Survey of Chinook Salmon (*Oncorhynchus tshawytscha*) carcasses in Whitehorse, Yukon - 2019

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Abstract

Carcass surveys can provide valuable information on spawning success, escapement, population characteristics, and run timing in anadromous fish stocks. During the 2019 Chinook Salmon (*Oncorhynchus tshawytscha*) run, carcass surveys were completed approximately daily to provide information on egg retention and spawning escapement of upper Yukon River Chinook Salmon downstream of the Whitehorse Hydro Plant (WHP). Carcasses were assessed for sex, size, and origin, and the total number of eggs remaining in the body cavity was estimated volumetrically. Surveys were also completed in the Teslin River downstream of Johnson's Crossing to determine whether egg retention rates observed in Whitehorse are similar to those observed in other nearby populations. Surveys identified 50 carcasses in the Yukon River and 96 in the Teslin River. In the Yukon River, the majority of carcasses recovered were female (86%). Female egg deposition rate was estimated at 77% (same as in 2018) in the Yukon River compared to 93% in the Teslin River. A lower proportion of Yukon River fish spawned completely (35%), compared to fish on the Teslin River (78%). Complete pre-spawn mortality was confirmed in one female fish each from the Yukon River and the Teslin River. Spawning escapement downstream of the WHP was estimated using the recovery rate of broodstock carcasses released downstream of the WHP. Although estimates are crude, they suggest a substantial proportion of the population migrating to Whitehorse terminated downstream of the WHP in 2019.

Introduction

Carcass surveys are a valuable tool used in fisheries management to understand spawning success, spawning escapement, run characteristics, and pre-spawn mortality (DeWeber et al. 2017; Rawding et al. 2014; Murdoch et al. 2010). Carcass surveys are well suited for Pacific salmon (*Oncorhynchus* spp.) given that they typically die over a small spatial area and temporal scale, in shallow habitats where carcasses can be recovered. Carcass surveys have been used throughout the Yukon River (Table 2), including a small number of surveys completed downstream of the Whitehorse Hydro Plant (WHP), YT. The WHP was constructed in 1958 and the Whitehorse Rapids Fishladder has operated there since 1959, passing an average of ~1200 adult Chinook Salmon (*Oncorhynchus tshawytscha*) of both wild and hatchery origin each year. Chinook Salmon are known to spawn downstream of the WHP in the section of river adjacent to Robert Service Way. Surveys of this spawning area found between 68-89 Chinook Salmon on redds each year between 1998-2002 (ACG and YES 2002). This area (and sections further downstream) has also been surveyed for carcasses in the past, but samples sizes remained small. In 2005, 14 carcasses were found over three surveys conducted in this reach (von Finster 2005). Of these, 13 were female and 5 had either released < 5% of their eggs or had not spawned.

To identify carcass deposition zones and develop carcass detection and retrieval methods, three pilot carcass surveys were conducted in Whitehorse, YT, in August 2017. Participants included the Canadian Wildlife Federation, Carcross/Tagish First Nation, Ta'an Kwäch'än Council, Carleton University, and A. von Finster. The goals of the pilot study were to assess carcass distribution and to inform future efforts to develop standardized carcass monitoring protocols. Egg deposition was variable during this study but was not quantified (Sebes and Lapointe 2017). Of 14 fish in good enough condition to estimate spawning status, 50% appeared to have retained >90% of their eggs. In 2018 survey effort was increased to 15 surveys downstream of the WHP, egg retention was measured volumetrically, and spawning status was visually assigned. Visual assessment is most commonly used for carcass surveys as a proxy for spawning success (78% of studies; Bowerman et al. 2016), though volumetric measurements are recommended for the Yukon River (YRP 2007).

Egg retention rates were high in this reach of the Yukon River in 2018 compared to other Chinook Salmon populations (Table 2). There are two hypotheses that could explain this phenomenon. First, egg retention may be a natural occurrence related to the extreme length of the migration undertaken in freshwater prior to reaching spawning grounds (>3000 km). Alternatively, egg retention could be a result of failed ladder passage (or fall back) at the Whitehorse Rapids Fish Ladder, preventing fish from reaching intended spawning sites. The observation of hatchery carcasses downstream of the fishway provides some support for the latter hypothesis, as all hatchery fish are stocked upstream and have high fidelity (93%) to stocking locations (De Graaf 2005). Some female fish terminating downstream of the WHP may also have passed the ladder and fell back through the spillway (though this has not been observed in any of the 33 fish acoustically tagged as part of Twardek and Lapointe 2020). To discern between these competing hypotheses, egg retention rates in Chinook Salmon terminating downstream of the WHP were compared to other upper Yukon River populations that complete migrations of similar length. If other upper Yukon River populations of Chinook Salmon have low egg retention rates, it would suggest that high egg retention in Chinook Salmon downstream of the WHP is related to passage issues associated with the Whitehorse Rapids Fish Ladder rather than the length of migration completed.

The main goals of the carcass surveys in 2019 were to;

1) provide further information on Chinook Salmon egg retention rate in the mainstem Yukon River downstream of the WHP. Specific objectives associated with this goal were to;

- Provide estimates of the egg retention rate of Chinook Salmon downstream of the WHP
- Investigate the sex, size, and origin (wild vs. hatchery) of carcasses and relate estimated egg retention to size, origin, and run timing
- Estimate total abundance of Chinook Salmon terminating downstream of the WHP

2) compare egg retention rates downstream of the WHP to that of other nearby populations of Chinook Salmon

- Quantify spawning success of Chinook Salmon in the Teslin River
- Compile information from previous carcass surveys on Chinook Salmon from the upper Yukon River

3) refine carcass survey methods for future surveys. Specific objectives associated with this goal were to;

- Identify additional carcass deposition sites downstream of the WHP
- Assess detectability and drift of carcasses
- Determine the timing of carcass deposition

Methods

Study site

Carcass surveys were completed every one to six days (23 surveys) between August 12th and September 12th (Table 1). Surveys comprised several transects between McIntyre Creek and the Robert Service Way spawning grounds (Figure 1). Sections of the river that were too deep to detect and retrieve carcasses from were not surveyed. Similarly, fast sections of river that were not likely to retain carcasses were only surveyed once. After repeatedly locating carcasses in distinct locations along the river, we restricted our surveys to established sites (Figure 1). These locations generally corresponded to the major deposition sites identified in previous carcass surveys on this stretch of river (von Finster, 2005; Sebes and Lapointe,

2017) though additional locations were added. Surveys were also completed on the Teslin River approximately 4 km downstream of Johnson's Crossing (three surveys), on Michie Creek between Michie Lake and Byng Creek (one survey), and on the Takhini River from Kusawa Lake downstream 11 km (one survey).

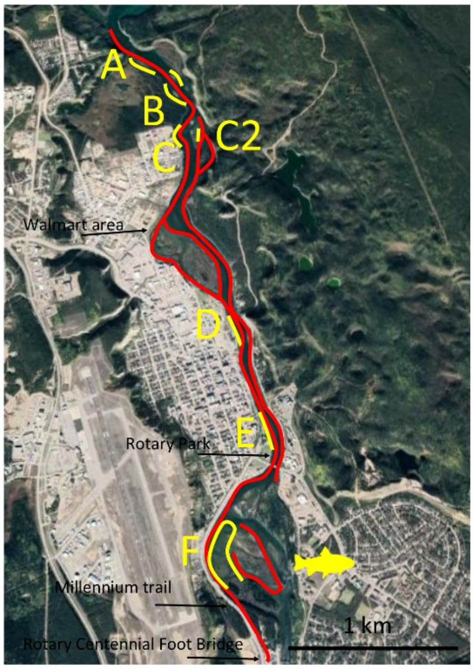

Figure 1. Transects surveyed for carcasses downstream of the Whitehorse Hydro Plant, Whitehorse, YT in 2019. The complete area searched (at least one search; red lines), zones where carcasses were observed (yellow lines), and the Whitehorse Rapids Fish Hatchery (yellow fish) are shown on the map.

<u>Sampling methods</u>

Carcass surveys were primarily completed by staff from Canadian Wildlife Federation, Carleton University, and Carcross/Tagish First Nation, with help from Yukon Fish and Game Association. To complete surveys, a jetboat was operated at slow speed (<10 km/h) approximately 5 m from the shoreline while two surveyors searched for carcasses. Surveys lasted between 1-7 hours depending on the number of carcasses found. When a carcass was observed, the boat driver held position in the river while surveyors retrieved the carcass using a telescopic window washing pole with a large treble hook attached at the terminal end of the pole. Carcasses were sampled on site following the Yukon River protocol for carcass/pre-spawning mortality data (Yukon River Panel 2007). Briefly, carcasses were photographed, assessed for sex, fork length, mid-eye fork length, and decomposition state. Decomposition was scored based on surface area covered in fungus (%), and presence of fin decay. Otoliths and tissues were sampled from most fish, depending on level of decomposition. Fish were classified as having completely-spawned, partially spawned, or experienced pre-spawn mortality (as per Quinn et al. 2007; see Figure 2). Complete spawning was assigned visually to fish that had less than 100 eggs retained in their body cavity. Partially-spawned fish could generally not be distinguished from those that experienced pre-spawn mortality visually. The distinction between partial spawning and pre-spawn mortality was later estimated using a length-based fecundity model derived from broodstock fish collected at the Whitehorse Rapids Fish Hatchery (described below). Gonads were photographed and measured volumetrically using a measuring cup to the nearest 25 mL and weighed to the nearest 10 grams. A subset of 50 eggs were measured in a 50 mL graduated cylinder. This measurement was used to estimate the total number of eggs per fish.

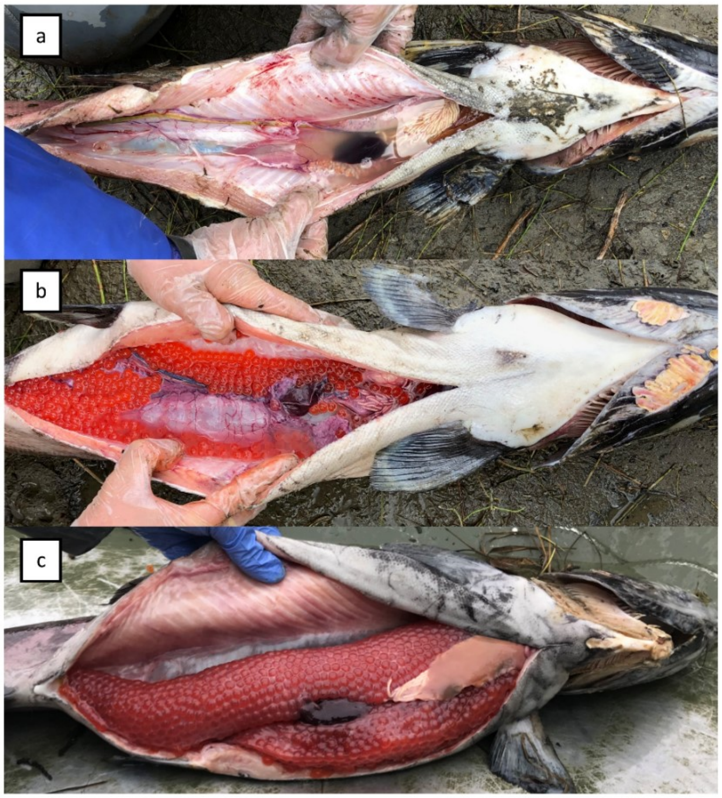

Figure 2. Chinook Salmon carcasses were classified as having: a) completely spawned, b) partially spawned, or c) experienced pre-spawn mortality.

Residency time

Five male broodstock carcasses in excellent condition were implanted with radio transmitters and released into the river outside the Whitehorse Rapids Fish Hatchery on September 6th, 2019. Only males were used because female body cavities had been opened during egg fertilization, which could further affect drift and deposition. These carcasses were actively tracked by jetboat on days 1 and 5 after release to determine travel rates and timing of deposition.

Spawning escapement estimates

The number of Chinook Salmon that terminated in the mainstem Yukon River downstream of the WHP was estimated using two different methods. The first method estimated the number of fish terminating downstream of the WHP using the terminal locations of 27 fish implanted with acoustic transmitters several kilometres downstream of the WHP during a concurrent telemetry study (Twardek and Lapointe, 2020). Four of the 27 fish terminated upstream of the ladder, indicating that 85% of fish that enter the study reach remain downstream of the WHP. We therefore assumed that the fish counted passing through the Whitehorse Rapids Fishladder represented 15% of the total population, and that 85% remained downstream (Equation 1). We note that many of these fish did not approach the ladder, and these numbers should not be interpreted as a measure of passage efficiency.

Equation 1. The equation used to estimate the number of Chinook Salmon that terminated downstream of the WHP in 2019 based on the proportion of fish tagged with acoustic transmitters that remained downstream of the WHP (Twardek and Lapointe 2020). This equation assumes that passage proportions are equivalent for males and females at the Whitehorse Rapids Fishladder. F_T= Total number of fish downstream of the ladder, L_T = total number of fish counted at the ladder, F_{NT}= number of fish tagged downstream of the WHP that did not pass, and P_{NT}= number of fish tagged downstream of the WHP that did pass.

$$F_T = L_T * F_{NT} / P_{NT}$$

The second method was based on an estimate of survey efficiency calculated from the recovery of broodstock fish. Broodstock carcasses from the Whitehorse Rapids Fish Hatchery are returned to the river throughout the season. These carcasses have their heads removed, making them distinguishable from in-river mortalities. The number of these carcasses found during subsequent surveys was recorded and was used to estimate survey efficiency (# of broodstock found / # of broodstock released). The total number of non-broodstock carcasses observed was then divided by the survey efficiency to estimate the total number of non-broodstock carcasses that terminated in this reach.

Statistical analyses

To estimate fecundity by size (fork length), a linear equation was developed from broodstock fecundity data from 2017-2019 provided by the Whitehorse Rapids Fish Hatchery. This information was then used to estimate egg deposition (% of predicted fecundity expelled from the body; as per Cook et al. 2011; McConnachie et al. 2012; Raby et al. 2013). We refer to egg deposition and retention rather than spawning success given that the site of egg deposition and extent of hatching success are unknown. To compare egg retention rates of fish from the Yukon and Teslin rivers (and control for size differences between fish), we divided retained egg mass by fish mass (i.e., retained gonadosomatic index; GSI). Differences in egg retention between the Yukon and Teslin rivers were tested with a Mann-Whitney Rank Sum test. Differences in fecundity among years were tested using ANOVA. Similarly, differences in fecundity between locations (Yukon and Teslin rivers) were tested using ANOVA. The relationship between egg retention and fish length was modeled using linear regression. Linear regression was also used to test the relationship between fecundity and fish length. The relationship between egg retention and date of sampling was depicted with a polynomial regression.

Table 1. Date and extent of each carcass survey completed in 2019. Sites are referenced from Figure 1.

Survey ID	Date	Extent
1	12/08/2019	Sites A, B
2	14/08/2019	Sites A, B
3	20/08/2019	Sites A, B
4	21/08/2019	Sites A, B, C, D
5	22/08/2019	Sites A, B
6	23/08/2019	Sites A, B, C, D, C2
7	24/08/2019	Sites A, B, C, D
8	25/08/2019	Sites A, B, C, D
9	26/08/2019	Sites A, B, C, D, E, C2, across from Site B, McIntyre flats and braided islands, McIntyre Creek
10	27/08/2019	Sites A, B, C, D, E, gravel bar between A and B.
11	28/08/2019	Sites A, B, C, D, E, C2

12	30/08/2019	Sites A, B, C, D, E, C2, gravel bar between A and B, Walmart area
13	01/09/2019	Sites A, B, C, D, E, C2, gravel bar between A and B, across from Site B, McIntyre flats
14	02/09/2019	Sites A, B, C, D, E, C2, McIntyre flats (right side), misc. other spots
15	03/09/2019	Sites A, B, C, D, E, C2, across from Walmart area
16	05/09/2019	Sites A, B, C, D, E, C2
17	06/09/2019	Sites A, B, C, D, E, C2
18	07/09/2019	Sites A, B, C, D, E, C2
19	09/09/2019	Sites A, B, C, D, E, C2
20	11/09/2019	Sites A, B, C, D, E, C2
21	04/09/2019	Teslin River – Johnson's Crossing
22	06/09/2019	Teslin River – Johnson's Crossing
23	12/09/2019	Teslin River – Johnson's Crossing

Results

Fifty carcasses (82±6 cm fork length) were sampled from the Yukon River compared to 96 (88±7 cm) from the Teslin River during surveys in 2019. Carcasses from the Yukon River were primarily female (86%) and wild in origin (92%). Carcasses were found at sites A (30%), B (24%), C (12%), C2 (4%), D (6%), E (12%), and F (12%). Carcass recovery began on August 24th, peaked September 6th, and continued until our last survey on September 11th (Figure 3). All fish sampled from the Teslin River were of wild origin, and most were female (79%). No intact carcasses were found during surveys in Michie Creek or the Takhini River.

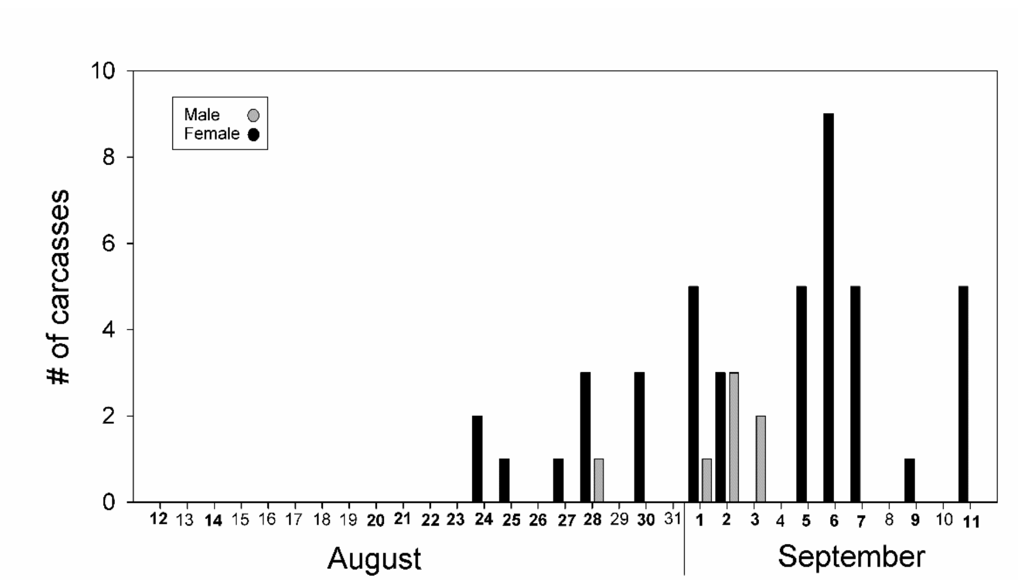

Figure 3. The number of carcasses recovered during each of our carcass surveys in the Yukon River downstream of the WHP in 2019. Days when carcasses surveys were completed are highlighted in bold.

<u>Fecundity</u>

From 2017-2019, Chinook Salmon (N=90) collected at the Whitehorse Rapids Fish Hatchery had an average fecundity of 4901 eggs (2086-7611 eggs). There was a positive relationship between fork length (mm) and fecundity (R^2=0.43, DF=89, p<0.01; Figure 4). Average fecundity did not differ significantly among 2017-2019 sampling years (DF=89, F-value=2.3, P=0.1; Figure 5).

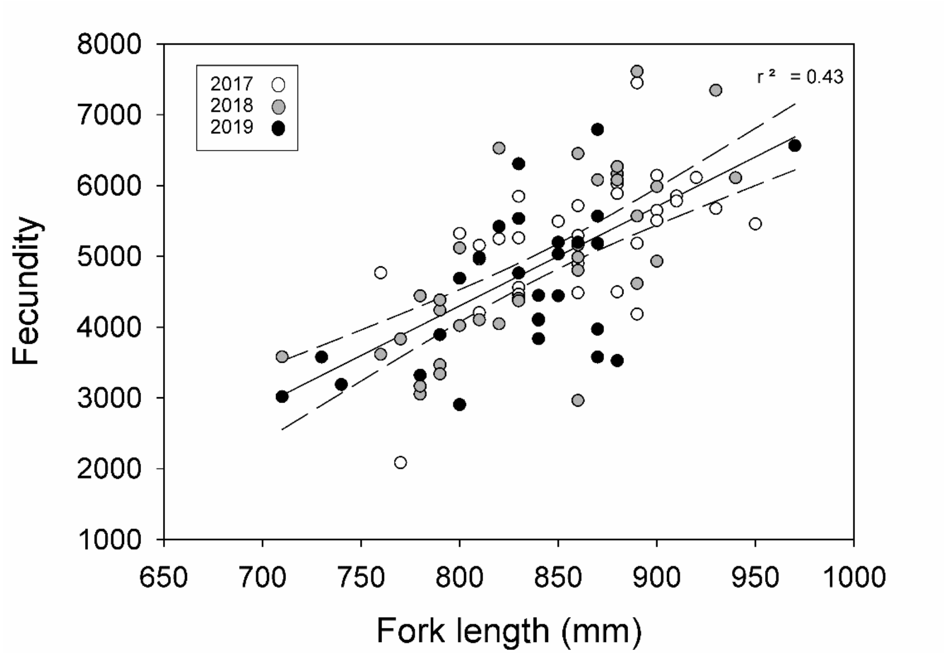

Figure 4. Fecundity of Chinook Salmon from the Whitehorse Rapids Fish Hatchery relative to fork length (mm) from 2017-2019. All years were combined for the linear regression analysis (y=14.03x – 6922.14; R^2=0.43, p<0.01).

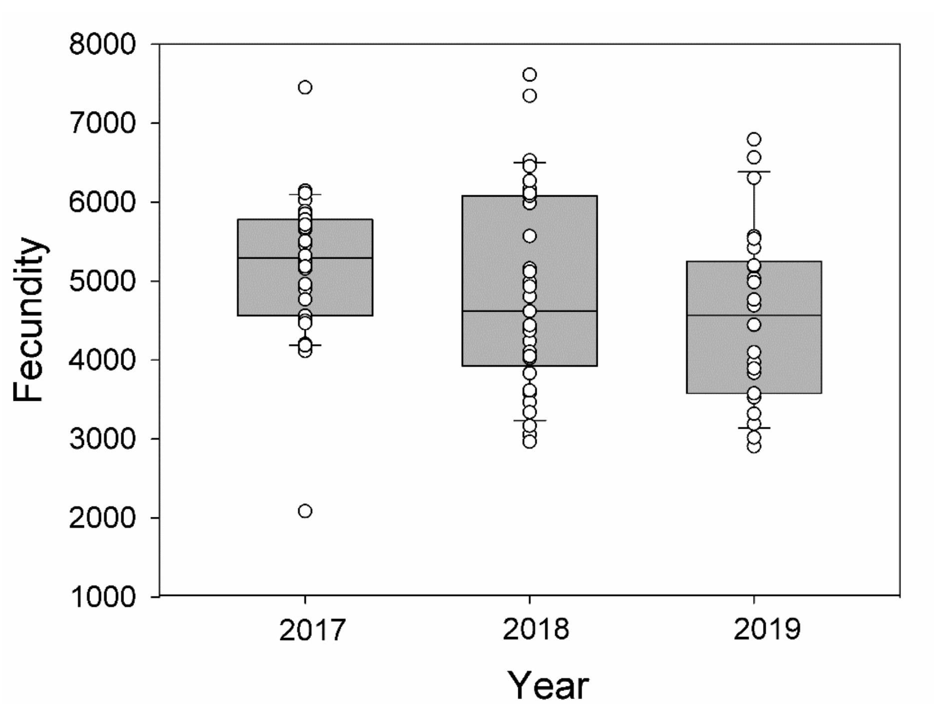

Figure 5. Fecundity of female Chinook Salmon from the Whitehorse Rapids Fish Hatchery from 2017-2019.

Egg retention

Visual surveys identified 35% of fish from the Yukon River as having spawned completely compared to 78% in the Teslin River. Relative to other nearby spawning populations in the Yukon River watershed, the rate of complete spawning in fish sampled downstream of the WHP is low (Table 1). It is unclear how many fish completely failed to deposit eggs (i.e. experienced pre-spawn mortality) because it is difficult to distinguish these fish from partially-spawned fish. However, one fish from each river was assigned as a pre-spawn mortality based on the estimated number of eggs retained relative to estimated fecundity. Egg retention in the Yukon River was approximately four times higher on average than egg retention on the Teslin River (DF=117, Mann-Whitney U Statistic= 922.0, $p<0.001$; Figure 6). It was estimated volumetrically that this corresponds to 23% of total fecundity retained in the Yukon River and 7% of total fecundity in the Teslin River. Egg retention did not correlate with fish length in the Yukon River ($R^2=0.06$, DF=42; p=0.1) or the Teslin River ($R^2<0.01$, DF=75; p=0.43; Figure 7). Egg retention in Yukon River Chinook Salmon carcasses was not significantly correlated with date during our survey period ($R^2=0.04$, DF=42, P=0.2; Figure 8).

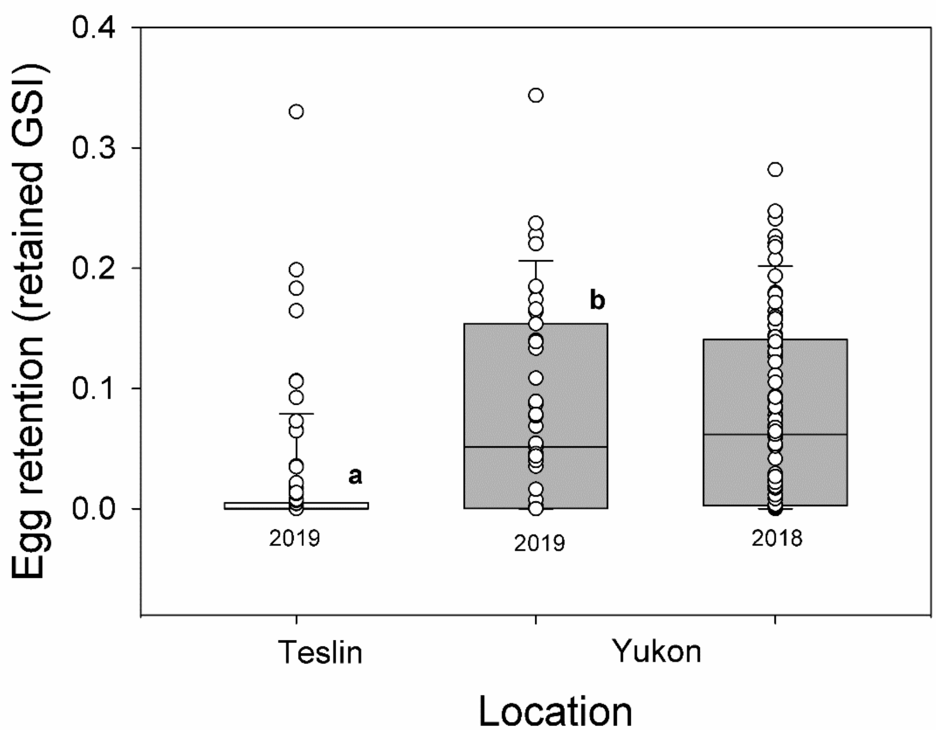

Figure 6. Boxplots depicting egg retention of Chinook Salmon sampled downstream of the Whitehorse Hydro Plant in 2018 (n=73) and 2019 (n=43) and in the Teslin River in 2019 (n=76). Egg retention was calculated as the weight of eggs remaining in the body cavity relative to the weight of the carcass (i.e., retained gonadosomatic index; GSI). Significant differences among groups are denoted by lowercase letters. Data from 2018 is presented but was not included in statistical tests.

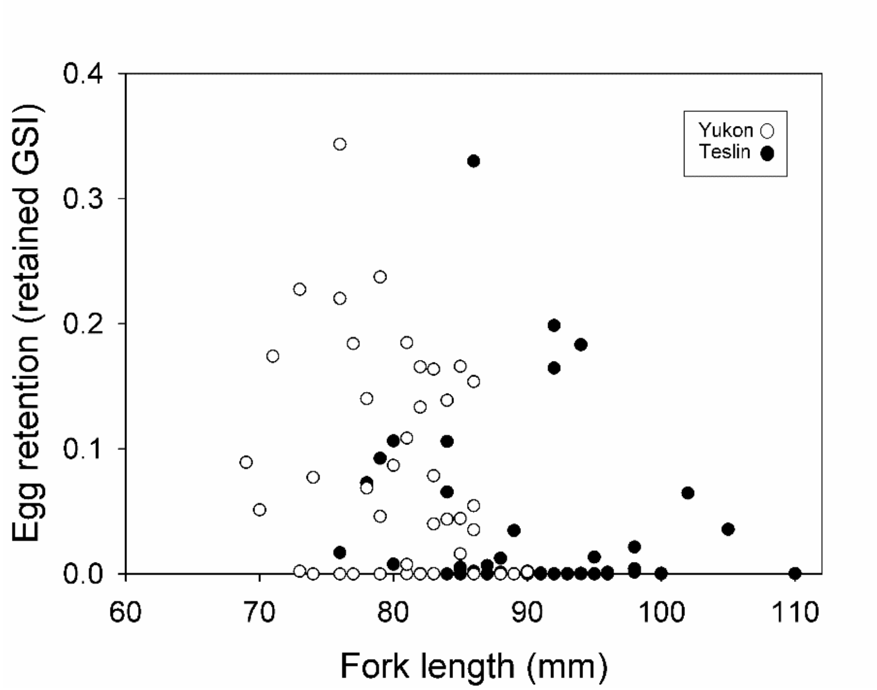

Figure 7. The relationship between egg retention and fork length (mm) for female Chinook Salmon sampled in the upper Yukon River downstream of the Whitehorse Hydro Plant (white circles) and the Teslin River (black circles) in 2019.

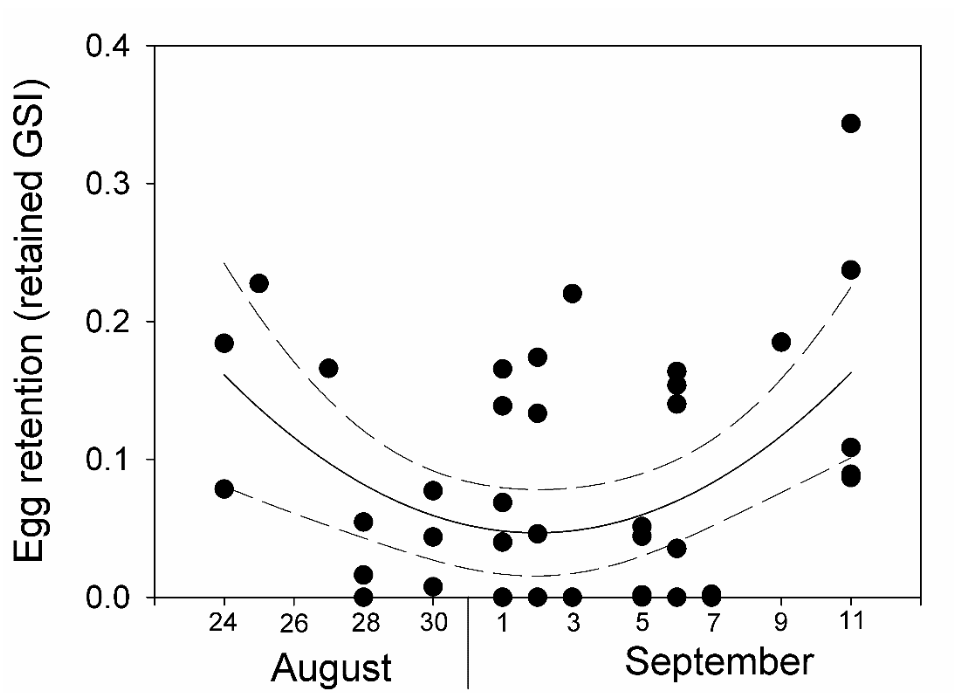

Figure 8. The relationship between egg retention and date (since August 20th) for female Chinook Salmon sampled in the upper Yukon River downstream of the Whitehorse Hydro Plant in 2019.

Movement of dead salmon

Broodstock carcasses implanted with radio tags drifted 500 m to 8 km from their release location over 5 days.

- One day after tagging, carcass 1 and 2 settled ~500 m downstream of the hatchery behind a gravel bar. Carcass 1 drifted a further 5.5 km downstream by September 11th, while the other was scavenged on the gravel bar.
- Carcass 3 was observed having drifted 4 km downstream one day after tagging. By September 11th this fish had drifted to McIntyre Flats another 3.5 km downstream (immediately downstream of transect A).
- Carcasses 4 and 5 drifted to McIntyre Flats after one day of tagging (~8 km). These carcasses remained on McIntyre Flats until September 11th when tracking stopped.

Spawning escapement estimates

The concurrent acoustic telemetry study indicated that 85% of Chinook Salmon tagged downstream of the WHP (N=27) terminated in that reach (Twardek and Lapointe 2020). This suggests that 460 female and 1161 male salmon terminated downstream of the WHP in total (based on the 80 females and 202 males counted at the ladder). It should also be noted that four hatchery-origin female carcasses were recovered downstream of the WHP, compared to 8 that returned to the ladder.

Hatchery staff placed 86 broodstock carcasses into the river near the Whitehorse Rapids Fish Hatchery (L. Vano and W. Kapaniuk, pers. comm.) by September 11th. During this period, 10 of the estimated total of 86 carcasses were recovered (12% survey efficiency). If the same proportion of wild and hatchery-origin carcasses were recovered during surveys, then 358 female and 58 male Chinook Salmon terminated in the study reach between August 10th and September 11th.

Discussion

Fifty Chinook Salmon carcasses were recovered from the upper Yukon River downstream of the WHP in 2019. There was a strong female bias in the recovered carcasses, and most female carcasses retained more than 100 eggs. The proportion of female Chinook Salmon downstream of the WHP that had deposited all or most of their eggs was low in this study relative to other Yukon River populations (Table 1), including a survey completed this year in the Teslin River. Population estimates indicated that many more Chinook Salmon terminate downstream of the WHP in the mainstem Yukon River than previously documented; however these estimates should be interpreted with caution because the sample sizes supporting these calculations are small. Surveys in 2020 will extend further into September to ensure we sample end of season carcasses, better informing abundance and egg retention estimates.

Egg deposition

The incidence of complete egg deposition in females was low (35%) compared to nearby populations of Chinook Salmon in the Yukon River watershed, where the average proportion of completely spent females across studies (various locations and years) was calculated at approximately 90% (Table 2). We estimated that egg deposition averaged 77% (identical to 2018), which aligns with the lowest egg deposition rates (56-77%) reported for Pacific salmon (Quinn et al. 2007). This estimate should be interpreted with caution, given that it is based on a length-fecundity relationship with considerable unexplained variance (R^2=0.45; Figure 4) and error estimates were not calculated. Nonetheless, it is most likely that we have over-estimated egg deposition given the potential for eggs to fall out of the body cavity after the fish has died. Aside from these uncertainties, egg retention was approximately four times higher than in the Teslin River. This suggests that migration length is not driving low egg deposition and that failed ladder passage may explain observed egg retention downstream of the WHP. A number of factors may contribute to egg retention, including various density-dependent, environmental, and condition-related factors (discussed in Quinn et al. 2007; McConnachie et al. 2012). In Bristol Bay, Alaska, Sockeye Salmon tended to have higher egg retention rates in streams with high spawning densities (Quinn et al. 2005). Female Pacific salmon will compete for spawning territories and may be pushed out after partially depositing their eggs by fish that arrive later (Schroder 1981). It may be that a proportion of Chinook Salmon are unable to find and navigate the WHP fish ladder to reach upstream natal spawning sites and revert to alternative sites downstream leading to inflated spawning ground densities. This behaviour of seeking out alternative spawning sites has been observed in Atlantic Salmon that are delayed at power stations (Webb 1990; Chanseau and Larinier 1999; Rivinoja et al. 2001; Thorstad et al. 2003b, 2005). Inflated spawning densities in the study reach may explain the partial egg deposition rates observed here. Alternatively, fish that are unable to reach their natal streams may simply fail to spawn (e.g., because of stress or exhaustion from searching). Salmon may be further challenged when environmental conditions are adverse such as when temperatures are elevated (Hinch et al. 2012). Indeed, in 2019 temperatures were abnormally warm in the lower Yukon River during the Chinook Salmon migration.

Table 2. A summary of carcass surveys for Chinook Salmon completed in tributaries of the Yukon River.

Location	Year	Female sample	Spawned completely	Complete spawn criteria	Proportion female	Method	Reference
Yukon downstream of the WHP	2019	43	15	<100 eggs	86%	Visual	Twardek and Lapointe 2020
Yukon River downstream of the WHP	2018	80	24	<100 eggs	93%	Visual	Twardek and Lapointe 2019
Yukon River downstream of the WHP	2005	14	7	'none OR almost all of their eggs'	93%	Visual	Von Finster 2005
Total	**2005-2019**	137	46	**<1% of eggs (generally)**		Visual	
Big Salmon River, YT	2015	81	76	<1% of eggs	63%	Visual	Mercer and Wilson 2016
Big Salmon River, YT	2014	73	71	<1% of eggs	51%	Visual	Mercer and Wilson 2015
Teslin River, YT	2019	76	59	<100 eggs	79%	Visual	
Teslin River, YT	2014	304	293	<1% of eggs	60%	Visual	Mercer 2015
Chena and Salcha Rivers, AK	2005-2006	652	561	<10% of eggs			Hamazaki et al. 2013
Mayo River, YT	2011	8	8	<1% of eggs	73%	Visual	Wilson 2011
Kalzas	2011	10	9	<1% of eggs	50%	Visual	White Mountain

River, YT							Environmental Consulting 2011
Salcha River, AK	2015	224	202	<1% of eggs	42%	Visual	Stark 2016
McQuesten River, YT	2011	33	33	<1% of eggs	67%	Visual	Can-Nic-a-Nick Environmental Sciences 2011
M'Clintock River, YT	2005	8	8	<1% of eggs	80%	Visual	de Graff 2005
Michie Creek, YT	2005	11	11	<1% of eggs	22%	Visual	de Graff 2005
Total	**2005-2019**	**1480**	**1331**	**<1% of eggs (generally)**			

Sex, size, and origin of carcasses

Nearly all fish identified in this survey were female, despite males comprising the majority of the run (72% of 282 fish) counted at the Whitehorse Rapids Fish Ladder immediately upstream of the survey area. Previous surveys at this location also identified large proportions of females (Sebes and Lapointe 2017; Von Finster 2005), and this pattern has been observed to a lesser extent in other carcass surveys in the Yukon River (Table 1). Wildlife surveys can suffer from detection bias (Kellner and Swihart 2014), and our survey may have been more likely to recover female than male fish. A Chinook Salmon carcass survey in the Chiwawa River found that male carcasses deposited an average of 4.5 km downstream of redds compared to female carcasses that deposited 150 m from redds, presumably due to post-spawning activity in males (Murdoch et al. 2009). In the Yukon River, this could have decreased the likelihood of detecting male carcasses, given that they may distribute over a broader area and settle in locations where water depth prohibits carcass detection, or drift downstream of the study area before expiring. Indeed, a concurrent telemetry study indicated that two male Chinook Salmon moved 30 km downstream from assumed spawning locations (Twardek and Lapointe 2020). That study showed that 26 female fish ceased movements by August 29th, but 18 male fish continued to move, some until September 6th. Another explanation for these observed differences is the potential for greater passage failure and subsequent mortality in female fish. Female Chinook Salmon typically have higher pre-spawn mortality rates following migratory stress such as fisheries captures, transport, and barriers (Keefer et al. 2010). Female Sockeye Salmon (*Oncorhynchus nerka*) approaching a fishway at a diversion dam in the Fraser River had considerably lower passage success than males (Burnett et al. 2014). Although sample sizes remain low across two years of fish passage research at the WHP, 18% of females and 64% of males that approached the WHP were successful in passing the facility (Twardek and Lapointe 2019; Twardek and Lapointe 2020).

The presence of four hatchery-origin female Chinook Salmon carcasses downstream of the WHP compared to the eight counted at the ladder indicates that a proportion of female hatchery fish did not reach their stocking sites (ie. strayed). In contrast, hatchery-origin fish do not appear to stray frequently upstream of the WHP. Recovery of coded-wire tags from Yukon River hatchery-origin fish upstream of the WHP indicated 93% fidelity to release sites (de Graff 2005). In 2018, thirteen hatchery carcasses recovered downstream of the WHP had coded wire tags that indicated stocking locations of Michie Creek, M'Clintock River, and the mainstem Yukon River. In both 2018 and 2019, a small number of the hatchery-origin carcasses observed in this study had completely deposited their eggs, suggesting that some fish attempted to spawn at alternative sites other than their release sites. The number of hatchery origin carcasses recovered was low in 2019 (four fish) so future surveys in 2020 will be necessary to provide further information on these relationships.

Spawning escapement estimates

Carcasses were recovered from several different sites along the Yukon River between the Whitehorse Hydro Plant and McIntyre Flats 7 km downstream. The low proportion of broodstock carcasses recovered (12%) suggests that there are many more carcasses downstream of the WHP than the 50 carcasses identified. The population estimate based on relocated broodstock carcasses has significant limitations. It is unclear whether broodstock carcasses would drift and settle in the same locations as naturally dying fish. Broodstock carcasses were returned to the river outside of the hatchery without their heads, and both release location and body shape could affect carcass drift. Therefore, a skewed proportion of broodstock carcasses may have been recovered. Further, some fish were returned to the river during the same day as our final carcass survey (September 11th). Additional surveys beyond this date may have resulted in more broodstock fish found, affecting our population estimate. Moreover, carcasses continued to be detected when surveys stopped on September 11th, 2019, suggesting that our broodstock recovery rate method underestimated population size because late-season sampling was truncated. Additional carcasses of male salmon would likely have been observed had surveys continued. Spatiotemporal differences in carcass availability relative to survey dates and locations likely explain the large discrepancy in estimates of the total number of males based on passage rates of tagged fish (1161) compared to broodstock carcass detection rates (58). Estimates of the number of female carcasses were more similar (460 based on tagged fish; 358 based on broodstock carcass detection rates), likely because surveys focused on locations and time periods that were suitable for female carcass deposition.

Mark-recapture estimates could have potentially been derived from our tracking of 23 fish implanted with radio transmitters that died downstream of the WHP as part of a related study (Twardek and Lapointe 2020). Rather strikingly, none of these fish were found among the 50 carcasses observed during our carcass surveys, making it impossible to estimate population size from this group of fish. Though it is unclear exactly when tagged fish died, many transmitters (>30%) were detected on shore with evidence of scavenging, while many others terminated in the McIntyre Flats area where carcasses were inaccessible. Both outcomes made it impossible to recover and sample these carcasses. Though a population size could not be derived from this group of tagged fish, they clearly indicate the number of fish terminating downstream of the WHP is much higher than that observed in our surveys.

The population estimates based on the passage of radio-tagged fish at the ladder is independent of the number of carcasses found. An assumption of this estimate is that handling and tagging did not affect passage success at the ladder. The equation we used also did not account for differences in ladder passage rates between males and females (due to low sample size), which may make the estimate particularly inaccurate for male fish. If passage success at the ladder is found to be higher for males in the future, then our equation would predict a lower number of males downstream. An additional year of telemetry data may tease apart sex-specific passage rates at the fish ladder, better informing our population estimates.

We demonstrated how carcass surveys and acoustic telemetry can be used to estimate the abundance of Chinook Salmon carcasses downstream of the WHP, though we have strong reservations about their accuracy. Given the limitations of both population estimates, we caution against interpreting them as exact estimates. They simply provide evidence that the number of carcasses in the study reach was higher than the number of recovered carcasses in 2019 and that a substantial proportion of the population entering this reach did not move upstream of the WHP. It is unclear why so many fish remained below the WHP, though factors such as previous migratory stress may have had an influence (the 2019 return was very low and was delayed returning to Whitehorse, suggesting fish may have been stressed relative to other years).

Conclusions

Carcass surveys are helpful in understanding egg deposition by salmon in the reach below the WHP, and how this relates to other salmon populations in the region. Compared to Chinook Salmon on the Teslin River, it appears that egg deposition is considerably lower on the Yukon River below the WHP. Some fish never approach the WHP. These fish may have hatched downstream of the WHP and return to spawn successfully here. Those fish that approach the WHP but do not pass could return downstream and fail to spawn due to exhaustion. Or, they could compete with wild Chinook Salmon for limited spawning habitat in this reach, reducing the spawning success of both populations. Either outcome, or both, could explain why egg deposition is lower in this reach of the Yukon River compared to the Teslin River, despite both populations undertaking highly similar migrations.

Carcass surveys can also be useful in estimating the population size of fish that terminate in Whitehorse. While only a subset of carcasses can be retrieved below the WHP, additional information can improve estimates of the total abundance of adult salmon downstream of the WHP. Investigations in 2020 will provide further information on egg deposition downstream of the WHP relative to other nearby populations and will improve our understanding of the Chinook Salmon population size in Whitehorse.

Acknowledgements

We would like to thank Yukon Energy Corporation, The Pacific Salmon Foundation, the Canadian Wildlife Federation, the Northern Scientific Training Program, and the W. Garfield Weston Foundation Fellowship Program, a program of the Wildlife Conservation Society Canada funded by The W. Garfield Weston Foundation. We extend our gratitude to Carcross/Tagish First Nation for extensive field support including both staff time and vehicles, particularly the efforts of Karlie Knight, Tami Grantham, and Cora Lee Johns. We also thank Cheyenne Bradley of Fisheries and Oceans Canada and Ciaran Shemmans and Kay Madere of the Canadian Conservation Corps for field support. We thank Nick de Graff, Al von Finster, Warren Kapaniuk, and Lawrence Vano for their expertise and advice.

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