	To detect fish that hold or terminate on the spawning grounds near Robert Service Way
13	Rotary Centennial Foot Bridge ~300 m downstream of ladder (right)	6729308.15, 497707.72	To detect fish that approach the WHP
14	Rotary Centennial Foot Bridge ~300 m downstream of ladder (left)	6729406.44, 497626.28	To detect fish that approach the WHP
R1	Ladder entrance	6728969.86, 497756.32	To detect fish holding at the ladder entrance (attraction efficiency)
R2	Lower ladder	6728970.08, 497760.25	To detect fish in the lower ladder and to separate attraction/entrance/passage elements of ladder efficiency
R3	Ladder turning basin	6729023.76, 497760.61	To detect progress between the ladder entrance and viewing chamber, and identify a potential holding location
15	Viewing chamber	6728972.63, 497778.54	To confirm detections in or adjacent to the viewing chamber
16	Schwatka Lake	6728697.66, 497917.18	To confirm ladder passage success and timing
17	Yukon River mainstem at Wolf Creek	6721227.12, 504750.44	To detect movement in and out of Wolf Creek
18	Wolf creek entrance	6720963.08, 504694.04	A known spawning tributary
19	Wolf creek upstream of the fish ladder	6718977.65, 502892.78	To evaluate use of the fish ladder in Wolf Creek at the Alaska Highway
20	Ibex River	6744470.93, 456052.43	To detect movement into the Ibex River, a tributary of the Takhini River
21	Tagging site on the Yukon River	6739408.96, 493677.39	To confirm tags were emitting frequencies at the time of tagging
22	Downstream of Lewes Dam	6716097.61, 516622.66	To detect passage at the Lewes Dam
23	Upstream of Lewes	6715793.51,	To detect passage at the Lewes

	Dam	517325.26	Dam
24	Mouth of the M'Clintock River	6714080.31, 527843.97	To identify entrance to the Michie Creek - M'Clintock River system
25	M'Clintock River, downstream of confluence with Michie Creek	6726547.10, 528785.88	To identify movement direction at the confluence of the M'Clintock River and Michie Creek
26	M'Clintock River, upstream of confluence with Michie Creek	6726899.03, 528682.90	To identify movement direction at the confluence of the M'Clintock River and Michie Creek
27	Michie Creek, upstream of confluence with M'Clintock River	6726563.37, 528884.43	To identify movement direction at the confluence of the M'Clintock River and Michie Creek
28	Michie Creek, downstream of confluence with Byng Creek	6727930.84, 539863.23	To identify movement direction at the confluence of Michie and Byng creeks
29	Byng Creek	6651830.92, 444223.75	To identify movement direction at the confluence of Michie and Byng creeks
30	Michie Creek, upstream of confluence with Byng Creek	6727871.25, 540064.20	To identify movement direction at the confluence of Michie and Byng creeks
31	Michie Creek, upstream of Michie Lake	6651830.92, 444223.75	To identify movements upstream of Michie Lake
32	Chinook Creek	6690085.44, 543191.68	To identify movement into a potential spawning site off Marsh Lake

Tagging methods

Chinook Salmon were gastrically implanted with Vemco V16 acoustic transmitters or 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 will be 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. A PVC pipe was used to apply transmitters, the end of which was coated in PlastiDip to prevent injury to the viscera. A transmitter was placed in the pipe, which was inserted into the mouth of the fish and pushed to 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 externally tagged behind the dorsal fin with a coloured Floy tag and 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 acoustic tagging and length measurements.

Tagging in the Whitehorse Rapids Fishladder Viewing Chamber

Chinook Salmon were tagged at the Whitehorse Rapids Fishladder by ladder and hatchery staff. A subset of salmon was tagged with V16 transmitters (n=14) while the remainder (n=22) were tagged with the combined acoustic/radio transmitters. Fish were selected for tagging based on size, sex, origin, and arrival data 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, 2019 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 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. Entanglement time averaged 108 s and air exposures averaged 57 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 800 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 9.2 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).

Fish were captured from gill nets in the Takhini River and tagged with V16 transmitters to control for the potential impacts of capture, tagging, and handling on the ability for Chinook Salmon to complete their migration. Though Eiler et al. (2014) observed a 98% post-tagging recovery rate using similar methods in the lower Yukon River, there was concern that Chinook Salmon in the upper Yukon River would be less resilient to handling because of their longer migration and proximity to spawning grounds. 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.

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 26th and September 11th by jet boat. The stretch of river between McIntyre Flats and Lake Laberge was tracked once during this period over September 4th/5th. On August 29th the upper reaches of Michie Creek from Michie Lake to Byng Creek were tracked by foot. A tracking survey was completed on September 3rd over the M'Clintock River, Michie Creek, and Wolf Creek using a Cessna 206.

Data analysis

Terminal reaches were assigned based on the receiver that fish were detected at by September 5th, 2019. 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. Travel times were calculated using the first detection at the downstream receiver of each reach and the first detection at the upstream receiver. Migration rates were calculated as the distance divided by the travel time. The distance between receivers was estimated by manually tracing a path along the thalweg of each reach in Google Earth. Survival of fish that moved back through the WHP was based off 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).

Results

Chinook Salmon were tagged at the ladder viewing chamber (n=36) and by gill net in the Yukon River (n=29) and Takhini River (n=5; Table 1). One fish captured in the viewing chamber was impaired after tagging and was unable to leave the vicinity of the viewing chamber. This fish was taken as broodstock and removed from further analyses and the tag was redeployed into a new fish. The last upstream movement of any fish was detected on September 4th, though downstream movement occurred after this date. After August 29th, 100% of fish detected were male (n=18), despite males comprising just 62% of tagged fish overall and similar average tagging dates of August 17th and 18th for females and males respectively.

Table 2. Origin, sex, and length of fish implanted with acoustic transmitters in 2019 for three treatments. 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	Gill net - Takhini
Large wild male	-	-	-
Medium wild male	23	13	2
Medium wild female	5	14	3
Small wild male	3	-	-
Medium hatchery male	1	-	-
Medium hatchery female	2	2	-
Small hatchery male	2	-	-
Mean fork length (cm±SD)	79±9	83±6	84±5

Fish migrating beyond the WHP

A total of 40 tagged Chinook Salmon migrated beyond the WHP via the ladder in 2019. Most fish (75%) terminated in the Michie Creek - M'Clintock River system (Table 3). Most of these fish terminated in Michie Creek upstream of Byng Creek (64%), 33% terminated in Michie Creek between Byng Creek and the M'Clintock River, and 3% in the M'Clintock River at its confluence with Michie Creek. Additionally, one fish terminated just downstream of the M'Clintock River in Marsh Lake. Finer scale terminal locations of fish in Michie Creek were determined by manual radio tracking on foot and in a Cessna 206 (Figure 3). Migration rates were highest from Schwatka Lake to the mouth of the M'Clintock River, and slowest from the mouth of Michie Creek to the mouth of Byng Creek (Table 4).

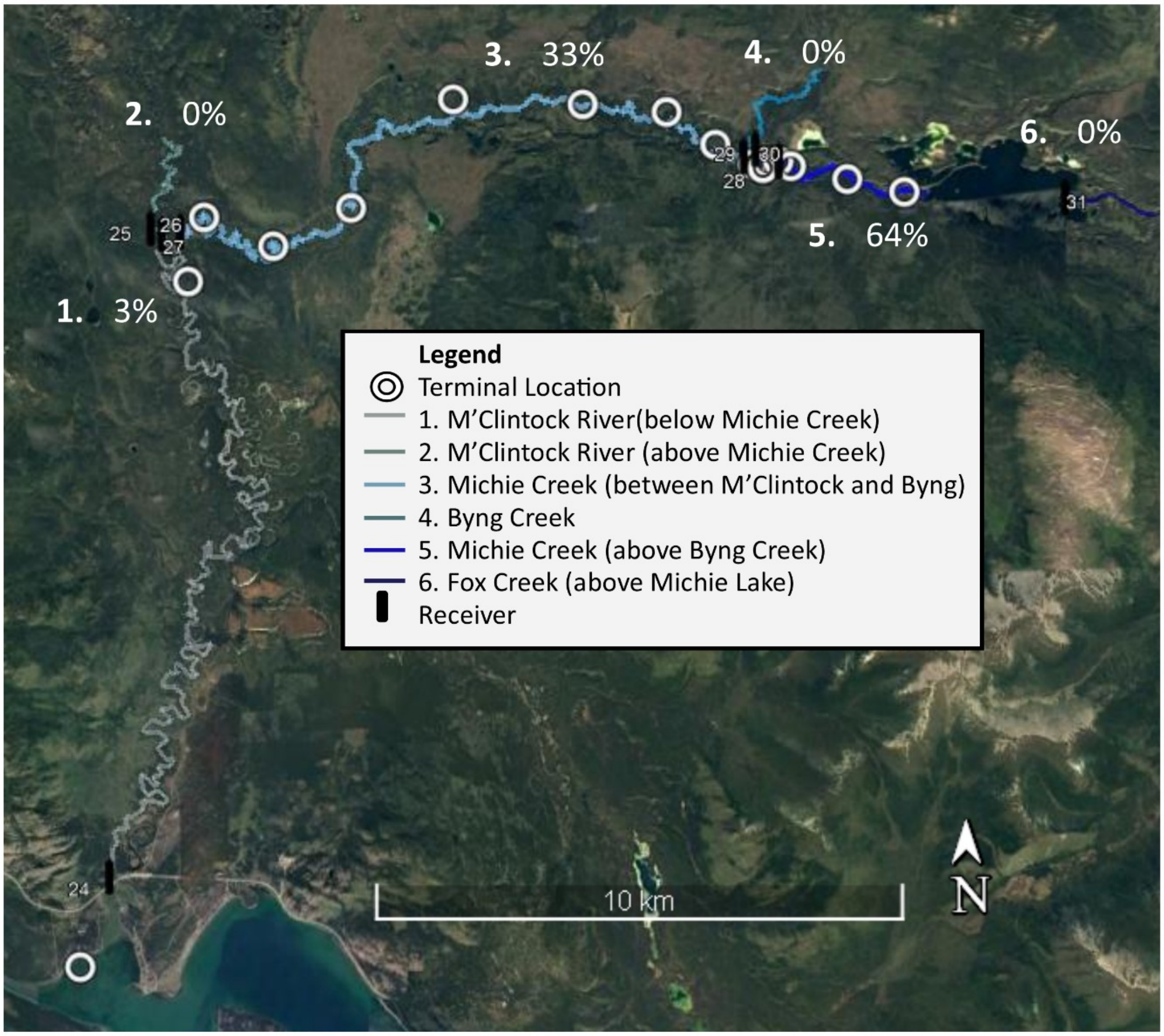

Figure 3. Terminal locations of Chinook Salmon in the Michie Creek - M'Clintock River system in 2019 (n=30 fish). Percentages refer to the proportion of fish terminating in this system that terminated in each reach. White circles represent terminal locations detected by radio tracking. In some cases, multiple fish were detected at the same white circle (ie. at the confluence of Michie and Byng Creek; see appendix Table 3 for GPS locations).

Six fish (15%; all wild males) returned back downstream after passing the WHP, presumably through the spillway. Two wild male fish returned downstream after spending 3 and 4 hours in Schwatka Lake, while three other wild male fish migrated several kilometres beyond the dam before moving back downstream through the dam. One fish went undetected by the Schwatka Lake receiver, making it unclear when it moved downstream through the dam. It appears all fish survived passage downstream through the spillway. Most fish (5/6 fish) were detected on the Robert Service Way spawning grounds, three of which spent an average of 77 ± 13.8 hours at this location. The other two fish in addition to the one fish that was never detected on the Robert Service Way spawning grounds, spent the majority of their time downstream of these spawning grounds (Figure 4).

Figure 4. The six downstream acoustic receivers in closest proximity to the WHP. Receiver 12 is positioned on the Robert Service Way spawning grounds while the reach between 9 and 11 indicates the area termed 'Yukon River between Rotary Park and McIntyre Creek' in this report. White circles represent the locations of fish detected by manual radio tracking by boat between August 30th – September 2nd, 2019. Note that carcasses have the potential to drift several kilometres in this reach of the river, so these sites should not be interpreted as the absolute terminal locations of these fish.

For the first time in this three-year study, no fish terminated in Wolf Creek or in the M'Clintock River upstream of Michie Creek. One female hatchery fish terminated in the mainstem Yukon River downstream of Wolf Creek but was never detected entering Wolf Creek. This fish moved upstream and passed the Lewes Dam before returning downstream at least 30 km (repeating this pattern three times in total before being predated/scavenged downstream of Wolf Creek [tag was recovered on the riverbank]). Three fish (7.5%) were last detected upstream of the Lewes Dam. A radio tracking flight on September 3rd, 2019 identified one of these fish (wild male) in Marsh Lake near the mouth of the M'Clintock River (Figure 5). Another one of these fish was last detected by an Environment Yukon receiver located in Tagish Lake, near Tutshi on August 24th, 2019. The final of the three fish was not detected again after moving upstream beyond the Lewes Dam. These locations warrant further tracking in July of 2020 when these transmitters are re-activated (Figure 6).

Figure 5. The location of a wild male Chinook Salmon (ID: 17875) that was detected during a radio telemetry tracking flight (white circle). This fish was only detected once at a low signal

strength. A low signal could be caused either by distance (±3 km) or deep water, both of which make it difficult to detect radio transmitters. The location of the nearest acoustic receiver in the M'Clintock River is shown (yellow #24), and this fish was not detected there.

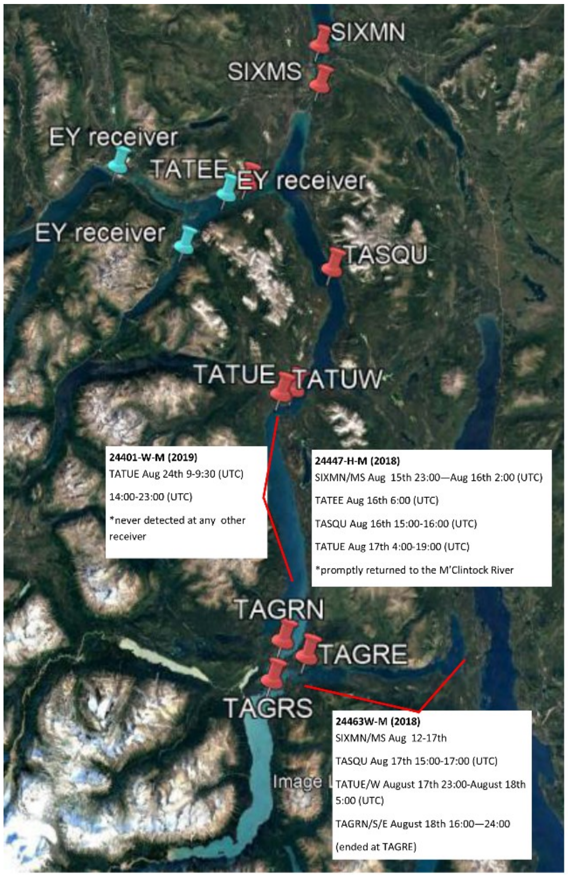

Figure 6. The location of Chinook Salmon (ID: 24463, 24447, 24401) that were detected in the Environment Yukon Southern Lakes receiver array (red and blue pins) in both 2018 and 2019.

Table 3. The proportion of Chinook Salmon migrating upstream of the WHP that terminated at various locations in the upper Yukon River in 2019 (n=40).

Fate	Count	%
Robert Service Way*	3	7.5%
Wolf Creek	0	0%
M'Clintock River upstream of Michie Creek	0	0%
Michie Creek between the M'Clintock River and Byng Creek	10	25.0%
Michie Creek-M'Clintock River Confluence	1	2.5%
Byng Creek	0	0%
Michie Creek upstream of Byng Creek	19	47.5%
Michie Creek upstream of Michie Lake	0	0%
Marsh Lake	1	2.5%
Tagish Lake	1	2.5%

Unknown^	1	2.5%
Mainstem Yukon River between WHP and Wolf Creek	1	2.5%
Mainstem Yukon River between Robert Service Way and the industrial area launch*	3	7.5%

*These fish fell back down through the WHP spillway.
^One fish last detected upstream of the Lewes Dam.

Migration rates

Table 4. Travel times, distances, and migration rates for Chinook Salmon in the upper Yukon River, 2019. The average movement rate represents the minimum movement rate, had fish traveled directly between receivers, and is based on the first detection at each receiver. For the viewing chamber, the last detection was used to control for potential time spent recovering after tagging. Sample sizes differ from terminal location counts due to fish occasionally passing receivers undetected. Data reflects all fish that passed between receivers, and where applicable data for fish captured by gill net is presented in parentheses for comparison.

Tagging location	Reach	Sample size	Distance (km)	Average time (hours)	Standard deviation (hours)	Min time (hours)	Max time (hours)	Average rate (km/hr)
Viewing chamber								
	Viewing chamber to Schwatka Lake	29 (4)	0.3	2.6 (1.1)	1.74	0.5	6.4	0.2
	Schwatka Lake to mouth of M'Clintock River	22 (3)	46.0	29.8 (18.0)	16.2	14.2	78.2	1.9
	Mouth of M'Clintock River to mouth of Michie Creek	29 (4)	32.3	29.2 (17.8)	0.7	11.9	122.0	1.5
	Mouth of Michie Creek to Byng Creek	20 (1)	21.5	75.4 (0.4)	48.5	32.5	241.2	0.4
Gill net (Yukon River)								
	Rotary Centennial Bridge to ladder entrance	7		1.6	2.2	0.4	6.5	0.3
	Entrance to first step of ladder	8		68.9	183.0	0.4	521.5	
	First step of ladder to ladder turning basin	7		17.3	14.4	0.4	37.2	
	Turning basin duration	7		1.6	2.4	0.01	5.7	
	Ladder turning basin to viewing chamber	5		4.3	6.6	0.5	15.7	

Viewing chamber duration	6		14.1	19.3	1.6	52.0	
Viewing chamber to ladder exit	3		14.8	19.0	2.2	47.7	
Gill net (Takhini River)							
Release site to Takhini River (km 15)	4	6.9-11.4	13.4	12.3	5.3	31.3	0.8
Takhini River (km 15) to Alaska Hwy crossing (km 57)	4	41.7	28.3	12.2	19.8	46.3	1.6
Alaska Hwy crossing (km 57) to Stoney Creek (km 87)	4	30.2	31.0	3.4	26.4	34.4	1.0

<u>Tagging by gillnet</u>

The majority of fish captured by gill net in the Yukon River moved upstream after capture (93%; n=29). Two fish (7%) moved downstream permanently after capture and tagging which may be indicative of tagging effects. Approximately 34% of fish tagged by this method (n=10) did not approach the dam or attempt ladder passage. These fish terminated either in the mainstem Yukon River between McIntyre Flats and Rotary Park or on the Robert Service Way spawning grounds (Table 5). Fish that approached the dam and fish ladder (n=17; 59%) were included in an assessment of fish ladder efficiency, aside from one fish that was near death upon reaching the viewing chamber (ie. n=16).

Table 5. The number of Chinook Salmon tagged by gill net downstream of the WHP that terminated at various locations in the upper Yukon River in 2019 (n=29).

Fate	Count	%
Downstream of tagging site*	2	6.9
Robert Service Way	6	20.7
Robert Service Way/Mainstem below the dam^	5	17.2
Mainstem below dam+	11	37.9
Viewing chamber$	1	3.5
Wolf Creek	0	0
M'Clintock River upstream of Michie Creek	0	0
Michie Creek between the M'Clintock River and Byng Creek	3	10.3
Michie Creek upstream of Byng Creek	1	3.5

*Unclear based on detection data whether fish survived capture and tagging

^These fish spent sufficient time on the Robert Service Way spawning grounds and in the other areas of the Yukon mainstem that it is possible they spawned in either location.

+Many of these fish also visited the Robert Service Way spawning grounds for a short period (up to several hours)

$This female fish was near death and was taken by hatchery staff to try and salvage eggs before the fish died.

Autopsy of the fish revealed rupturing of the stomach, which was likely caused by gastric implantation of the acoustic transmitter

The majority of Chinook Salmon (81%; n=16) that approached the dam (i.e., passed the Rotary Centennial Foot Bridge) were detected in the eddy outside the entrance of the ladder. After passing the bridge, fish traveled this ~300 m section and arrived at the entrance eddy in an average of 1.6 ± 2.2 hours. In an extreme case, the first fish tagged approached the ladder on August 2nd, 2019 and did not return until August 25th. During this three week period, this particular fish spent approximately 18 days in the mainstem Yukon River between the dam and Rotary Park before quickly moving downstream at least as far as the confluence of the Takhini River. It then returned upstream to the fish ladder, passed the dam, and arrived at Michie Creek on August 26th. Of the 13 fish that reached the entrance eddy, 77% entered the ladder. Salmon took an average of 4.0 ± 6.1 hours to enter the ladder after arriving at the entrance eddy (excluding one fish that took 521 hours). Of the 10 fish that entered the ladder, all but one (90%) reached the turning basin and did so in an average of 17.3 ± 14.4 hours, including many fish that first left the ladder before reaching the basin during this time. Inside the turning basin, fish took an average of 1.6 ± 2.4 hours before progressing further up the ladder. From the turning basin, seven fish (77%) progressed to the viewing chamber. Fish arriving at the viewing chamber from the turning basin did so in an average of 4.3 ± 6.1 hours. Five fish successfully swam beyond the viewing chamber and exited the ladder into Schwatka Lake. Four fish that passed the viewing chamber reach did so in 4.0 ± 2.2 hours (one fish went undetected at Schwatka Lake) while the two fish that failed to pass the viewing chamber spent 17 and 52 hours respectively in the vicinity of the viewing chamber (summed over the course of several approaches to the viewing chamber). Overall passage through the fish ladder was 31% of those that approached the WHP (n=16; Table 6).

Table 6. Overall passage of tagged Chinook Salmon at the Whitehorse Rapids Fishladder from 2017-2019, including attraction, entrance, and passage efficiencies. Radio receivers were deployed in 2019, allowing passage efficiency to be quantified across various segments of the fish ladder.

	Downstream sample	Entered tail race	Attraction	Entrance	Passage			Overall passage
2019	29	16*	81% (13/16)	77% (10/13)	50% (5/10)			31% (5/16)
					Turning Basin	Viewing chamber	Ladder exit	
					90% (9/10)	77% (7/9)	71% (5/7)	
2018	10	9	>78% (n=9)	>78% (n=9)	>78% (n=9)			66% (6/9)
2017	10	≥6						0% (0/6)

*Value was corrected (added 1 individual) to account for detection probability in tail race. The probability of detecting a fish passing both receivers at the Rotary Centennial Bridge was 78%. If a fish failed to enter the fish ladder it would inherently pass the receivers again at Rotary Centennial Bridge as it moved back downstream. The likelihood of passing these receivers twice undetected was 4.8%. Given that 16 individuals were detected passing these receivers, we predict one additional fish passed these receivers and entered and left the tail race undetected.

Gill netted fish that migrated upstream of the WHP had similar or slightly faster migration rates compared to fish tagged in the viewing chamber, suggesting recovery after capture (Table 4). Most fish (80%; n=5) tagged following gill net capture in the Takhini River were successful in migrating >10 km upstream of the tagging site (a similar distance as the WHP is from the Yukon River tagging site). These fish took an average of 13 hours to reach this location, compared to the multi-day process passing the dam. All fish that moved upstream were last detected in the mainstem Takhini River upstream of Stoney Creek (Table 7). Fish migrated between km 15 and 57 (Alaska Highway at the Takhini River; 41.7 km) of the Takhini River in an average of 28 ± 12 hours compared to the ~118 ± 120 hours it took fish to swim from the Rotary Centennial Bridge to the M'Clintock River (46 km).

Table 7. The number of Chinook Salmon tagged by gill net in the Takhini River that terminated at various locations in the Takhini River in 2019 (n=5).

Fate	#
Upstream of Takhini River km 87	4
Unknown*	1

*Fish was never detected after tagging. It likely terminated between the confluence of the Yukon and Takhini rivers and Takhini River km 12.

Discussion

Spawning sites

The distribution of terminal locations in 2019 (as well as 2017 and 2018) confirms traditional ecological knowledge and other scientific 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 8). Cleugh and Russel (1980) observed 87% of the run entering 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 2017-2019 suggest that 80% of fish that pass the WHP enter 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 the upper reach of 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 52% of fish entering the Michie Creek - M'Clintock River system terminated in Michie Creek upstream of Byng Creek.

In 2017, 2018, and 2019, 11%, 7%, 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, and 33% in 2019). Manual radio tracking by plane in 2019 highlighted several locations that Chinook Salmon may be spawning in this stretch of river (Figure 3). Over three years of this study, just one tagged Chinook Salmon terminated in the M'Clintock River downstream of Michie Creek (fish terminated at the confluence), indicating that this reach may not have suitable or favourable spawning habitat. Further investigations such as spawning ground surveys may be warranted in the lower reaches of Michie Creek where we identified terminal locations in 2019.

In contrast to the first two years of this study, no 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). Two fish explored the creek but left and continued their migration upstream. 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 natural recruitment within this system, though it is unclear whether the creek contains a self-sustaining population or if these are only the direct descendants of returning hatchery-origin fish (i.e., acts as an ecological sink). 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, 15% (all males) returned downstream of the WHP, presumably through the spillway, and never returned 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 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 2019 than in 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).

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 Yukon River fish that moved back through the spillway appeared to survive the event based on their detection patterns downstream of the WHP, including detection on the Robert Service Way spawning grounds receiver located outside of the main river channel. It is unclear whether these fish suffered injuries, or whether they spawned successfully downstream of the dam, though three spent considerable time on the Robert Service Way spawning grounds. Spawning success of fish terminating downstream of the WHP appears variable based on carcass surveys in 2018 and 2019. 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 50 carcasses found downstream of the WHP in 2019, 43 were female, and most females were wild (92%). Of these, 35% had completely spawned, and at least 2% had not spawned at all (ie. experienced pre-spawn mortality; Twardek and Lapointe, 2020). A fecundity model based on broodstock egg counts at the Whitehorse Rapids Fish Hatchery in 2017-2019 estimates that fish found downstream of the WHP exuded ~77% of their eggs (full details in Twardek and Lapointe, 2019, 2020). On the Teslin River, 78% of females had completely spawned, while it was estimated ~93% of eggs in Teslin River fish were released by females (Twardek and Lapointe 2020).

Three fish in 2019 (7.5%) were last detected passing the Lewes Dam with several days remaining in the migration. One of these fish was detected while returning from a tracking flight over Michie Creek. A single detection indicates that fish terminated in Marsh Lake near the mouth of the M'Clintock River (see Figure 5). A second of the three fish was last detected near Tutshi by an Environment Yukon acoustic receiver in Tagish Lake. Attempts will be made in 2020 to manually track the location of these fish by foot, boat, or aircraft. The number of fish terminating in the Southern Lakes was greater than that in the first two years of this study. In 2017, one female fish terminated in an unknown location in Marsh Lake, and in 2018 one male fish terminated in Graham Inlet of Tagish Lake. In 1998, one radio tagged female Chinook Salmon (3% of the total) moved upstream of the Tagish Bridge but eventually terminated in Michie Creek (Matthews 1999a). This behaviour was also observed in one fish in 2018. It is possible that fish terminating in the Southern Lakes spawned, though additional habitat and juvenile surveys would be needed to confirm this (e.g. Von Finster 1995). It is also possible that salmon simply strayed beyond their natal spawning grounds and died without spawning, however, none of the 33 hatchery fish have strayed into the Southern Lakes during the first three years of our study.

Table 8. The proportions of tagged Chinook Salmon that terminated at various locations in the upper Yukon River each year that telemetry projects have been completed in Whitehorse, YT.

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

* 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

After two pilot studies, the number of fish captured by gillnet was increased in 2019. These fish were captured and tagged downstream of the dam as a means to evaluate the effectiveness of the ladder at facilitating fish movement upstream. Migration rates of fish captured by gill net in the Yukon River were comparable to those of fish tagged in the viewing chamber for the sections of river upstream of the WHP (Table 4) indicating recovery of migratory ability soon after capture. Interestingly, a large proportion of fish tagged downstream of the WHP did not approach the WHP despite moving upstream several kilometres from the tagging site.

Movement through the ladder

Overall passage efficiency through the fish ladder was low at just 29% of the seventeen fish that approached the facility. This passage rate is considerably lower than that observed in 2018 (66%) and is also much lower than the average upstream passage rate observed for salmonids in fishways around the world (62%; Noonan et al. 2011). Salmon failed to navigate several different aspects of the fish ladder including finding the entrance, entering the ladder, reaching the turning basin, reaching the viewing chamber, passing the viewing chamber, and in one case reaching the exit. The greatest proportional loss occurred at the viewing chamber, where two fish of seven that arrived were unable to progress further despite spending several hours in the vicinity of the viewing chamber. This was also observed in one fish in 2018. It is unclear why these fish did not pass this area, though in some cases fish approached at night when passage was not possible due to the upstream gate of the chamber being closed. However, these fish also spent time in the chamber when it was open during the day. Fish will often spend time milling 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 improvements if this pattern continues in 2020. 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 most fish this is likely to reflect an inability of fish to enter and pass the WHP 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 below the hydro plant, and effluent from the hatchery may further impact salmon olfactory navigation.

Fish typically moved through various phases of the ladder within two hours but would often move downstream in the ladder before progressing further upstream, increasing total passage times. Further, a small number of fish navigated the ladder twice after falling back through the spillway, further increasing the time associated with ladder passage. Fish ladders can be energetically costly as 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 no indication that salmon have failed to reach spawning areas after passage, though we cannot rule out potential impacts on spawning success as we have been unable to assess spawning status through carcass surveys upstream of the WHP.

Results in 2018 suggest higher overall passage efficiency (66%) than similar tagging in 2019 (31%) and 2017 (0%). In 2017, 6 fish tagged downstream of the WHP (60%) reached the ladder entrance, though just one reached the viewing chamber and it did not pass further. It is also possible that the four other fish captured by gill net in 2017 also approached the WHP but were not detected, given that fewer receivers were deployed downstream of the WHP in 2017. There are multiple reasons why these differences may be observed between years including sampling bias (small sample sizes each year), improved handling practices following 2017, and environmental differences (e.g. flow). Challenging environmental conditions in 2019 likely decreased the resilience of fish to capture/tagging and migratory delays associated with dam passage. August average daily water temperatures in the Yukon River at Whitehorse were higher in 2019 (15.6 °C) than in 2018 (15.1 °C) while water levels (30 m) remained consistent (Environment Canada). Record high water temperatures in the Yukon River in Alaska and spawning tributaries were presumed to be the cause of a mass Summer Chum Salmon mortality event. The elevated temperatures in the Yukon River in Alaska were likely to have had a negative impact on Chinook Salmon as well. The run of Chinook Salmon to Whitehorse (282 fish) was the lowest since the hatchery began operation, and fish were late returning to the ladder relative to recent years. Both observations suggest fish may have been stressed earlier in the run resulting in delayed migration and mortalities. Similarly, tagged fish seemed to fare more poorly than in previous years, with a smaller proportion passing the ladder than in 2018, a greater proportion falling back after passing the ladder, and two fish dropping back after gill net tagging. While it seems likely that challenging environmental conditions had an impact on the response to tagging and ability for fish to complete their migration, sample sizes remain small and results should be interpreted with caution. Moving forward, it is expected water temperatures will increase in the Yukon (Goulding 2011), which will undoubtedly impact Chinook Salmon migrations in the terminal reaches of the upper Yukon River.

Conclusions

Acoustic tagging of Chinook Salmon in the upper Yukon River in 2019 highlighted the importance of multiple spawning areas within Michie Creek, consistent with our previous findings. Interesting differences existed in the terminal locations of fish in 2019, with no fish terminating in Wolf Creek or the upper M'Clintock River, and at least two fish terminating in the Southern Lakes area. Although sample sizes remain small over three years, preliminary estimates of overall ladder passage efficiency have been generated and will be refined with additional data in 2020. Further consideration should be given to the mainstem Yukon River below the WHP and the Robert Service Way spawning grounds, given the high proportion of fish that terminated in this area.

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Appendices

Appendix 1. Detection rate of a range test tag placed near each receiver for a fixed period of time in 2018.

Receiver #	Location	Rationale	Distance (m)	Detection rate
1	Confluence of the Yukon and Takhini rivers	Directly across from receiver on opposite bank	150	24%
2	Takhini River km 11	Directly across from receiver on opposite bank	87	74%
7	Industrial boat launch	Upstream of receiver on opposite bank	280	0%
8	Rotary Park	Directly across from receiver on opposite bank	150	0
10	~500m downstream of ladder	Directly across from receiver on opposite bank	71	7%
11	Turbine eddy	Beside receiver	1	70%
11	Turbine eddy	End of the eddy	5	0%
12	Weir eddy	End of the eddy	30	1%
12	Weir eddy	End of the eddy in main channel	35	0%
13	Platform eddy	End of the eddy in main channel	50	0%
14	Ladder entrance	Beside receiver	2	26%, 19%
14	Ladder entrance	Beyond retaining wall within eddy 10m	5	0%
14	Ladder entrance	Beyond retaining wall within eddy	10	0%
14	Ladder entrance	Inside ladder, beyond entry	3	0%
14	Lower ladder (first step)	First step	1	69%
15	Lower ladder (first step)	First step below, first step above	3	0%, 0%
16	Ladder turning basin	Lower end of basin	2	69%
16	Ladder turning basin	Upper end of basin	3	39%
16	Ladder turning basin	First step below, first step above	5	0%
17	Viewing chamber	At lower end of the chamber	5	70%
17	Viewing chamber	First step below	7	44%
17	Viewing chamber	Second step below	10	0%
18	Spillway	Near receiver	3	0%
18	Spillway	Lower end of eddy	30	0%

21	Upper Wolf Creek	Near receiver	1	~25%
21	Upper Wolf Creek	Near receiver	1.5	~25%
21	Upper Wolf Creek	Near receiver	2	~25%
21	Upper Wolf Creek	Downstream run	10	0%
21	Upper Wolf Creek	Downstream run	12	0%
22	Lewes Dam	Upstream of receiver, just downstream of the Lewes Dam	450	48%
23	Mouth of the M'Clintock River	Directly across from receiver on opposite bank	55	75%
30	Michie Creek, upstream of Michie Lake	Same bank	5	42%

Appendix 2. The detection efficiency of fish passing each receiver based on subsequent detection at upstream receiver sites in 2019. 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.

Receiver	Detection efficiency (%)
Industrial Boat Launch	43% (n=22)
Rotary Park	33% (n=21)
Rotary Centennial Bridge	66% (n=12)
Ladder entrance	100% (n=9)
Ladder first step	100% (n=8)
Ladder turning basin	100% (n=6)
Viewing chamber	97% (n=30)
Schwatka Lake	75% (n=36)
Below Lewes Dam	100% (n=36)
Above Lewes Dam	100% (n=30)
Yukon @ Wolf Creek	66% (n=36)
Mouth of M'Clintock River	100% (n=22)
Michie Creek at the M'Clintock River	100% (n=20)
Michie Creek at Byng Creek	100% (n=20)

Appendix 3. The terminal locations of each Chinook Salmon tagged with an acoustic transmitter in 2019. Fish were captured and tagged at the Whitehorse Rapids Fishladder viewing chamber (n=36), by gill net downstream of the WHP in the Yukon River (n=29), or by gill net in the Takhini River (n=5). 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 (<1 km 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	Date final loc.	Terminal Location
Ladder	17837	05/08/2019	M	74	wild		Michie Creek upstream of Byng Creek 8 V 540431 6727793 (minimal error)
Ladder	30458	06/08/2019	F	81	wild		Michie Creek upstream of Byng Creek
Ladder	17840	10/08/2019	M	62	wild		Michie Creek downstream of Byng Creek 8 V 540158 6727772 (±1 km)
Ladder	17880	11/08/2019	M	79	wild		Michie Creek upstream of Byng Creek 8 V 540348 6727699 (minimal error)
Ladder	24473	11/08/2019	M	72	wild		Michie Creek upstream of Byng Creek
Ladder	17839	12/08/2019	M	93	wild		Michie Creek upstream of Byng Creek 8 V 540646 6727831 (minimal error)
Ladder	24393	12/08/2019	M	76	hatch		Michie Creek upstream of Byng Creek
Ladder	17846	13/08/2019	M	85	wild		Michie Creek upstream of Byng Creek 8 V 540348 6727699 (exact location)
Ladder	17858	14/08/2019	F	86	hatch		Yukon River mainstem upstream of dam 8 V 502849 6720727 (exact location)
Ladder	17859	15/08/2019	F	85	wild		Michie-M'Clintock Confluence 8 V 529335.90, 6725533.78 (low error)
Ladder	24401	15/08/2019	M	71	wild		*Last detected upstream of Lewes Dam*
Ladder	24448	15/08/2019	F	83	wild		Michie Creek upstream of Byng Creek
Ladder	17852	16/08/2019	F	92	wild		Michie Creek upstream of Byng Creek 8 V 540350 6727714 (exact location)
Ladder	17857	16/08/2019	M	87	wild		Michie Creek upstream of M’Clintock River 8 V 529644.14, 6726762.65 (low error)
Ladder	24464	16/08/2019	M	68	wild		Michie Creek upstream of Byng Creek
Ladder	17861	17/08/2019	F	85	wild		Michie Creek upstream of M’Clintock River 8 V 532462.83, 6726944.08 (low error)
Ladder	24444	17/08/2019	M	71	wild		Michie Creek upstream of Byng Creek 8 V 540882 6727735 (exact location)
Ladder	17853	18/08/2019	M	89	wild		Yukon River between Rotary Park and McIntyre Creek
Ladder	17854	18/08/2019	M	85	wild		Michie Creek upstream of Byng Creek 8 V 540417 6727823 (minimal error)

Ladder	17862	18/08/2019	M	85	wild	Michie Creek upstream of Byng Creek 8 V 544599 6726169 (high error)
Ladder	17867	20/08/2019	F	81	hatch	Michie Creek upstream of M'Clintock River 8 V 539442.99, 6728154.37 (low error)
Ladder	24399	20/08/2019	M	63	hatch	Michie Creek upstream of Byng Creek
Ladder	17868	21/08/2019	M	54	hatch	Tagging mortality
Ladder	24405	21/08/2019	M	87	wild	Michie Creek upstream of Byng Creek
Ladder	24418	21/08/2019	M	85	wild	Robert Service Way spawning grounds
Ladder	24474	21/08/2019	M	66	wild	Michie Creek upstream of Byng Creek (confluence)
Ladder	24422	22/08/2019	M	78	wild	Michie Creek upstream of M'Clintock River
Ladder	24454	22/08/2019	M	88	wild	Michie Creek upstream of Byng Creek
Ladder	17841	23/08/2019	M	80	wild	Michie Creek upstream of Byng Creek 8 V 541963 6727488 (±4 km)*
Ladder	17875	24/08/2019	M	76	wild	Marsh Lake near the M'Clintock River 8 V 527267.86, 6712369.15 (high error)
Ladder	17813	25/08/2019	M	84	wild	Yukon River between Rotary Park and McIntyre Creek 8 V 495800 6736912 (minimal error)
Ladder	17812	26/08/2019	M	78	wild	Michie Creek upstream of M'Clintock River 8 V 534420.60, 6729029.42 (low error)
Ladder	17818	26/08/2019	M	79	wild	Michie Creek upstream of M'Clintock River 8 V 538510.38, 6728780.60 (low error)
Ladder	17819	26/08/2019	M	82	wild	*Last detected upstream of Lewes Dam*
Ladder	17868	26/08/2019	M	73	wild	Robert Service Way spawning grounds
Ladder	24409	30/08/2019	M	73	wild	Robert Service Way spawning grounds
Downstream gill net	17844	1-08-2019	M	85	wild	Michie Creek upstream of M'Clintock River 8V 536903.02, 6728928.56 (low error)
Downstream gill net	17878	11-08-2019	F	78	hatch	Yukon River between Rotary Park and McIntyre Creek
Downstream gill net	17842	11-08-2019	F	83	wild	Michie Creek upstream of M'Clintock River 8 V 530971 6726212 (±1 km)
Downstream gill net	17849	11-08-2019	M	92	wild	Yukon River between Rotary Park and McIntyre Creek 8 V 495685 6736190 (minimal error)
Downstream gill net	17845	17-08-2019	F	77	wild	Downstream of tagging site on Yukon River

Downstream gill net	17855	17-08-2019	F	92	wild	Robert Service Way spawning grounds 8 V 495545 6737291 (minimal error)
Downstream gill net	17847	18-08-2019	M	82	wild	Robert Service Way spawning grounds 8 V 495715 6736182 (minimal error)
Downstream gill net	17836	18-08-2019	M	81	wild	Michie Creek upstream of Byng Creek 8 V 540417 6727823 (exact location)
Downstream gill net	17850	18-08-2019	M	87	wild	Robert Service Way spawning grounds/YR mainstem downstream of dam 8 V 495756 6735942 (exact location)
Downstream gill net	17851	18-08-2019	F	80	wild	Robert Service Way spawning grounds 8 V 497080 6730445 (minimal error)
Downstream gill net	17843	18-08-2019	F	79	wild	Yukon River between Rotary Park and McIntyre Creek 8 V 497293 6731951 (exact location)
Downstream gill net	17876	18-08-2019	F	81	wild	Robert Service Way spawning grounds/YR mainstem downstream of dam 8 V 495911 6736695 (minimal error)
Downstream gill net	17863	18-08-2019	F	87	wild	Downstream of tagging site on Yukon River 8 V 495801 6756068 (minimal error)
Downstream gill net	17864	18-08-2019	F	84	wild	Downstream of tagging site on Yukon River 8 V 495720 6736156 (minimal error)
Downstream gill net	17865	18-08-2019	M	73	wild	Robert Service Way spawning grounds/YR mainstem downstream of dam 8 V 495585 6736531 (exact location)
Downstream gill net	24425	18-08-2019	F	81	wild	Robert Service Way spawning grounds/YR mainstem downstream of dam
Downstream gill net	17869	20-08-2019	M	79	wild	Yukon River between Rotary Park and McIntyre Creek
Downstream gill net	17870	21-08-2019	F	88	wild	Robert Service Way spawning grounds/YR mainstem downstream of dam 8 V 495146 6736928 (exact location)
Downstream gill net	17871	21-08-2019	M*	74	wild	Robert Service Way spawning grounds 8 V 496601 6733814 (exact location)
Downstream gill net	17866	21-08-2019	M	75	wild	Yukon River between Rotary Park and McIntyre Creek
Downstream gill net	17860	22-08-2019	M	82	wild	Robert Service Way spawning grounds 8 V 495641 6755226 (minimal error)
Downstream gill net	17874	22-08-2019	M	89	wild	Yukon River between Rotary Park and McIntyre Creek

Downstream gill net	17877	22-08-2019	M	95	wild	Yukon River between Rotary Park and McIntyre Creek
Downstream gill net	17816	22-08-2019	F	84	wild	Yukon River between Rotary Park and McIntyre Creek
Downstream gill net	17820	22-08-2019	F	80	wild	Viewing chamber
Downstream gill net	17814	22-08-2019	F	90	wild	Robert Service Way spawning grounds 8 V 497080 6730445 (minimal error)
Downstream gill net	17821	22-08-2019	F	78	wild	Yukon River between Rotary Park and McIntyre Creek 8 V 495907 6736801 (minimal error)
Downstream gill net	17815	22-08-2019	F	92	hatch	Yukon River between Rotary Park and McIntyre Creek 8 V 497251 6730288 (minimal error)
Downstream gill net	24462	22-08-2019	M	74	wild	Michie Creek upstream of M'Clintock River
Takhini gill net	24402	14-08-2019	F	85	wild	Upstream of Takhini River km 87
Takhini gill net	24439	14-08-2019	M	87	wild	Upstream of Takhini River km 87
Takhini gill net	24442	14-08-2019	M	91	wild	Upstream of Takhini River km 87
Takhini gill net	24400	16-08-2019	F	77	wild	Upstream of Takhini River km 87
Takhini gill net	24406	16-08-2019	F	81	wild	NO DATA (likely between Takhini River km 0 and km 12)

*Fish 17841 was detected at the mouth of Michie Lake on August 19, 2019 but later appeared to move downstream to spawn.

+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 several cases, transmitters were retrieved from the riverbank after the tagged fish was preyed/scavenged upon.