Survey of Chinook Salmon (*Oncorhynchus tshawytscha*) carcasses in Whitehorse, Yukon - 2018

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Abstract

Carcass surveys can provide valuable information on escapement, population characteristics, and run timing in anadromous fish stocks. During the 2018 Chinook Salmon (*Oncorhynchus tshawytscha*) run in the upper Yukon River, carcass surveys were completed daily to provide preliminary information on egg deposition rates and spawning escapement of Chinook Salmon downstream of the Whitehorse Hydro Plant (WHP) and refine carcass survey methods. Carcasses were assessed for sex, size, and age. The total number of eggs remaining in the body cavity was estimated volumetrically. Surveys identified 86 wild- and hatchery-origin (21%) Chinook Salmon carcasses. Of these, 93% were female while females comprised 33% of the run counted immediately upstream at the Whitehorse Hydro Plant viewing chamber. Female egg deposition rate was estimated at 77%, based on the fecundity measurements of broodstock fish at the Whitehorse Rapids Fish Hatchery. Pre-spawn mortality of female fish was confirmed in one individual, while 30% spawned completely. The recovery rate of broodstock carcasses released downstream of the WHP was approximately 46% during surveys. If a similar proportion of naturally occurring carcasses was recovered, then we estimate that 173 females terminated downstream of the WHP before September 4th (compared to 228 at the viewing chamber). Approximately half of the carcasses marked during surveys remained within an eddy for three or more days. The observation of hatchery fish terminating downstream of the WHP where none were stocked suggest either fish passage issues associated with the Whitehorse Rapids Fishladder, or high levels of straying from their primary stocking location ~70 rkm upstream. Future work could include additional survey locations throughout the upper Yukon River and could extend until mid-September to account for the entirety of the run.

Introduction

Carcass surveys are a valuable tool used in fisheries management to understand 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 within a small spatial and temporal scale in shallow habitats where carcasses can be recovered. This method has been used throughout the Yukon River (Table 1), including a small number of surveys 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 Chinook Salmon (*Oncorhynchus tshawytscha*) per year.

Carcass surveys have been conducted downstream of the WHP to assess the egg deposition rates of Chinook Salmon, which are known to spawn in the mainstem Yukon River downstream of the WHP. Surveys on spawning grounds here between 1998-2002 found an average of 68-89 Chinook Salmon on redds per year (ACG and YES 2002). Carcasses have been found in the Yukon River between the WHP and the Takhini River, though total abundance was not estimated and sample sizes were 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. The Ta'an Kwäch'än Council conducted carcass surveys in this reach from 2007 to 2012 (Environmental Dynamics Inc. [EDI] 2008a; EDI 2008b; EDI 2009; EDI 2011; EDI 2012; EDI 2013). Eight carcasses were discovered in 2011 but no carcasses were observed in other years; this was attributed to high water conditions in those years.

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 and egg retention was measured volumetrically and was visually estimated. Visual assessment is most commonly used during carcass surveys and is used as a proxy for spawning success (78% of studies; Bowerman et al. 2016), though volumetric measurements are recommended for the Yukon River (YRP 2007). The main goals of the carcass surveys in 2018 were to;

1) provide further information on Chinook salmon egg deposition rates on the Yukon River mainstem downstream of the WHP. Specific objectives associated with this goal were;

- Provide preliminary estimates of the egg deposition rate of Chinook Salmon downstream of the WHP
- Investigate the sex, size, and origin of carcasses and relate estimated egg deposition to origin, size, and run timing
- estimate total abundance of Chinook Salmon terminated downstream of the WHP

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

- Develop methods of estimating % of eggs deposited
- Identify the locations of carcass deposition sites

- Assess detectability, stream life (i.e., how long a carcass remains within an eddy in a condition that allows the carcass to be measured), and drift of carcasses
- Determine the timing of carcass deposition

Table 1. 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
Big Salmon River	2015	81	76	<1% of eggs	63%	Visual	Mercer and Wilson 2016
Big Salmon River	2014	73	71	<1% of eggs	51%	Visual	Mercer and Wilson 2015
Teslin River	2014	304	293	<1% of eggs	60%	Visual	Mercer 2015
Chena and Salcha Rivers	2005-2006	652	561	<10% of eggs			Hamazaki et al. 2013
Mayo River	2011	8	8	<1% of eggs	73%	Visual	Wilson 2011
Kalzas River	2011	10	9	<1% of eggs	50%	Visual	White Mountain Environmental Consulting 2011
Salcha River	2015	224	202	<1% of eggs	42%	Visual	Stark 2016
McQuesten River	2011	33	33	<1% of eggs	67%	Visual	Can-Nic-a-Nick Environmental Sciences 2011
M'Clintock River	2005	8	8	<1% of eggs	80%	Visual	de Graff 2005
Michie Creek	2005	11	11	<1% of eggs	22%	Visual	de Graff 2005
Total	**2005-2015**	**1404**	**1272**	**<1% of eggs (generally)**			

Methods

Study site

Carcass surveys were completed every one to five days (15 surveys) between August 10th and September 4th with a single survey completed on September 13th (Table 2). Initial surveys were completed along the entirety of both banks of the river from McIntyre Creek upstream to the braided channels of the spawning grounds by Robert Service Way (Figure 1). Certain sections of the river were too deep to detect and retrieve carcasses from and were therefore not surveyed further. After repeatedly locating carcasses in distinct locations along the left bank of the river, we restricted our surveys to five locations within the river (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).

Sampling methods

Carcass surveys were primarily completed by staff from Canadian Wildlife Federation, Carleton University, and Carcross/Tagish First Nation, with help from Ta'an Kwäch'än Council. To complete surveys, a jetboat was operated at a slow speed (<10 km/h) approximately 5 m from the shoreline while two surveyors searched for carcasses. Surveys lasted between 2-6 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 four large fishing hooks attached at the terminal end of the pole. Carcasses were sampled on site following the Yukon River protocol of 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 (%), presence and absence of fin decay on each fin, and presence of both eyes. All fish were sampled for scales and otoliths and tissue samples were taken from a subset of fish. Fish were classified as either completely-spawned, partially spawned, or pre-spawn mortalities (as per Quinn et al., 2007). 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 pre-spawn mortalities visually. The distinction between partially-spawned and pre-spawn mortality was later estimated based off of a length-based fecundity model derived from the broodstock fish collected at the Whitehorse Rapids Fish Hatchery (described below). In one instance a fish had fully intact skeins and therefore had not partially spawned. Gonads were photographed and measured volumetrically using a measuring cup to the nearest 50 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.

Residency time

Following processing, 23 carcasses were marked with a Floy tag and returned to the river to evaluate residency time within eddies. These Floy-tagged carcasses were monitored during the remaining surveys, but all carcasses were monitored on day three and four following tagging to determine the proportion of carcasses that remain in eddies for at least three days.

Spawning escapement estimates

Preliminary estimates of spawning escapement in the mainstem Yukon River downstream of the WHP were completed using two different methods. The first method estimated the number of fish terminating downstream of the WHP using the terminal locations of ten fish implanted with acoustic transmitters several kilometres downstream of the WHP during a concurrent telemetry study (Twardek and Lapointe, 2018). Six of these ten fish passed the ladder, indicating that 40% of fish that travel upstream of the Takhini River remain downstream of the WHP. We therefore assumed that the fish counted passing through the Whitehorse Rapids Fishladder represented 60% of the total population, and that 40% remained downstream (Equation 1).

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).

Equation 1. Equation used to estimate the number of females that terminated downstream of the Whitehorse Hydro Plant in 2018 based on the proportion of fish tagged with acoustic transmitters that remained downstream of the WHP in Twardek and Lapointe (2018). This equation assumes that passage proportions are equivalent for males and females at the Whitehorse Rapids Fishladder.

Total number of fish below the ladder = total number of fish counted at the ladder * number of fish tagged below the WHP that did not pass / number of fish tagged downstream of the WHP that did pass

Statistical analyses

To estimate fecundity by size (mid-eye fork length), a linear equation was developed from broodstock fecundity data provided by the Whitehorse Rapids Fish Hatchery. This information was then used to estimate egg deposition (% of predicted egg total expelled from the body). We employed two biological rules when estimating egg deposition; that a fish could not retain more than 100% of its eggs, and that all fish had a fecundity of at least 1000 eggs. We use the term egg deposition rather than spawning success given that the site of egg deposition and hatching success are unknown. An ANOVA model was used to evaluate the relationship between egg deposition values and origin (wild or hatchery). The relationships between egg deposition and fish length as well as date of sampling were modeled using separate linear regressions.

Figure 1. Transects surveyed for carcasses downstream of the Whitehorse Hydro Plant, Whitehorse, YT in 2018. Sites A-E were the only locations where carcasses were found and were surveyed regularly.

Table 2. Date and extent of each carcass survey completed in 2018. Sites are referenced from Figure 1.

Survey ID	Date	Extent
1	10/08/2018	YR (Site C)
2	15/08/2018	YR (Site C)
3	17/08/2018	YR (Site C, shoreline across from Site C, Walmart area)
4	20/08/2018	Left shoreline from McIntyre Creek to Rotary Centennial Foot Bridge (braided channels not searched)
5	21/08/2018	YR (left shoreline from McIntyre Creek to Walmart area and Site E, right shoreline for 100 m upstream of Robert Campbell Bridge and across from Site C)
6	23/08/2018	YR (left shoreline from McIntyre Creek to Rotary Park)
7	24/08/2018	YR (left shoreline from McIntyre Creek to Rotary Park, Millennium Trail from Rotary Centennial Foot Bridge to Robert Campbell Bridge)
8	26/08/2018	YR (Sites D, E, Millennium Trail from Rotary Centennial Foot Bridge to Robert Campbell Bridge)
9	27/08/2018	YR (Sites A, B, C, D, E)
10	28/08/2018	YR (Sites A, B, C, D, E, briefly scanned the shore all the way from McIntyre Creek to Takhini River but none found)
11	29/08/2018	YR (Sites D, E)
12	31/08/2018	YR (Sites A, B, C, D, E, right shoreline from Robert Campbell Bridge to across from Site C)
13	02/09/2018	YR (Sites B – partial, D, E)
14	04/09/2018	YR (Sites A, B, C, D, E)
15	13/09/2018	YR (Site A)

Results

A total of 86 carcasses (83±7 cm fork length) were sampled from the Yukon River during surveys in 2018. Carcasses were primarily female (93%) and wild in origin (79%). Thirteen hatchery carcasses were recovered with coded-wire tags that indicated stocking locations in Michie Creek (n=9), M'Clintock River (n=2), and the mainstem Yukon River (n=2). Carcasses were found at sites A (50%) and B (38%), with a smaller proportion found at sites C (2%), D (2%) and E (6%), F (2%). Carcass recovery was highest on the second last day of surveys on September 4th (Figure 2).

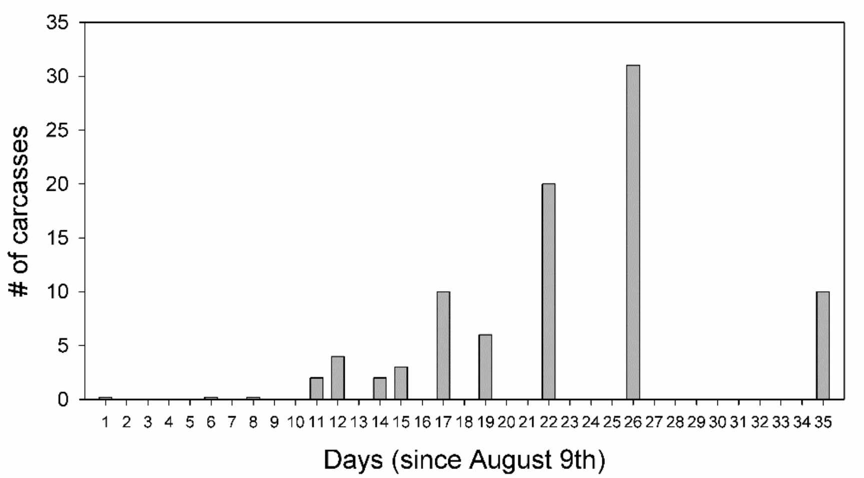

Figure 2. The number of carcasses recovered during each of our carcass surveys on the Yukon River downstream of the WHP (partial surveys excluded). Days 1, 5, and 7 also had surveys but no carcasses were recovered.

Fecundity

In 2017 and 2018 Chinook Salmon (N=64) collected at the Whitehorse Rapids Fish Hatchery had an average fecundity of 4677 eggs (2086-7611 eggs). There was a positive relationship between mid-eye fork length (mm) and fecundity (R^2=0.45, DF=63, t-value=4.35, p<0.01; Figure 3).

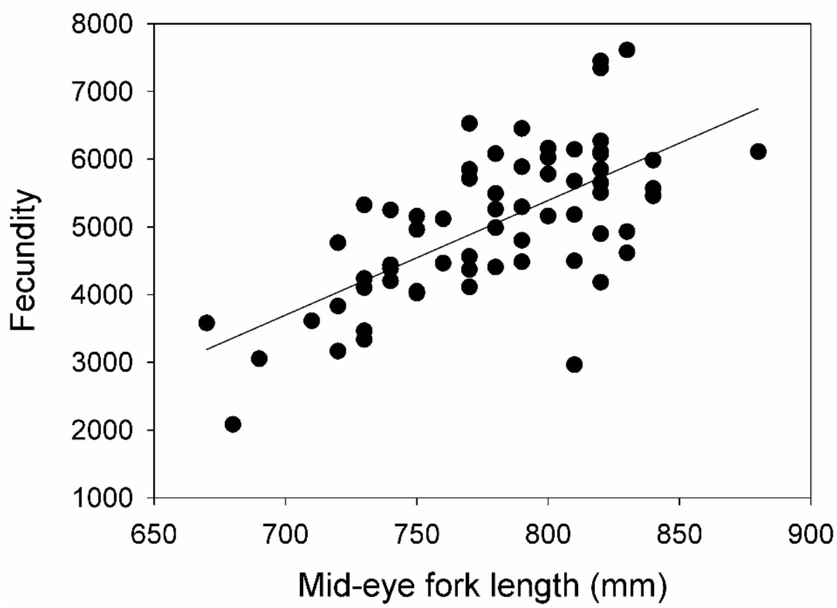

Figure 3. Fecundity of Chinook Salmon from the Whitehorse Rapids Fish Hatchery relative to mid-eye fork length (mm). Linear regression (y=16.93x – 8151.76; R^2=0.45, p<0.01).

Egg deposition

Visual surveys identified 30% of fish as having spawned completely. Visual assessments confirmed one fish had intact skeins and had succumbed to pre-spawn mortality. The number of pre-spawn mortalities could be higher but could not be distinguished with certainty from partially-spawned carcasses. Egg deposition averaged 77%. Egg deposition was higher for wild (N=58) than hatchery-origin females (N=15; DF=72, F-value=6.43, p=0.01; Figure 4) but did not correlate with the size of fish (R^2=0.03, DF=72, t-value=1.45, p=0.15; Figure 5). Egg deposition tended to increase with the date of carcass recovery (R^2=0.25, DF=72, t-value=4.99, p<0.01; Figure 6).

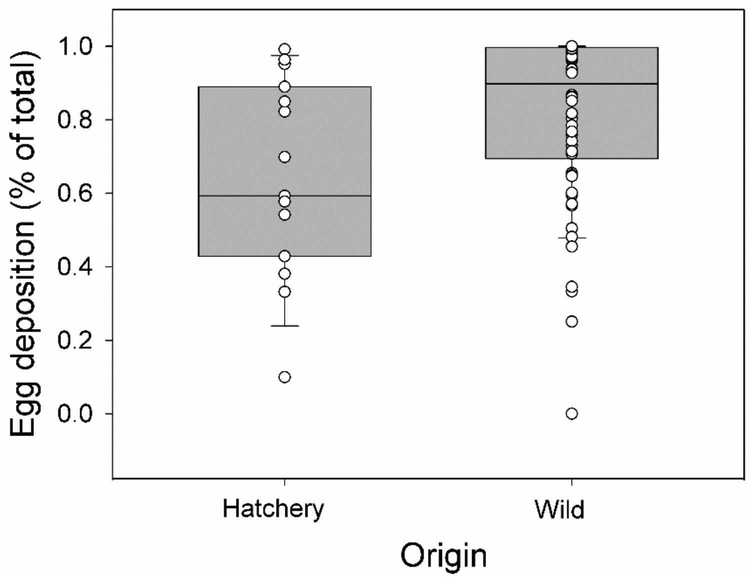

Figure 4. Boxplots showing egg deposition (% of estimated total based on length) of female Chinook Salmon of hatchery (N=15) and wild (N=58) origin in the upper Yukon River downstream of the Whitehorse Hydro Plant in 2018. Wild fish had higher deposition rates than hatchery-origin fish (ANOVA; DF=72, F-value=6.43, p=0.01)

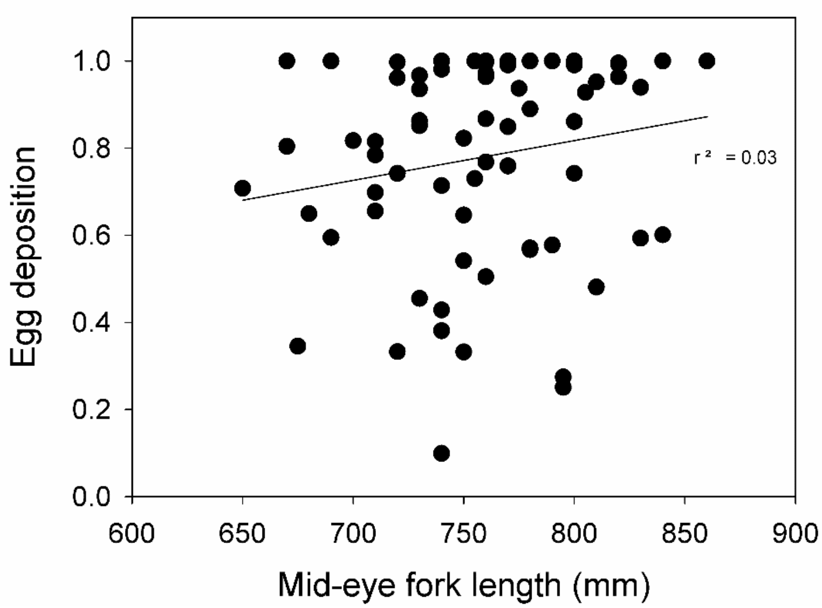

Figure 4. The relationship between egg deposition (% of estimated total based on length) and mid-eye fork length (mm) for female Chinook Salmon sampled in the upper Yukon River downstream of the Whitehorse Hydro Plant in 2018. Linear regression (y=0.000911x + 0.0882, R^2=0.03, p=0.15).

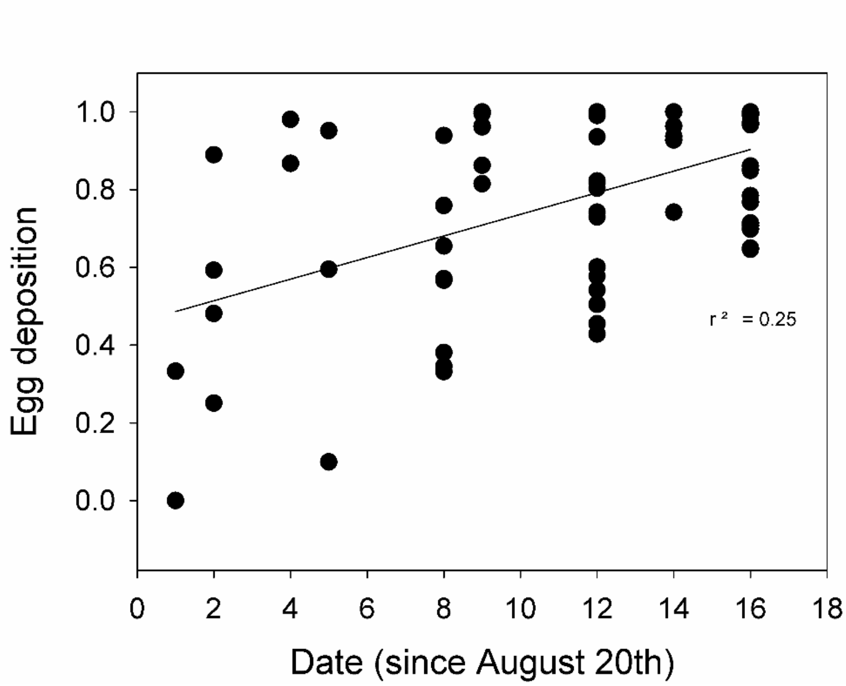

Figure 5. The relationship between egg deposition and date (since August 20th) for female Chinook Salmon sampled in the upper Yukon River downstream of the Whitehorse Hydro Plant in 2018. Linear regression ($y=0.0278x + 0.459$, $R^2=0.25$, $p<0.01$).

Residency time

Fourteen carcasses were marked with Floy tags, placed in eddies, and monitored during subsequent surveys until the carcass disappeared or decayed severely. Approximately half of the carcasses remained in deposition zones for at least 3 days (57%). No fish was found in a different deposition zone once missing from the original deposition zone. Most fish had experienced severe decay by day five which may have precluded measurement of length, weight, and other features.

Spawning escapement estimates

The concurrent acoustic telemetry study indicated that 40% of Chinook Salmon tagged downstream of the WHP (N=10) terminated in that reach (Twardek and Lapointe 2018). This suggests that 152 female and 309 male salmon terminated downstream of the WHP in total (based on the 228 females and 463 males counted at the ladder).

On August 26th, 27th, 31st, and September 3rd hatchery staff placed 5, 7, ~17, and ~25 broodstock carcasses into the river by the Whitehorse Rapids Fish Hatchery (L. Vano and W. Kapaniuk, pers. comm.). During this period, 25 of the estimated total of 54 carcasses were recovered (46% survey efficiency). Exact counts of carcasses were not kept on August 31st and September 3rd. If we were therefore able to find 46% of all carcasses deposited during our surveys, we can estimate that there were actually 173 female and 13 male carcasses found between August 10th and September 4th based on our counts of 80 female and 6 male carcasses during this period, though estimates remain preliminary.

Considering only hatchery-origin female fish, we estimate that 34 (broodstock-based and telemetry-based estimates are equal) hatchery-origin female Chinook Salmon terminated downstream of the WHP. This compares to 51 hatchery-origin females that were counted at the ladder.

Discussion

Eighty-six Chinook Salmon carcasses were recovered from the upper Yukon River in 2018. This was far higher than in previous years; however, effort was also higher, focused on previously-identified deposition zones, and continued later into season when more carcasses were present. There was a strong female bias in the recovered carcasses, and most female carcasses retained either some or all of their eggs. The proportion of female Chinook Salmon that had deposited all or most of their eggs was considerably lower in this study relative to other Yukon River populations (Table 1). We provided two separate population estimates, which indicated that there were many more Chinook Salmon terminating downstream of the WHP on the mainstem Yukon River than previously documented; however these estimates should be interpreted with caution. Findings from this study indicate that future carcass surveys to investigate egg deposition are warranted to expand on preliminary calculations conducted within this report.

Nearly all the fish identified in this survey were female, despite males comprising the majority of the run (67% of 691 fish) counted at the Whitehorse Rapids Fishladder immediately upstream of the survey area. Previous surveys at this location also identified large proportions of females (Sebes and Lapointe 2017; Von Finster 2005), though this was not a common pattern observed in other carcass surveys in the Yukon River (Table 1). There are a few reasons why we may have observed more females fish than male fish during our surveys. 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). On the Yukon River, this could have decreased the likelihood of detecting male carcasses, given that they may have be distributed over a broader area and settled in locations where water depth prohibited carcass detection. A concurrent telemetry study indicated that male Chinook salmon continued moving until September 10th, whereas females were only detected moving until September 1st (Twardek and Lapointe 2018). Further, movements of nine acoustically-tagged Chinook Salmon downstream of the WHP had ceased by September 4th. If additional carcass surveys had been conducted after September 4th we may have recovered a greater proportion of males. Another possibility is that surveys may be more likely to recover large fish that settle to the bottom (Zhou 2002), and hatchery records over the last two years indicate that females are somewhat larger than males (845 mm vs. 747 mm). Planned telemetry research downstream of the WHP in 2019 may provide insight as to whether there are differences in the detection probability of male and female Chinook Salmon carcasses based on their deposition sites. 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). We do not currently have the information to distinguish between these possible explanations.

The incidence of complete egg deposition in females was low (30%) compared to similar investigations on Chinook Salmon in tributaries of the upper Yukon River. Across 8 other studies in this system, the proportion of completely spent females was 90% (Table 2). We estimated that egg deposition averaged 77%, 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 3) and error estimates were not calculated. A number of hypotheses exist to explain egg retention, but ultimately it appears to be a combination of density-dependent and environmental factors (discussed in Quinn et al. 2005). Surveys of Chinook Salmon across their entire distribution indicate that partial spawning is uncommon (Bowerman et al. 2016), but may be related to spawner density (Quinn et al. 2007). 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 complete 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 where they compete with the population of Chinook Salmon that appears to spawn naturally in this reach. Atlantic Salmon that are delayed at power stations may attempt to spawn elsewhere (Webb 1990; Chanseau and Larinier 1999; Rivinoja et al. 2001; Thorstad et al. 2003b, 2005). Fish that fail to pass the WHP could lead to inflated spawning densities in the study reach and partially explain the partial egg deposition rates observed here, however, results are preliminary and should be interpreted with caution.

The presence of 16 hatchery-origin female Chinook Salmon carcasses downstream of the WHP compared to the 51 counted at the ladder indicates that a substantial proportion of hatchery female fish strayed from upstream stocking sites. Estimates of spawning escapement based on recovery rates of broodstock carcasses and telemetry data indicate that an even greater number of hatchery fish likely terminated downstream of the WHP. Hatchery-origin fish do not appear to stray frequently upstream of the WHP. Of the 28 hatchery-origin fish implanted with acoustic transmitters in 2017 and 2018 that passed the ladder, 3 fell back and the remainder travelled to known spawning grounds in Wolf Creek or the M'Clintock River – Michie Creek system (Sebes and Lapointe 2017; Twardek and Lapointe 2018). Further, recovery of coded-wire tags in Yukon River hatchery-origin fish indicated 93% fidelity to release sites upstream of the WHP (de Graff 2005), corroborating telemetry data. Thirteen hatchery carcasses recovered 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 had completely deposited their eggs, suggesting that some fish attempted to spawn at alternative sites other than their release sites. Egg deposition appeared to be lower for hatchery- than wild-origin fish based on the length-fecundity model, a finding that has been observed for other populations (Christie et al. 2014). An increased sample size in future years will provide further information on these relationships.

Residency time

Preliminary information on residency time of carcasses at deposition sites was obtained by monitoring the presence of externally-tagged carcasses over successive days. Approximately half of the carcasses we monitored remained at deposition sites for over three days, suggesting that future surveys should be completed frequently to encounter the majority of deposited carcasses. Residency time estimates will need to be refined with further data collection in future years where more carcasses are externally-tagged, and carcass surveys are completed more regularly.

Spawning escapement estimates

We demonstrated how carcass survey and acoustic telemetry can be used to estimate the abundance of Chinook Salmon carcasses downstream of the WHP. Though these methods produced very similar results, we have strong reservations about their accuracy. We did not find any of the nine Chinook Salmon implanted with acoustic transmitters that terminated downstream of the WHP as part of a concurrent telemetry project (Twardek and Lapointe, 2018). These fish include four that did not pass the WHP, along with five that passed then fell back. The lack of recovery of any of these fish is likely random owing to the small sample size, but suggests a much higher population size than the two estimates provided here. Similarly, the population estimate based on ladder passage rates (60%) of fish tagged downstream of the WHP is also based on a small sample size (N = 10) and may not reflect the true proportion of fish that terminate in the study reach. The proportion of fish that fall back after passing the WHP was not considered. Our derived population estimate would vary considerably if the actual passage and retention rates differ from what was observed for these 10 fish.

The population estimate based on relocated broodstock carcasses also 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, the extent to which deposition sites of broodstock carcasses reflect those of naturally dying fish is unknown, and a different proportion of broodstock carcasses may have been recovered. Hatchery staff were unable to provide the exact number of broodstock carcasses returned to the river, so this number is merely a best-estimate.

Given the limitations of both population estimates, we caution against interpreting them as actual estimates. They simply provide evidence that the actual number of carcasses in the study reach was higher than the number of recovered carcasses. These estimates could be improved in future years with more accurate counts of hatchery broodstock carcasses, and increased sample size of fish tagged with acoustic transmitters downstream of the WHP. Telemetry could also be used to track the drift patterns of broodstock carcasses relative to fish that died naturally, to better assess whether recovery rates are similar for both carcass types.

Acknowledgements

We would like to thank the Yukon River Panel, Yukon Energy Corporation, The Pacific Salmon Foundation, the Canadian Wildlife Federation, and the Northern Scientific Training Program for their direct financial support of this project in 2018. 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, Dan Cresswell, and Tami Grantham. We thank Nick de Graff, Al von Finster, Warren Kapaniuk, and Lawrence Vano for their expertise and advice.

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