Survey of Chinook Salmon (*Oncorhynchus tshawytscha*) carcasses in Whitehorse, Yukon - 2020

William M. Twardek[1], and Nicolas W. R. Lapointe[2]

[1] Carleton University, 1125 Colonel By Dr. Ottawa, ON, K1S 5B6. william.twardek@gmail.com
[2] Canadian Wildlife Federation, 350 Michael Cowpland Dr., Ottawa, ON, K2M 2W1

Abstract

Carcass surveys can provide valuable information on spawning success, escapement, population characteristics, and run timing in anadromous fish stocks. During the 2020 Chinook Salmon (*Oncorhynchus tshawytscha*) run, carcass surveys were completed approximately daily to provide information on egg retention 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 26 carcasses in the Yukon River and 35 in the Teslin River. In the Yukon River, the majority of carcasses recovered were female (85%). Female egg deposition rate was estimated at 78% (nearly identical to 2018 and 2019) in the Yukon River compared to 94% in the Teslin River. A lower proportion of Yukon River females spawned completely (41%), compared to females on the Teslin River (82%). While a low adult return limited our carcass recovery in 2020, findings from this year provide further evidence that egg retention is abnormally high in females terminating in this area of the Yukon River.

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 ~950 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 and 2019, 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 and 2019 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 Graff 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 37 females acoustically tagged as part of Twardek and Lapointe 2021). 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 2020 were to;
1) provide further information on Chinook Salmon egg retention rates 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

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

- Quantify egg retention 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
- Determine the timing of carcass deposition

Methods

Study site

Carcass surveys were completed every one to six days (10 surveys) on the Yukon River between August 23rd and September 14th (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. These locations included 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).

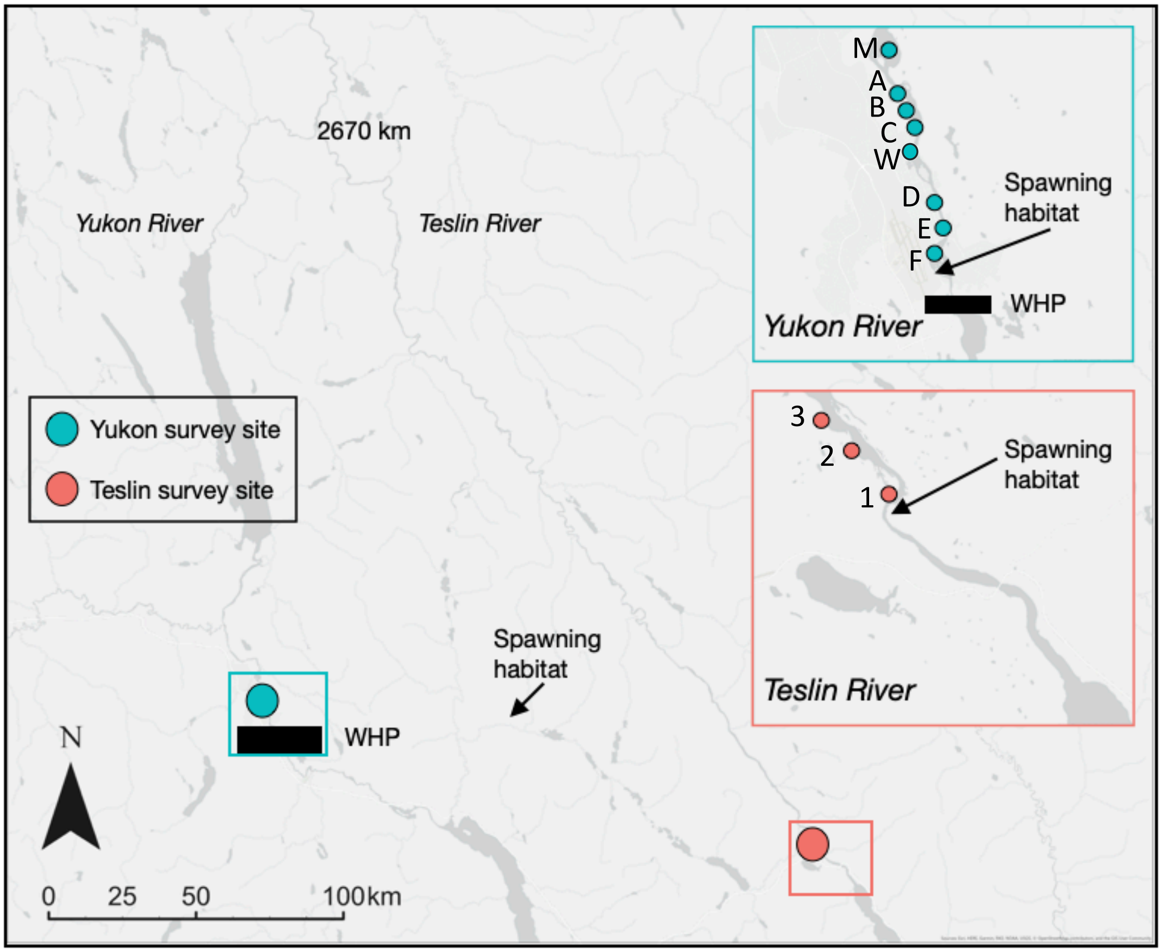

Figure 1. Transects surveyed for carcasses downstream of the Whitehorse Hydro Plant, Whitehorse, YT on the Yukon River and in the Teslin River in 2020. Coordinates for each survey site are provided in Appendix 1.

Sampling methods

Carcass surveys were primarily completed by staff from Canadian Wildlife Federation 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 1-5 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 indicators of decomposition. Indicators of decomposition included fungal development which was scored based on the surface area covered in fungus (%), and presence of decay on each fin. Tissue was sampled from most fish, depending on the level of decomposition. Females 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, measured volumetrically (measuring cup; to the nearest 25 mL), and weighed (hanging scale; 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.

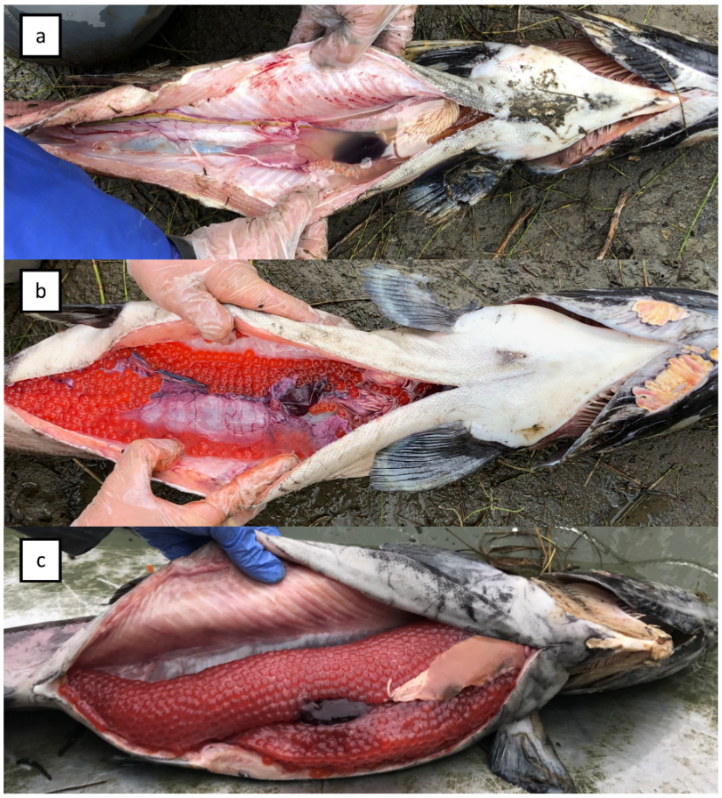

Figure 2. Chinook Salmon carcasses were classified as having: a) completely spawned, b) partially spawned, or c) experienced pre-spawn mortality.

Statistical analyses

To estimate the percentage of total fecundity retained within each female, we first predicted fecundity for each carcass using a length-based fecundity model developed from broodstock females collected at the Whitehorse Rapids Fish Hatchery from 2018-2020. The relationship between length and fecundity was assessed using linear regression. 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 Wilcoxon rank sum test. Differences in fecundity among years were tested using ANOVA.

Table 1. Date and extent of each carcass survey completed in 2020. Sites are referenced from Figure 1.

Survey ID	Date	# found	Extent
1	23/08/2020	0	Sites A, B, C, D
2	24/08/2020	0	Sites A, B, C, D
3	25/082020	0	Sites A, B, C, D, E, Across from Site C
4	26/08/2020	0	Sites A, B, C, D, E, Across from Site C
5	29/08/2020	3	Sites A, B, C, D, E
6	01/09/2020	2	Sites A, B, C, D, E, Across from Site C, W
7	03/09/2020	1	Sites B - by foot
8	04/09/2020	5	Sites A, B, C, D, E, Across from Site C, W
9	08/09/2020	10	Sites A, B, C, D, E, Across from Site C, W, M
10	14/09/2020	5	Sites A, B, C, D, E, Across from Site C, W, M
11	28/09/2020	0	Teslin River 1, 2, 3
12	02/09/2020	6	Teslin River 1, 2, 3
13	11/09/2020	29	Teslin River 1, 2, 3

Results

Twenty-six carcasses (830±60 mm fork length) were sampled from the Yukon River compared to 31 (890±70 mm) from the Teslin River during surveys in 2020 (four other Teslin carcasses were too decomposed for assessment). Carcasses from the Yukon River were primarily female (85%) and wild in origin (88%). Carcasses were found at sites A (31%), B (15%), across from C (4%), M (31%), and W (19%). Carcass recovery began on August 29th, peaked September 8th, and continued until our last survey on September 14th. All fish sampled from the Teslin River were of wild origin, and most were female (91%).

Fecundity

From 2017-2020, female Chinook Salmon (N=114) collected at the Whitehorse Rapids Fish Hatchery had an average fecundity of 5047 eggs (2086-7661 eggs). There was a positive relationship between fork length (mm) and fecundity ($R^2=0.48$, $N=114$, $p<0.01$; Figure 3). Average fecundity was similar across 2017 (5202±918 eggs), 2018 (4874±1258 eggs), 2019

(4578±1086 eggs), and 2020 (5592±1150 eggs) but was significantly greater in 2020 than 2019 (N=114, P-adj<0.01).

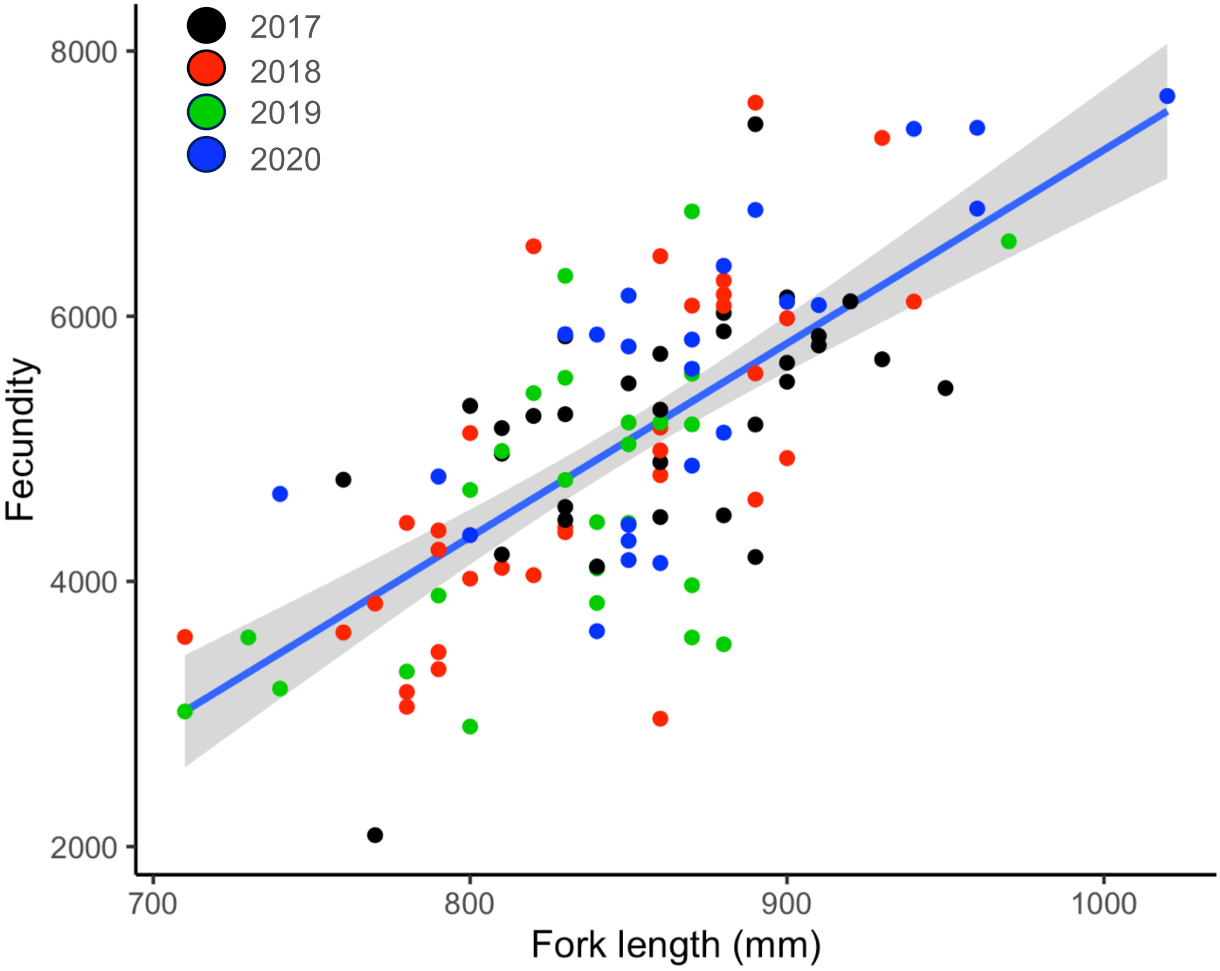

Figure 3. Fecundity of Chinook Salmon from the Whitehorse Rapids Fish Hatchery relative to fork length (mm) from 2017-2020. All years were combined for the linear regression analysis ($y=14.60x - 7345.17$; $R^2=0.48$, $p<0.01$).

Egg retention

Surveys identified 41% of fish from the Yukon River as having spawned completely compared to 82% 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 the Teslin River was assigned as a pre-spawn mortality based on the estimated number of eggs retained relative to estimated fecundity. Egg retention in Yukon River females was approximately 3.5 times higher on average than egg retention in Teslin River females in 2020 (N=50, W=169.5, p<0.01; Figure 4). It was estimated volumetrically that this corresponds to 22% of total fecundity retained in the Yukon River and 6% of total fecundity in the Teslin River.

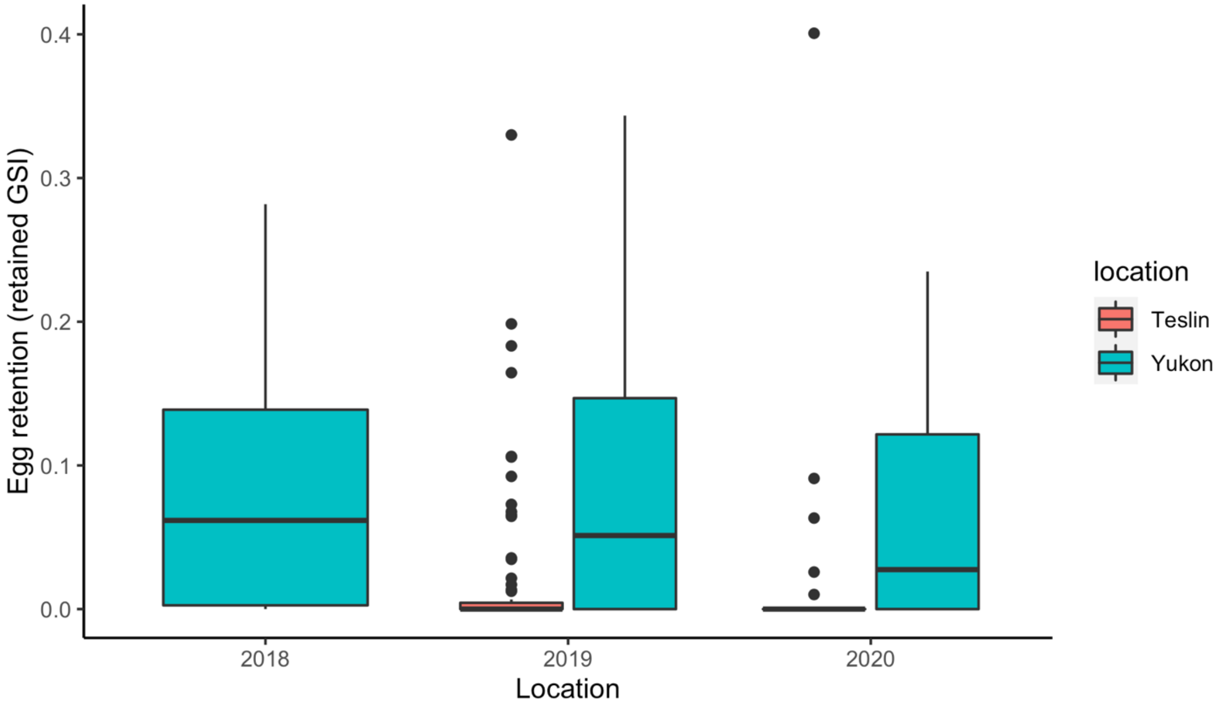

Figure 4. Boxplots depicting egg retention of Chinook Salmon sampled downstream of the Whitehorse Hydro Plant in 2018 (n=73), 2019 (n=43), and 2020 (n=22) and in the Teslin River in 2019 (n=76), and 2020 (n=28). Egg retention was calculated as the weight of eggs remaining in the body cavity relative to the weight of the carcass (i.e., retained gonadosomatic index; GSI).

Discussion

Low salmon abundance and high water levels limited our success retrieving Chinook Salmon carcasses in 2020 compared to other years of this study. Nonetheless, 26 carcasses were recovered from the upper Yukon River and 35 from the Teslin River, building on our knowledge of Chinook Salmon spawning success in these areas. The low proportion of female Chinook Salmon downstream of the WHP that deposit all or most of their eggs compared with other Yukon River populations (Table 2), suggests that a site-specific factor is likely leading to elevated rates of egg retention at this location. We hypothesize that this site-specific factor is the inability for some female salmon to pass the hydro plant and arrive at natal spawning sites upstream (Twardek and Lapointe 2021). Interestingly, however, it appears almost every female salmon downstream of the hydro plant deposits some of their eggs, highlighting that females failing passage will still attempt to spawn even if they cannot reach natal spawning locations.

Egg deposition

The incidence of complete egg deposition in females was low (41%) 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 78% (nearly identical to 2018 and 2019), which aligns with some of 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=0.48; 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 and drifts down river. 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). Downstream of the WHP, it appears a proportion of Chinook Salmon are unable to find and navigate the WHP fish ladder to reach upstream natal spawning sites and instead revert to alternative sites downstream. 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. 2003, 2005). Depending on the available spawning habitat, this could lead to inflated spawning ground densities. 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). Alternatively, fish that are unable to reach their natal streams may simply fail to spawn (e.g., because of stress or exhaustion from searching).

Table 2. A summary of Chinook Salmon carcass survey data from downstream of the WHP on the Yukon River and from various free-flowing tributaries of the Yukon River.

Location	Year	Female sample	Spawned completely	Complete spawn criteria	Proportion female	Method	Reference
Yukon River							
Yukon downstream of the WHP	2020	23	9	<100 eggs	85%	Visual	Present study
Yukon downstream of the WHP	2019	43	15	<100 eggs	86%	Visual	Present study
Yukon River downstream of the WHP	2018	80	24	<100 eggs	93%	Visual	Present study
Yukon River	2005	14	7	‘none OR almost all	93%	Visual	Von Finster 2005

downstream of the WHP				of their eggs'			
Total	**2005-2020**	**160**	**34%**	**<1% of eggs (generally)**	**90%**	**Visual**	
Nearby free-flowing rivers							
Teslin River, YT	2020	28	23	<100 eggs	80%	Visual	Present study
Teslin River, YT	2019	76	59	<100 eggs	79%	Visual	Present study
Teslin River, YT	2015	347	337	<5% of eggs	68%	Visual	Mercer 2016
Teslin River, YT	2014	304	292	<5% of eggs	60%	Visual	Mercer 2015
Big Salmon River, YT	2017	44	28	<5% of eggs	52%	Visual	Mercer and Wilson 2018
Big Salmon River, YT	2016	73	70	<5% of eggs	62%	Visual	Mercer and Wilson 2017
Big Salmon River, YT	2015	81	76	<5% of eggs	63%	Visual	Mercer and Wilson 2016
Big Salmon River, YT	2014	69	66	<5% of eggs	51%	Visual	Mercer and Wilson 2015
Mayo River, YT	2011	8	8	<1% of eggs	73%	Visual	Wilson 2011
Kalzas River, YT	2011	10	9	<1% of eggs	50%	Visual	White Mountain Environmental Consulting 2011
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
Salcha River, AK	2015	224	202	<1% of eggs	42%	Visual	Stark 2016
Chena and Salcha Rivers, AK	2005-2006	652	561	<10% of eggs	-		Hamazaki et al. 2013
Total	**2005-2020**	**1968**	**91%**	**<1% of eggs (generally)**	**58%**		

Sex, size, and origin of carcasses

Nearly all fish identified in this survey were female, despite males comprising the majority of the run (75% of 216 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 has indicated that male Chinook Salmon move for a longer period of time and further distances than females from assumed spawning locations (Twardek and Lapointe 2021). 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 (Hinch et al. 2021). 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). Across four years of research at the WHP, 13% of females and 47% of males that approached the WHP were successful in passing the facility (Twardek and Lapointe 2021).

The observation of four hatchery-origin Chinook Salmon carcasses downstream of the WHP (compared to the 47 counted at the ladder) indicates that a proportion of 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. Interestingly, a small number of the hatchery-origin carcasses observed in this study (across all years) had completely deposited their eggs, suggesting that some fish attempted to spawn at alternative sites other than their release sites. Future carcass surveys downstream of the hydro plant should further explore hatchery salmon spawning success.

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. It is clear this population comprises fish that are natal to this area (ie. hatched there) and some fish that approached but do not pass the WHP to reach upstream spawning sites. It may be that natal fish return to spawn successfully here, while those fish that approach the WHP but do not pass fail to fully spawn due to exhaustion. Or, they could compete with natal 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. Future investigations would provide further information on egg deposition downstream of the WHP relative to other nearby populations. These surveys may also provide a useful indication of whether changes at the WHP fish ladder are improving passage, as increased passage success should result in reduced egg retention rates in the female population downstream of the WHP.

Acknowledgements

We would like to thank Yukon Energy Corporation, The Pacific Salmon Foundation, the Canadian Wildlife Federation, 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, Sonny Parker, and Tami Grantham. We appreciate the equipment support from Fisheries and Oceans Canada including use of a jet boat. We also thank Brandon Crawford of Yukon Fish and Game Association, Edna Knight, and Pier-Anne Ménard for field support. We thank Nick de Graff, Brandy Mayes, Ben Schonewille, Al von Finster, Warren Kapaniuk, and Lawrence Vano for their expertise and advice.

References

Access Consulting Group and Yukon Environmental Services 2002. Robert Service Way reconstruction project fish habitat compensation plan 2002 annual monitoring report - with a five year summary discussion draft. 27 pp.

Bowerman, T., M. L. Keefer, and C. C. Caudill. 2016. Pacific Salmon Prespawn Mortality: Patterns, Methods, and Study Design Considerations. Fisheries 41(12):738–749.

Burnett N. J., Hinch SG, Donaldson MR, Furey NB, Patterson DA, Roscoe DW, Cooke SJ. 2014. Alterations to dam-spill discharge influence sex-specific activity, behaviour and passage success of migrating adult sockeye salmon. Ecohydrology. doi:10.1002/eco.1440

Can-Nic-A-Nick Environmental Services. 2011. Enumeration and identification of spawning habitat of Chinook Salmon in the McQuesten River, Yukon Territory (August 2011). Unpublished report pp 46.

Chanseau M, Larinier M (1999) Étude du comportement du saumon atlantique (Salmo salar L.) au niveau de l’aménagement hydroélectrique de Baigts (gave de Pau) lors de sa migration anadrome. Bull Fr Pêche Piscic 353/354:239–262

Cook, K.V., McConnachie, S.H., Gilmour, K.M., Hinch, S.G. and Cooke, S.J., 2011. Fitness and behavioral correlates of pre-stress and stress-induced plasma cortisol titers in pink salmon

(Oncorhynchus gorbuscha) upon arrival at spawning grounds. Hormones and Behavior, 60(5), pp.489-497.

de Graff, N. 2005. Chinook Salmon carcass recovery data from the Michie Creek – M'Clintock River system. Unpublished data.

DeWeber, J.T., J.T. Peterson, C. Sharpe, M.L. Kent, M.E. Colvin, C.B. Schreck. 2017. A hidden-process model for estimating prespawn mortality using carcass survey data. North American Journal of Fisheries Management. 37(1):162-175.

Hamazaki, T., E. Kahler, B. M. Borba, and T. Burton. 2013. Impact of ichthyophonus infection on spawning success of yukon river chinook salmon oncorhynchus tshawytscha. Diseases of Aquatic Organisms 106(3):207–215.

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

Hinch, S.G., Bett, N.N., Eliason, E.J., Farrell, A.P., Cooke, S.J. and Patterson, D.A., Exceptionally high mortality of adult female salmon: a large-scale pattern and a conservation concern. *Canadian Journal of Fisheries and Aquatic Sciences*, (ja).

Kellner, K. F., and R. K. Swihart. 2014. Accounting for imperfect detection in ecology: A quantitative review.

McConnachie, S. H., Cook, K. V., Patterson, D. A., Gilmour, K. M., Hinch, S. G., Farrell, A. P. and Cooke, S. J. 2012. Consequences of acute stress and cortisol manipulation on the physiology, behavior, and reproductive outcome of female Pacific salmon on spawning grounds. Hormones and Behavior 62: 67–76.

Mercer, B. 2015. 2014 Teslin River Chinook Sonar Project. Report submitted to the Yukon River Panel CRE-01N-14 pp 47.

Mercer, B. 2016. 2015 Teslin River Chinook Sonar Project. Report submitted to the Yukon River Panel. CRE-41-15. pp 29.

Mercer, B., J. K. Wilson. 2015. 2014 Chinook Salmon sonar enumeration on the Big Salmon River. Report submitted to the Yukon River Panel CRE-41-14 pp 30.

Mercer, B., J. K. Wilson. 2016. 2015 Chinook Salmon sonar enumeration on the Big Salmon River. Report submitted to the Yukon River Panel CRE-41-15 pp 29.

Mercer, B., J. K. Wilson. 2017. 2016 Chinook Salmon sonar enumeration on the Big Salmon River. Report submitted to the Yukon River Panel CRE-41-16 pp 35.

Mercer, B., J. K. Wilson. 2018. 2017 Chinook Salmon sonar enumeration on the Big Salmon River. Report submitted to the Yukon River Panel CRE-41-17 pp 29.

Murdoch, A. R., T. N. Pearsons, and T. W. Maitland. 2009. Use of carcass recovery data in evaluating the spawning distribution and timing of spring Chinook Salmon in the Chiwawa River, Washington. North American Journal of Fisheries Management 29(5):1206–1213.

Murdoch, A.R., T.N. Peasons, T.W. Maitland. 2010. Estimating the spawning escapement of hatchery- and natural-origin cpring Chinook Salmon using redd and carcass data, North American Journal of Fisheries Management. 30(2):361-375.

Quinn, T. P., D. M. Eggers, J. H. Clark, and H. B. Rich, Jr. 2007. Density, climate, and the processes of prespawning mortality and egg retention in Pacific salmon (Oncorhynchus spp.). Canadian Journal of Fisheries and Aquatic Sciences 64(3):574–582.

Raby, G.D., Cooke, S.J., Cook, K.V., McConnachie, S.H., Donaldson, M.R., Hinch, S.G., Whitney, C.K., Drenner, S.M., Patterson, D.A., Clark, T.D. and Farrell, A.P. 2013. Resilience of pink salmon and chum salmon to simulated fisheries capture stress incurred upon arrival at spawning grounds. Transactions of the American Fisheries Society 142: 524-539.

Rawding, D.J., C.S. Sharpe, S.M. Blankenship. 2014. Genetic-based estimates of adult chinook salmon spawner abundance from carcass surveys and juvenile out-migrant traps. Transactions of the American Fisheries Society. 143(1):55-67.

Rivinoja P, McKinnell S, Lundqvist H. 2001. Hindrances to upstream migration of Atlantic salmon (Salmo salar) in a northern Swedish river caused by a hydroelectric power-station. Reg Riv Res Mgmt 17:101–115

Schroder, S.L. 1981. The role of sexual selection in determining the overall mating patterns and mate choice in chum salmon. School of Fisheries, University of Washington, Seattle, Washington.

Sebes, J., N.W.R, Lapointe. 2017. The 2017 survey of Chinook Salmon (*Oncorhynchus tshawytscha*) carcasses in Whitehorse, Yukon. Pp 7.

Stark, C. 2016. Salcha River Chinook and Chum Salmon Counting Tower, 2015 RM 12-15. Unpublished report pp 10.

Thorstad EB, Økland F, Kroglund F, Jepsen N (2003) Upstream migration of Atlantic salmon at a power station on the River Nidelva, Southern Norway. Fish Manage Ecol 10:139–146

Thorstad EB, Fiske P, Aarestrup K, Hvidsten NA, Hårsaker K, Heggberget TG, Økland F (2005) Upstream migration of Atlantic salmon in three regulated rivers. In: Spedicato MT, Lembo G, Marmulla G (eds) Aquatic telemetry: advances and applications. Proceedings of the Fifth

Conference on Fish Telemetry held in Europe, Ustica, Italy, 9–13 June 2003. FAO/COISPA, Rome, pp 111–121

Twardek, W.M., N.W.R, Lapointe. 2021. Assessing the fate of returning upper Yukon River Chinook Salmon – 2017-2020. Pp 29.

von Finster, A. 2005. Pre-spawn Chinook Salmon mortality – downstream of Whitehorse Yukon. Canadian Department of Fisheries and Oceans memorandum. 2 p.

Webb J (1990) The behaviour of adult Atlantic salmon ascending the Tivers tay and Tummel to Pitlochry dam. Scott Fish Res Rep 48:1–27

White Mountain Environmental Consulting. 2011. Big Kalzas River, Adult Chinook Salmon, Genetic Collection Program August 2011. Unpublished report pp 6.

Yukon River Panel. 2007. Protocol for the collection of carcass/pre-spawning mortality data. Unpublished report May 7, 2007 pp 3.

Appendix 1. Carcass survey locations in the Yukon River (near Whitehorse, YT) and Teslin River (near Johnson’s Crossing, YT) from 2018-2020. Site letters refer to those used in Figure 1.

Site	Coordinates (middle of site)
A	60.754232, -135.072324
B	60.750332, -135.065286
C	60.745131, -135.064600
D	60.726943, -135.053356
E	60.716218, -135.046146
F	60.705888, -135.052068
M	60.766432, -135.075414
W	60.739189, -135.065287
Teslin River 1	60.512877, -133.362065
Teslin River 2	60.523733, -133.384638
Teslin River 3	60.531376, -133.400517