

Cowichan Adult Chinook Enumeration Methodology Change

Pacific Salmon Commission – Southern Fund

Technical Report – Year 2

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Abstract

A five year program to develop an alternative method for enumerating Fall Run Cowichan River Chinook using Passive Integrated Transponder (PIT) tags was initiated in 2017. In spring 2018, a total of 4,676 hatchery and 3,557 wild juvenile Cowichan River Chinook were implanted with 12 mm FDX-B PIT tags. In addition, 276 mature Chinook were captured and tagged in river during early fall. An array of 12 antennas located at the counting fence detected 150 tags inside returning Chinook from previous tagging years between August 31 and November 8, 2018. A secondary antenna in the Skutz Falls fishway produced 87 tag detections of which 29 were from the group tagged as juveniles and 58 from mature fish tagged in the lower river. The counting fence (operated since 1988) was staffed between September 7 and October 26, 2018 yielding a count of 7,049 adults and 2,900 jacks. Based on the PIT tag data we estimated 49.6% of the population migrated after the fence was removed resulting in an expanded count of 13,860 adults with a standard deviation (SD) of 1,249 and a coefficient of variation (CV) of 9.0%. The natural spawning jack escapement was estimated at 5,754 fish based on the ratio of adults to jacks observed during fence operations. A total of 408 adults and 1,532 jacks were enumerated in the Skutz Falls fish way during 50 hours of video review. A total of 38 PIT tagged fish were detected during this time yielding an independent escapement estimate of 10,336 adults +/- SD 2,885 and a CV of 27.9%. The jack estimate from this site was more precise at 5,602 +/- SD 864 and a CV of 15.4%. These results indicate that PIT tags are proving to be a useful tool for expanding Chinook escapement estimates in the Cowichan River and that Skutz Falls continues to show promise as an alternative monitoring site provided modifications are made to infrastructure as outlined.

Introduction

Cowichan River Chinook have been selected by the Pacific Salmon Commission (PSC) as one of nine indicator stocks in British Columbia that contribute to Southern Boundary Area Fisheries (www.PSC.Org). The Cowichan River indicator has represented the Lower Georgia Strait area since 1988 (Baillie et al. 2015). As a result, this stock is rigorously monitored and through the PSC has an increased Coded Wire Tag (CWT) program to allow for greater resolution in stock/catch analysis. Since the program inception, adult returns have been monitored through the use of a counting fence in the lower river (approximately 7 km above tidewater) in conjunction with an upper river dead pitch program.

The counting fence, though providing reasonable escapement data on most years, has been re-located once and rebuilt several times. Persistent issues include difficulty to maintain function at higher flows, re-occurring maintenance and rebuilding costs, high labor costs (24 hr. staffing) as well as delays to upstream fish passage at low flows. The latter has resulted in the local Cowichan Tribes First Nation pushing for an alternate escapement monitoring strategy.

A five year project to explore other enumeration methods for this stock was funded by PSC in 2017/18. In 2016, the British Columbia Conservation Foundation (BCCF), funded primarily by the Pacific Salmon Foundation (PSF), as part of the Salish Sea Marine Survival Project (SSMSP), installed an array of 12 Passive Integrated Transponder (PIT) tag antennas at the current DFO counting fence site. The two transects of 6 antennas have the ability to detect tags implanted in Chinook throughout their life including juvenile out migrants and adult returns. A PIT tag based mark-recapture approach is a logical alternative to the counting fence, however several years of overlap is required to ensure data consistency between the two methods.

Detailed objectives outlined in the year two proposal were as follows:

- A) Tag up to 10,000 juvenile Cowichan Chinook (mixed hatchery and wild spawned) with PIT tags resulting in 50-150 returning tagged adults in each age group in coming years.
- B) Use the PIT antenna array to estimate the number of tagged fish returning to fresh water (these fish were tagged as part of the SSMSP). Tags/fish will also be counted through the existing fish fence to evaluate the permanent array during this first year of comparison.
- C) PIT and external tag 250-500 mature Chinook in the lower river during the fall
- D) Install and operate a camera and PIT antenna system as a pilot in the Skutz Falls Fishway
- E) Determine, using one or methods/sites, the ratio of tagged to untagged adult Chinook to be used as an expansion factor to estimate the total run size.

Since 2014 BCCF has tagged a total of 56,566 Chinook Juvenile salmon for the SSMSP (2014 n=7,048, 2015 n=15,748, 2016 n=22,790, 2017 n=10,906). Though not originally tagged for the purpose of this project, all returning tagged fish can be included as they are expected to return through 2020.

Study Area

The Cowichan River originates at Cowichan Lake and flows east for approximately 46 km before reaching tide water at Cowichan Bay. The intertidal mud flats extend for an additional 2.5 km between the Tzouhalem Road bridges and the deep water drop off within the bay (Figure 1 - upper). A bifurcation occurs 1.3 km upstream of

the bridges (river km 1.3) which separates the river into the North and South Arms. The Trans-Canada Highway 1 crosses the Cowichan River at km 5.3 while the current counting fence and PIT tag detection array are located at river km 7, just downstream of the Allenby Road Bridge (Figure 1). Based on current knowledge, the majority of Cowichan Chinook spawn in the upper river above river km 20, well above the detection array. However, Chinook spawning has been documented as far downstream as Duncan, including in 1976 where an estimated 23% of the run spawned in this region (Lister et al. 1981). Skutz Falls is located at the upstream end of Marie Canyon at river km 33.6. There are a series of fish ladders and bypass channels on the north side of the river which were initially constructed in 1931 and added to or modified several times since to improve fish passage (Carl 1937).

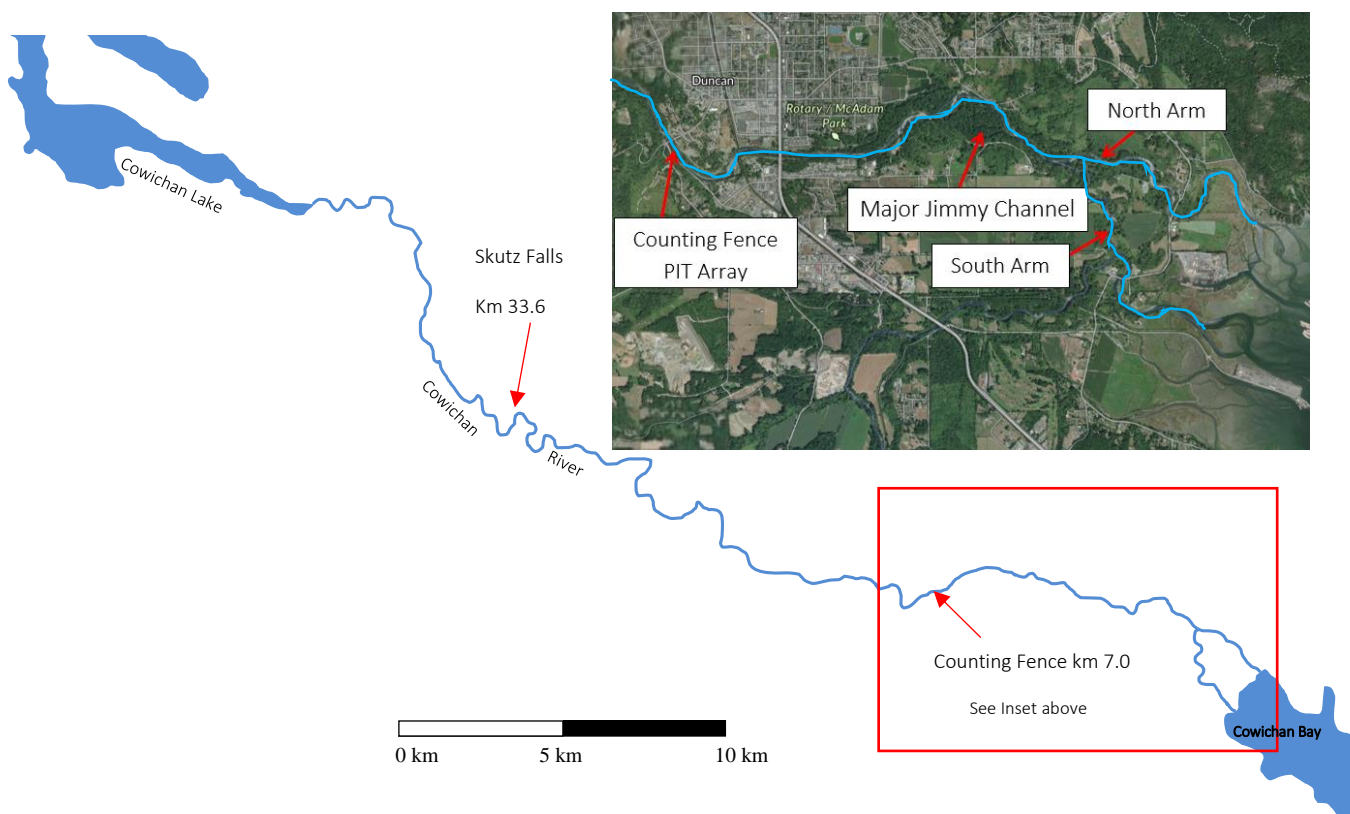


Figure 1. Map of the Cowichan River between the lake and the bay including an inset aerial image with PIT tag detection array/counting locations.

Methods

Fish Capture and Tagging

Juvenile Chinook were implanted with 12 x 2.12 mm PIT tags (0.1 g in air), injected into their body cavity using a hollow 12 gauge needle. All tags were purchased in pre-loaded individual 12 gauge needles to increase efficiency in the field, ensure every needle was sharp, and provide sterilization between fish. Two different tag technologies were implemented in year one (2017) – Half and Full Duplex B (HDX/FDX-B). The difference between the two is in how the tags are de-coded using changes in amplitude or frequency (similar to AM/FM radio). A portion of the hatchery fish in 2017 were tagged with 12 mm HDX tags due primarily to the flexibility

of antenna design options for a targeted predation estimate project (as part of the PSF - SSMSF). In year two (2018) FDX-B tags were applied to all fish due to the slight advantage in noise resistance and better read range. All tagging moving forward will be conducted with FDX-B tags.

Needles and tags come loaded in plastic trays¹ of 100 which also allowed for easy accounting prior to field visits and during tagging. Needles were inserted into tagging guns¹ by pushing the gun down onto the plastic end of the needle. The tag was expelled by squeezing the gun which activated a push rod. An additional plastic push rod between the tagging gun and the tag ensured the gun remained sterile between fish. The empty needle was then expelled from the gun by pulling the trigger at the front of the implanter. This tagging cycle was repeated with every fish.

Tag insertion and fish handling techniques described in the Columbia River PIT Tag Marking Procedures Manual² were modified slightly. As per recommendations from the DFO Veterinarian³, the procedure for tagging was to insert the needle ahead of the pelvic girdle along the midline and inject the tag forward (Figure 2).

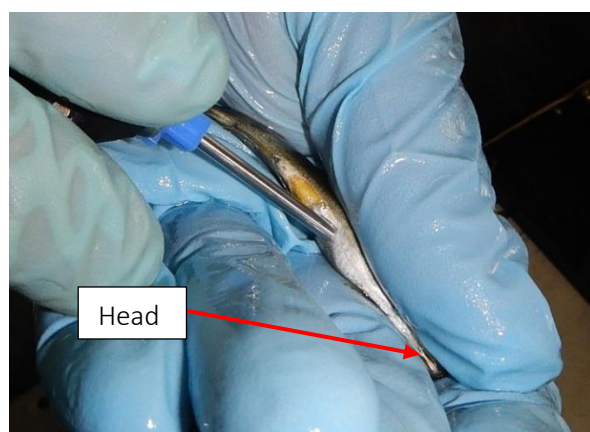


Figure 2. Photos demonstrating the tag insertion location used since 2015 as per recommendations from the DFO Veterinarian.

Hatchery Tagging

In 2018, a separate batch of 5,000 AD/CWT fish were set aside for PIT tagging operations which were isolated in the CWT data base as experimental (separate from indicator tags). Hatchery fish were taken off food at least 24 hrs. prior to tagging and feeding was reinstated two days afterwards. Tagged fish were held in aluminum “cap troughs” until release for a period of approximately three weeks. Fish were measured for fork length and scanned the day prior to in-river release. The last four digits of the PIT tag were recorded with each fork length, thus a size at release was recorded for every fish. The scanner was later downloaded and the data/time stamp as well as PIT ID were linked to the tagging data to ensure no transcription errors were made. Any mortalities or lost tags during holding (recovered from the bottom of the tanks) were scanned and recorded. Fish were released at pre-determined locations in the middle and lower mainstem Cowichan River on May 23 and 24, 2018.

¹ Biomark HDX 12/FDX B 12 pre-load tray and MK 25 implanter

² PIT Tag Marking Procedures Manual. Version 2.0. 1999. Prepared for Columbia Basin Fish and Wildlife Authority PIT tag steering committee. ftp://ftp.ptagis.org/Documents/PIT_Tag_Marking_Procedures_Manual.pdf

³ Christine MacWilliams

River Tagging

In 2018, the proposed tagging location was changed in order to take advantage of the fence operated for a parallel Coho smolt tagging project. A notional target of 5,000 wild Chinook was set for year two in order to produce ~75 tag returns at an estimated 1.5% survival.

A fence style smolt trap was set up in the North Arm of the lower Cowichan River (Figure 1) with the intention of capturing out-migrating Coho smolts near tidewater. The trap consisted of 10 screened⁴ panels, each 0.9 m x 3.0 m, and 3.0 m long by 1.2 m x 1.2 m screened funnel tapering down to a 4.0 m flexible fish safe pipe. Fish were transferred from the pipe to a 1.2 m x 2.0 m x 0.6 m three-chambered plywood trap box.

In addition, a smolt fence was also constructed in the Major Jimmy side channel (Figures 1 & 3) and consisted of parts of the mainstem smolt trap described above. A third second smolt trap was installed in the hatchery side channel a short distance downstream. Similar to the mainstem, the smolt fences consisted of five 0.5 m X 3.0 m screened panels and a screened intake that funnelled water and fish into 15.2 cm diameter flexible fish safe pipe which was fed into a 1.2 m x 2.0 m x 0.6 m, three-chambered plywood trap box.



Figure 3. Panoramic view of the Major Jimmy smolt trap, 2018.

Regardless of tagging site, fork length was recorded for each fish using a 30 cm board and corresponding capture/tagging information was collected for uploading to a database, managed by DFO. Information included date & time of capture, location name and coordinates, fork length, origin and species. PIT tags were scanned during implantation and the last four digits were noted on the tagging sheets. The scanner was later downloaded and the data/time stamp as well as PIT ID were linked to the tagging data to ensure no transcription errors were made.

Cowichan Bay Tagging Event

In 2017, a 23 m commercial fishing vessel “*Ocean Venture*” was chartered to capture wild juvenile Chinook in Cowichan Bay (Pellett and Damborg 2018). This work was funded by PSF and represented the last year of tagging under the SSMSP, therefore the vessel was unavailable in 2018. Due to slower than expected catches in the river, the crew switched to beach seining in Cowichan Bay in 2018 (Figure 4) to fulfil tagging targets. Two nets were employed for this activity ranging from 22 m to 38 m in length and 1.5 m to 2.5 m in depth. Panel size varied from $\frac{3}{4}$ ” to $\frac{1}{4}$ ” stretch mesh with $\frac{1}{2}$ ” being the most common material. Nets were deployed from

⁴ Vexar®, 6.4 mm mesh size (1/4”)

a 5.5 m aluminum boat (runabout style) while a team of 2-4 people pursed the net in from the shore. Up to 10 sets per day were made depending on catch rates and processing time.

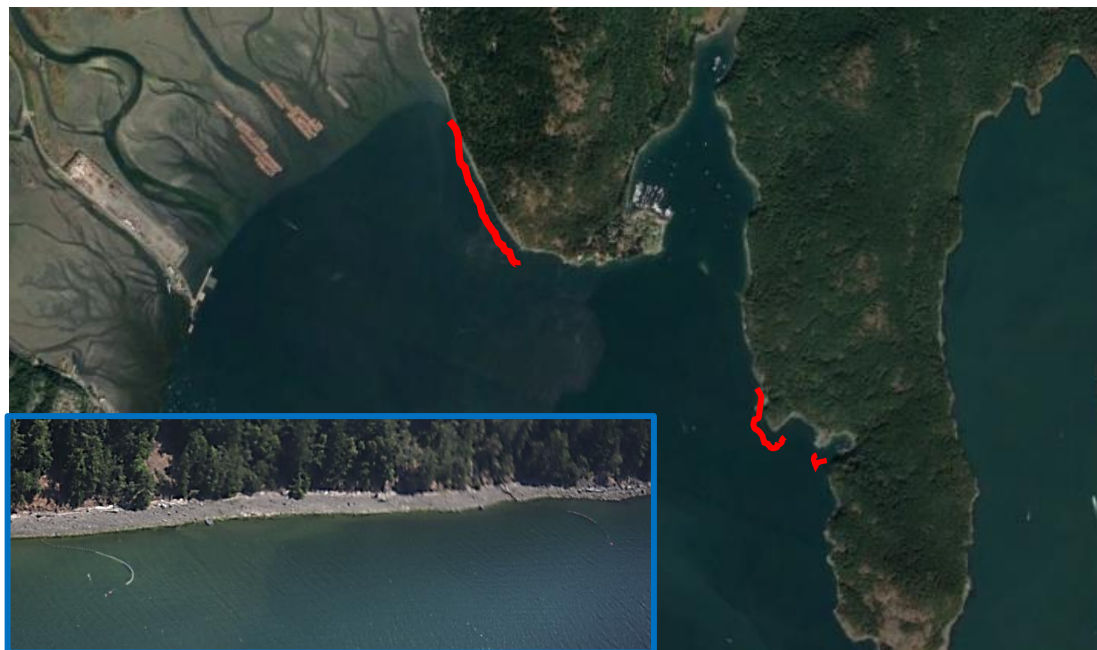


Figure 4. General area (red lines) in Cowichan Bay where juvenile Chinook were captured and tagged by beach seining in June 2018. Inset; aerial view of beach seine deployments.

Once pursed in, crews would sort the bycatch (eg. jellyfish, herring, squid, stickleback) from the main net, and using a small brailer, scoop juvenile salmonids into the large live wells. Further sorting would occur until only juvenile Chinook remained. A crew of 2-4 would then anesthetize, tag and measure juvenile Chinook using methods described as above. Those unfit for tagging (scale loss/damage) or which already contained a PIT tag were measured and released only. Following tagging, fish were placed in a recovery tank prior to release (Figure 5).



Figure 5. PIT tagged juvenile Chinook holding in the recovery tank prior to release back into Cowichan Bay.

In a typical day, catch rates of approximately 200 – 500 Chinook were achieved. A small number of fish failed to recover from the stress of anesthesia and tagging; these fish were not released and the tag numbers were recorded so that they could be later removed from the database.

In-River Fall Tagging

A tagging target of 250-500 mature Chinook was set to aid in mark-recapture estimates at Skutz Falls. Fish were collected by beach seining approximately 500 m downstream of the counting fence. The majority of fish were captured as hatchery brood stock, surplus fish were provided to tagging crews after targets were met. The 50 m x 5 m seine net was deployed from a small skiff in a downstream direction and retrieved by a crew of 8-12. Fish were transferred from the purse of the net to vinyl coated canvas “brood tubes” then into a plastic “half tote” for tagging (Figure 6). A continual flow of water was provided by a small gas powered trash pump to both tagging and recovery totes.

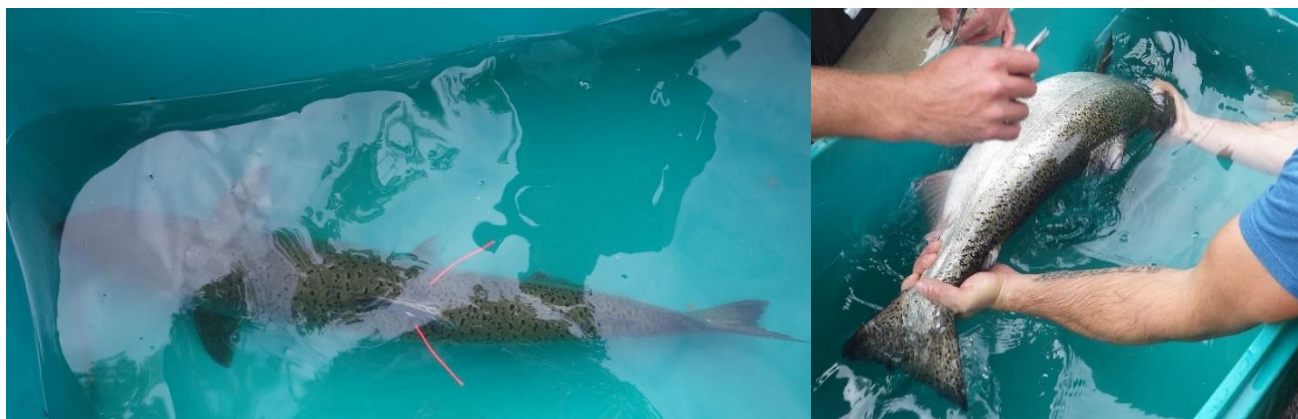


Figure 6. Anchor tagged Cowichan River chinook in recovery tote (left) and scale sample collection (right), September 25, 2018.

The tagging process consisted of biological data collection including length (POH - Post Orbital Hypural and NF- Nose Fork), sex, origin (adipose clip status) on all fish and scales on select fish. Tag application included two dorsal “T-Bar” anchor tags⁵ (Figure 6) as well as an internal PIT tag. Anchor tag ID and colour were documented along with PIT tag ID's, with the last four PIT tag digits recorded on the data sheets.

PIT Tag Detection Arrays

Passive Integrated Transponder (PIT) tags have been deployed in juvenile Cowichan River Chinook since 2014 to support several research initiatives funded by the Pacific Salmon Commission (PSC) and Pacific Salmon Foundation - Salish Sea Marine Survival Study (PSF- SSMSF; Pellett 2017). The primary research objective was to track the survival to adult return (SAR) from four stages between May and September of their first year. In order to detect returning tags a permanent detection array was installed at the counting fence site in May 2016. Two arrays, consisting of six antennas each, were anchored to the bottom with each array spanning the wetted width of the channel (~ 37 m, Figures 7 and 8). One of the arrays was installed 21 m downstream of the anchor rail for the counting fence and the other 25 m upstream such that 46 m separates the two arrays. This allows fish movement to be tracked in an upstream or downstream direction based on the sequence of detections.

The arrays remain operational year-round and at all discharge levels. Tags are energized as they pass within the detection field of an antenna which typically extends about 50 cm above the substrate depending on tag type and electrical “noise”. The antennas decode the unique tag ID's as they pass within the detection field

⁵ FLOY Tag <http://www.floytag.com>

along with a date/time stamp. All twelve antennas are wired in a network configuration and managed by a master controller that manages all operational and individual antenna settings (Figure 7). The master controller and antennas operate on 24V DC power supplied via two banks of 12V batteries in series. The batteries are charged using 120V AC power at the site but isolated from the reader by a switching device to limit electrical “noise”. This also allows the system to continuously function in the event of a power outage.



Figure 7. Cowichan River PIT tag antennas (left), master controller/modem (center) and installed array of 6 antennas (right).

As the charging field from one antenna can interfere with adjacent antennas a scan sequence is programmed. This sequence activates antennas in pairs with only one antenna in each transect firing at a time. Antennas are labeled in sequence starting with A1 on the upstream transect on left bank and ending with A12 on the right bank of the downstream transect. Real time data and diagnostic information can be accessed remotely from the master controller via a cellular modem to monitor performance.

A secondary tag detection site was established in the primary fish way at Skutz Falls (Figure 9; river km 33.6) in order to properly estimate lower river detection efficiency. Although fish can bypass the Skutz Falls fish way at certain flows, tags detected in the fish way were assumed to represent a random sub-sample of fish passing over the lower river arrays. The proportion of Skutz Falls tags detected at both sites was used to estimate lower river detection efficiency and also provide information on migration speed/timing.

Two additional PIT tag detection antennas were operated in the lower Cowichan River during fall 2018. Temporary antennas ranging from 12-15 m wide each were deployed in the North Arm (September 21-October 27) and South Arm (September 10 – October 28; Figure 1). Construction materials and methods can be found in Pellett (2017). These antennas were deployed to collect information on the relative use of the channels relative to low flows and gravel removal works. As coverage was not complete and detections were considered random, data was used to estimate losses to the fence and expand final escapement estimates.

Tag detections were downloaded from the master controller in .log file format then imported into MS Excel (.csv; Table 1). Each unique tag code was then sorted to remove duplicate detections on each antenna (leaving only the first hit on each antenna). Each ID was then linked back to the tagging database to determine age based on tagging year. The first detection at the counting fence (antennas 7-12) was then binned by 8 hour fence shift to calculate the number of “arrivals”. Next, the first detection on any of the upper antennas (1-6) was binned to calculate the number of “passage” events by shift. This method ensured each unique tag was only counted once during the estimation of PIT tag ratios in each shift. It also allowed

behavioral parameters to be estimated including passage time through the fence (delay) and fate (eventual passage or non-passage).

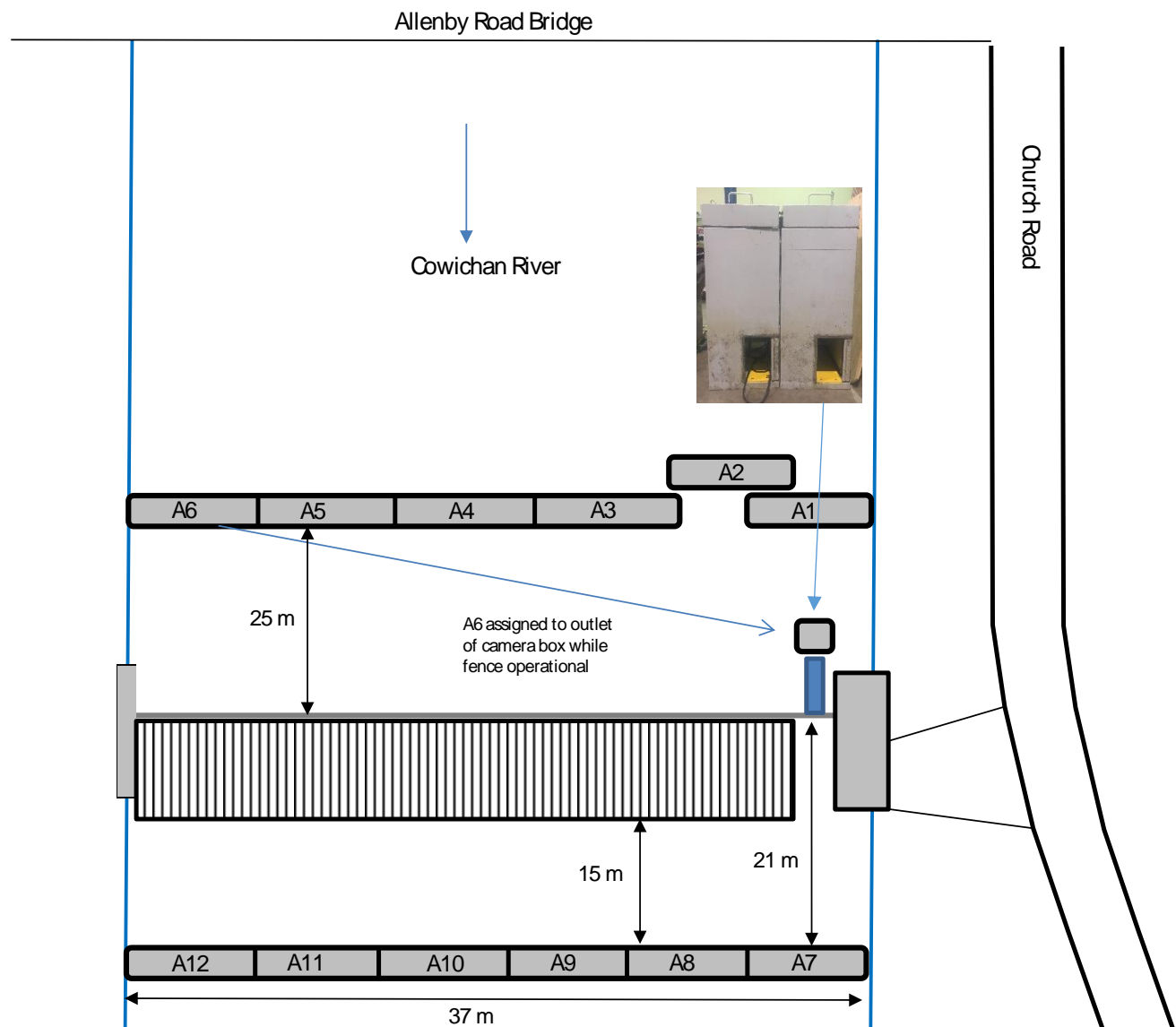


Figure 8. Plan view of the permanent PIT tag array in the lower Cowichan River relative to the seasonally operated counting fence.

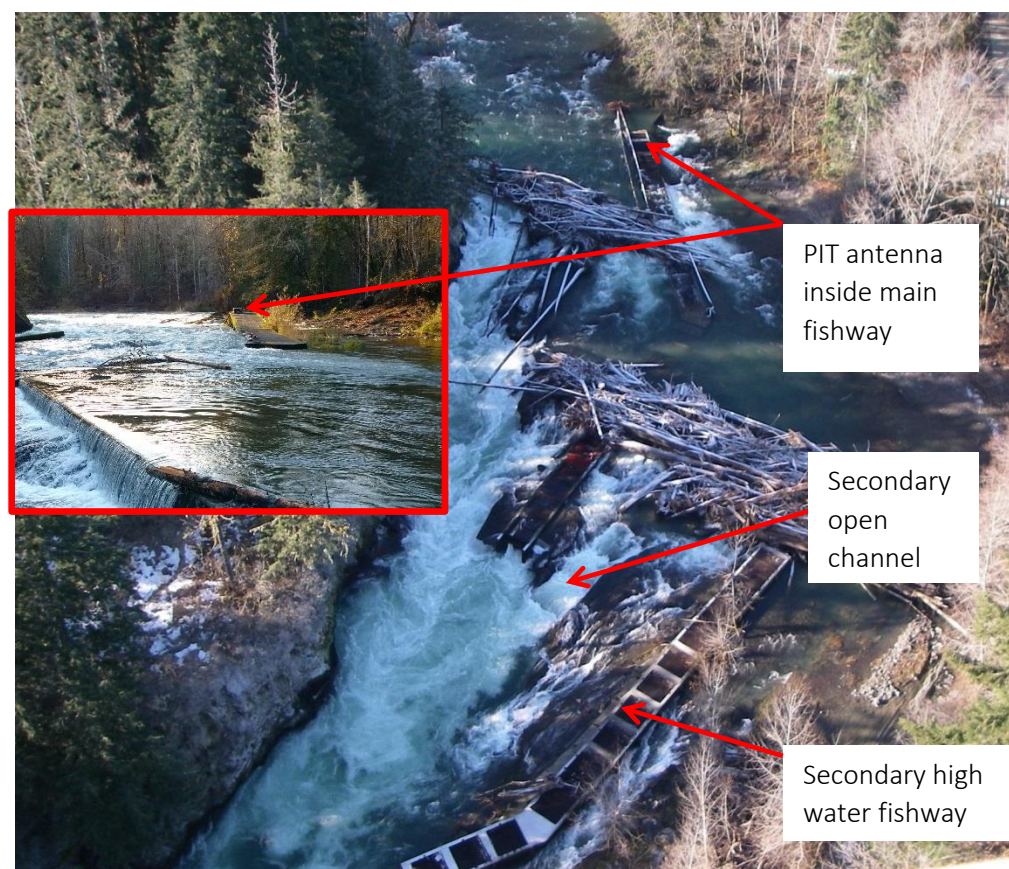


Figure 9. Aerial photo of Skutz Falls fishways. The primary (upstream) fishway was instrumented with a pass-through PIT antenna three cells from the top. The secondary open channel and fishway are only functional at moderate to high flows and are often limited by debris accumulation as shown.

Table 1. Example of tag detection data from the mainstem array prior to processing.

Reader Date	Reader Time	Antenna ID	DEC Tag ID
10/19/2017	13:47:56.490	11	982.000406599096
10/19/2017	13:47:57.280	11	982.000406599096
10/19/2017	13:47:57.330	11	982.000406599096
10/19/2017	13:48:13.680	1	989.001005665110
10/19/2017	13:48:13.710	1	989.001005665110
10/19/2017	13:48:14.500	1	989.001005665110

Tags were also detected in bed-load moving over the antennas when flows increased significantly. These could be teased out easily by the large number of detections at each antenna (seconds to minutes in the read range) along with their downstream direction (hours to days between arrays). The vast majority of these tags were applied in freshwater and represent juveniles which did not successfully migrate to the ocean or rejected their tag. These tags were removed from the analysis to ensure only live tags were included in the study.

Data processing for Skutz Falls was far simpler as only one antenna was monitored. Two antennas were operated in previous years but detection efficiency was found to be >99%. As detections were a random sub-sample due to bypass there was no advantage to running a second antenna. Tag detections were also far easier to process as fish generally proceeded in an upstream direction avoiding duplicate detections over time. The date/time stamp for the first detection for each tag was kept and all redundant detections filtered out. Tag IDs were linked back to the data base to verify species such that any non-Chinook or juvenile detections could be filtered out.

Other Monitoring

Adult Chinook were captured by Cowichan River Hatchery staff in the lower river downstream of the counting fence. Fish were loaded into waiting trucks with holding tanks and transported a short distance back to the hatchery. It was not practical to scan individual fish as they were loaded into tanks due to concerns over increased stress from prolonged handling so fish were scanned during egg takes using a hand held reader (Figure 10).

In addition, crews drifted the upper river collecting post-spawn fish as part of the annual dead pitch program. Each fish was sampled for the standard suite of biological data and snouts were removed from hatchery fish identified by a missing adipose fin for CWT recovery. Each fish was also manually scanned for a PIT tag and inspected for an external T-Bar tag from lower river tagging operations.



Figure 10. Hand held PIT tag reader (Biomark HPR Lite) employed for scanning individual fish.

Escapement Estimates

Fence and fishway counts are considered incomplete in all years and must be expanded to derive an escapement estimate for the season as fish can migrate outside of the operating window or ascend Skutz Falls naturally. The combination of video and PIT tag data provides the necessary foundation for a Peterson

mark recapture estimate. The relatively high proportion of the population re-sampled at the fence every year (~50-90%) lends well to an estimate providing high confidence and low uncertainty.

Several different equations can be used to estimate both population size and uncertainty. In 2017, a Bayesian based model was implemented to expand the aggregate fence count of adults and jacks (Equation 1). Since then we have researched other options and have provide and alternate hypergeometric model (Equation 2). Cowichan Chinook population estimates are conducted without replacement; individuals are only scanned/counted once. In other mark-recapture estimates animals can be released and re-captured several times out of the same population. The hypergeometric model is best suited to sampling without replacement and is considered a better fit for the data set.

Model parameters in order to estimate population size (N) are as follows:

The number of animals marked on the first visit (n) is represented by the number of PIT tags detected in returning fish for juvenile tagging operations or the number of tags deployed in mature fish during in river tagging. In either case they can be further divided into natural spawners (fish that migrated upstream of the fence) or total population (all tags regardless of behavior).

The number of animals captured on the second visit (K) is represented by either fence or fishway counts (all fish, regardless of tag status).

The number of recaptured animals (k) is equal to the number of PIT tag detections from either group (juvenile or in river) within the population that was counted at either site (fence or fishway). Tags detected outside of the counting period are excluded from the recaptures in order to derive an accurate mark rate in the population.

Jack and adult counts were tallied independently at each location while PIT tag detections were also able to be divided accordingly based on tagging year (juvenile tags) or length at tagging (in river). Jack and adult populations were estimated independently at each site in order to remove any bias in the counts (i.e. differential fish way use by jacks).

Equation 1. A Bayesian mark-recapture formula for estimating the mean population and standard deviation after Webster and Kemp (2013).

Bayesian Model

Mean value +/- standard deviation

Let

N = Number of animals in the population

n = Number of animals marked on the first visit

K = Number of animals captured on the second visit

k = Number of recaptured animals that were marked

$$N \approx \frac{(K - 1)(n + 1)}{(k - 2)} \pm \sqrt{\frac{(K - 1)(n - 1)(K - k + 1)(n - k + 1)}{(k - 2)(k - 2)(k - 3)}}$$

Equation 2. A Hypergeometric mark-recapture formula for estimating the mean population and standard deviation adapted from Schwartz (2006).

Hypergeometric Model

Mean value +/- standard deviation

Let

N = Number of animals in the population

n = Number of animals marked on the first visit

K = Number of animals captured on the second visit

k = Number of recaptured animals that were marked

$$N \approx \frac{(n+1)(K+1)}{(k+1)} \pm \sqrt{\frac{(n+1)(K+1)(n-k)(K-k)}{(k+1)^2(k+2)}}$$

Assumptions

Table 2. Summary of assumptions and potential bias in the PIT tag based escapement estimate.

Assumption	Validation	Likelihood of Violation	Potential Bias
PIT tagged fish are randomly mixed within the population. Pooled tag estimate assumes similar run timing for all age classes.	Tags were applied in juveniles and detected throughout the migration window as expected. Ratio of jacks (age 2) to adults constant.	<i>Low</i> Not all age classes represented (no age 5), high proportion of Age 2.	If age 2 fish arrive early then adult escapement under-estimated/age over-estimated after fence removal.
Detection probability is the same at all water levels and independent of fence operations	Tag detections at Skutz Falls indicate high detection efficiency for fish passing the lower river arrays at all operational conditions	<i>Low</i> Poor detection efficiency was noted in 2015 (~20%) based on same method. Mainstem array installed in 2016 dramatically improved detections (93% in 2016, 100% in 2017)	Missed tags during fence counts would under-estimate tag proportion and over-estimate escapement. Only possible if detection probability was higher when fence was out. Lower detection probability at high flows would under-estimate escapement. Missed detections during all periods would have no effect.
All tags passing the fence did so via the counting tunnel	Could go back through the data and isolate detections on the outlet of the counting tunnel vs. upstream array	<i>Low to Moderate</i> Fish were noted leaping over the fence and a low number of jacks passing through fence pipes. Likely concentrated during partial/missed counting periods which were removed from analysis of tag ratio	Tags bypassing the counting box would bias the tag proportion high resulting in an under-estimate of escapement.
Tag loss between initial detection and passage was zero	The brood holding pond at the hatchery was scanned for tags after holding fish for up to two months. Four tags were detected brood but none on the floor of the pond.	<i>Low to Moderate</i> This may partially explain some of the tags which failed to pass the site as they could have been shed between the initial detection and passage.	If tags were shed throughout the season then the true tag ratio would decline over time. As the early season ratio was used to expand the late season detections escapement would be under-estimated.
Detection probability was the same for all shifts (day/night)	Compare tag ratio per shift No evidence of low detection efficiency for any time period based on random re-sample of Skutz Falls tags.	<i>Low to Moderate</i> RF noise is present at the site from 6pm to 6am. This reduces read range and possibly detection efficiency of antennas (main issue in 2015). Unknown source but	Majority of early season (low water) counts occur at night but fish tend to move in the day when the water comes up (fence out). This would under-estimate

		could be investigated further	the tag ratio and over-estimate escapement.
Count of non-tagged fish is accurate on all shifts	Compare tag ratios in low/medium and high count shifts	<i>Moderate</i> Suspect under-counting in shifts with high fish movement which also represent a large number of tag detections	Under counting non-tagged fish during busy periods would increase the proportion of tags in the population resulting in an under-estimate of escapement.

As the alternative PIT tag based escapement estimate relies on several new data sources it is important to understand potential biases and assumptions. Table 2 describes several assumptions embedded within this estimate methodology and the potential direction of bias relative to the escapement estimate. The list is not necessarily exhaustive but covers a variety of factors that could have influenced the estimate and may do so into the future depending on how the project is conducted.

Results

Fish Capture and Tagging

A total of 4,900 hatchery-origin Chinook salmon (AFC/CWT) were tagged on May 2 and May 3, 2018 at the Cowichan River Hatchery. Sixty-six mortalities (1.3%) and 158 tag rejections (3.2%) were recorded during three weeks that fish were held in isolation at the hatchery before release. After accounting for tag loss and mortalities a total of 4,676 viable PIT tagged hatchery origin fish were released in 2018.

A more detailed investigation of individual tagger effect was conducted in 2018 by tracking which tag trays were applied by each crew member. It was found that one person who applied 10% of the tags was responsible for 48% of the mortalities and 70% of the tag rejections. Removing this person's fish from the tagging groups yielded a corrected mortality rate of 0.8% and rejection rate of 1.1% for the remaining 4,400 fish.

Each fish was measured prior to release on May 23 and 24 in order to achieve an accurately representation of size. Fork length ranged between 52 and 108 mm with an average of 85.5 mm and a standard deviation of 5.0 mm (Figure 11). This was significantly larger than 2017 when fish averaged 69.8 mm prior to release.

A total of 562 wild origin (natural spawned) juvenile Chinook were captured and tagged in the lower Cowichan River in spring 2018. Of these, 304 were tagged in the Major Jimmy Channel, 257 at the North Arm Trap and one in the Hatchery Channel. In general, wild fish were smaller than hatchery fish and averaged 67.4 mm with a standard deviation of 6.7 mm (Figure 12).

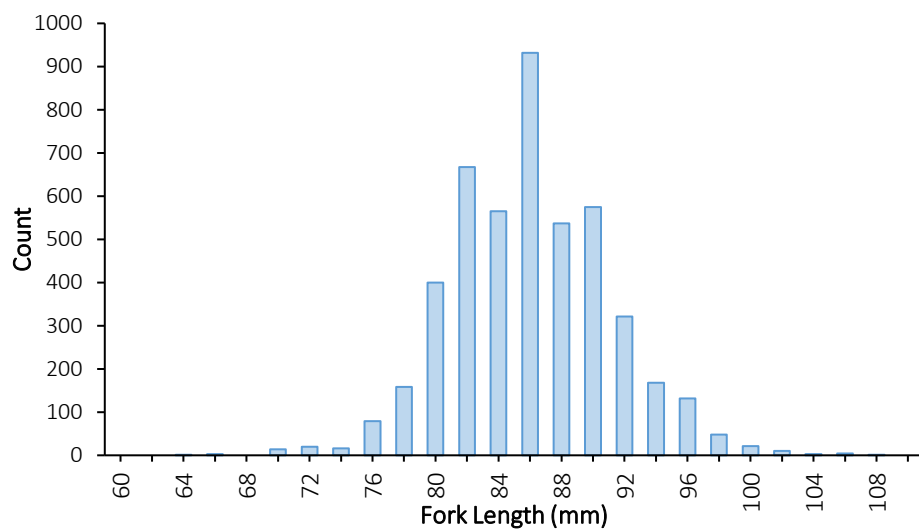


Figure 11. Size distribution of 4,676 PIT tagged hatchery Chinook measured prior to release, spring 2018.

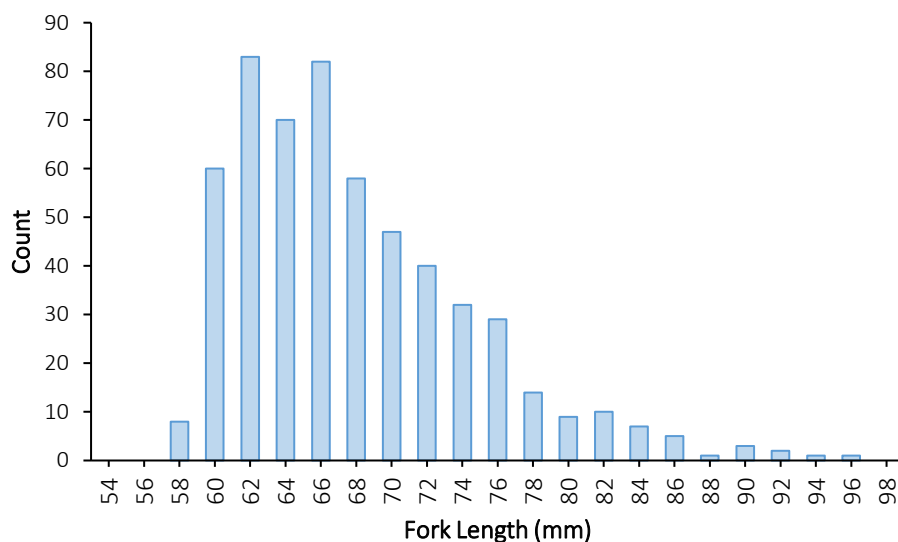


Figure 12. Histogram of wild Chinook size distribution from fish tagged in mainstem or side channel locations (n=562), spring 2018. Note: only fish larger than 60 mm were tagged.

Cowichan Bay Tagging Event

A total of 2,995 juvenile Cowichan River Chinook were captured, tagged and released in Cowichan Bay over six days between June 5-13, 2018 (Table 3). In addition, 22 Chinook were recaptured including 10 hatchery fish (river releases), three wild fish from the lower river trap and nine wild fish from beach seining (same or previous day).

Table 3. Summary of Chinook PIT tagging in Cowichan Bay during beach seining operations, June 2018

Date	CN Tagged	Length (mm)	SD (mm)
05-Jun-18	340	72.2	5.4
06-Jun-18	593	74.2	6.3
07-Jun-18	729	73.8	5.8
11-Jun-18	647	74.0	6.3
12-Jun-18	505	73.4	5.8
13-Jun-18	181	74.8	7.1
TOTAL	2995	73.7	6.1

Natural origin (wild) fish composed approximately 85% of the Chinook catch while hatchery fish were measured and released untagged. They were also found to be significantly smaller on average than their hatchery counterparts at 73.7 mm with a SD of 6.1 mm compared to 79.1 mm and a SD of 7.6 mm for hatchery fish. See Figure 13 for further details on the size distribution for the tagged wild component.

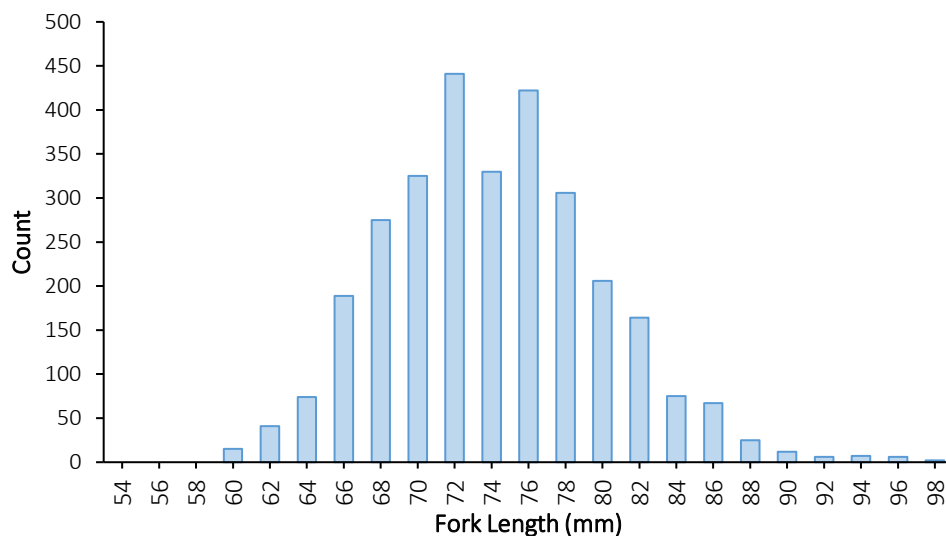


Figure 13. Size distribution for 2,995 wild Chinook implanted with PIT tags in Cowichan Bay; June 5-13, 2018.

In-River Fall Tagging

A total of 276 mature Chinook (194 adults and 82 jacks) were captured and PIT tagged below the counting fence between September 25 and October 10 (Table 4). Of these, 274 received coloured Floy tags in addition to PIT tags for later mark-recapture work via Skutz Falls video and dead pitch operations. Hatchery origin (adipose clipped) fish totaled 46 for a mark rate of 16.7%.

Table 4. Summary of mature Chinook tagged in the Cowichan River between September 25 and October 10, 2018.

	W	H	Total
J	63	19	82
M	107	7	115
F	58	20	79
			276

Fish were also measured twice to develop a Cowichan-specific relationship of post orbital hypural length (POH) to nose-fork length (NFL). This is important for a number of reasons including deriving an appropriate cut-off for camera based jack/adult counts as well as understanding what fraction of the return was under the minimum marine fishery size limit (62 cm). Fork lengths were found to range between 321 mm to 952 mm out of 276 fish sampled while POH and NFL were found to be highly correlated ($r^2 = 0.975$, Figure 14).

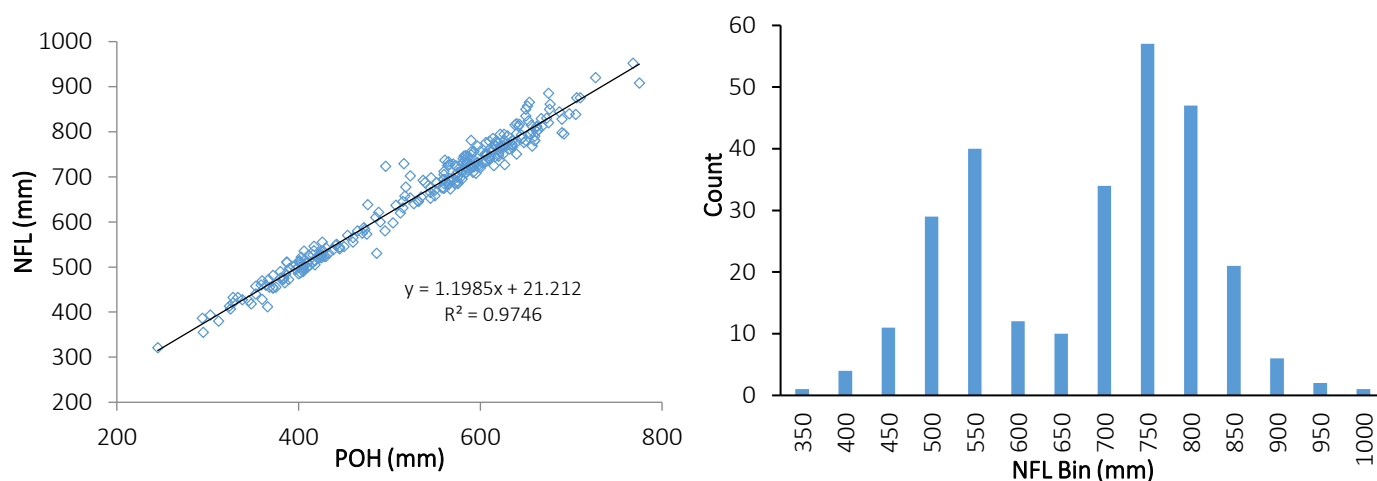


Figure 14. Relationship between nose fork length (NFL) and post orbital hypural length (POH) for Cowichan River Chinook in 2018 (left) and histogram of NFL for the in-river tag group (right; $n=276$).

Adult Enumeration

Counting Fence

All panels of the counting fence were installed on September 7 with the first shift starting at 16:00; one full week earlier than 2017. Chinook were found to be migrating on the first shift with 30 adults and 28 jacks enumerated by the third day. By the end of the first week 98 adults and 50 jacks had passed through the camera box. Relative to 2017 there were fewer migrants in September but more through October including two pulses the week of the 6th and 27th (Figure 15).

The overall adipose clip rate for fish which could be accurately assessed was estimated at 8.9% for adults and 10.4% for jacks ($n=6,938$). A fence panel was removed and an additional passage was opened on the afternoon of October 11th in light of significant numbers of fish holding below the fence following the large

pulse on October 2. Unfortunately the large number of fish holding 500 m downstream of the fence throughout October caused concerns over migration delays resulting in the decision to cease operations on the 26th.

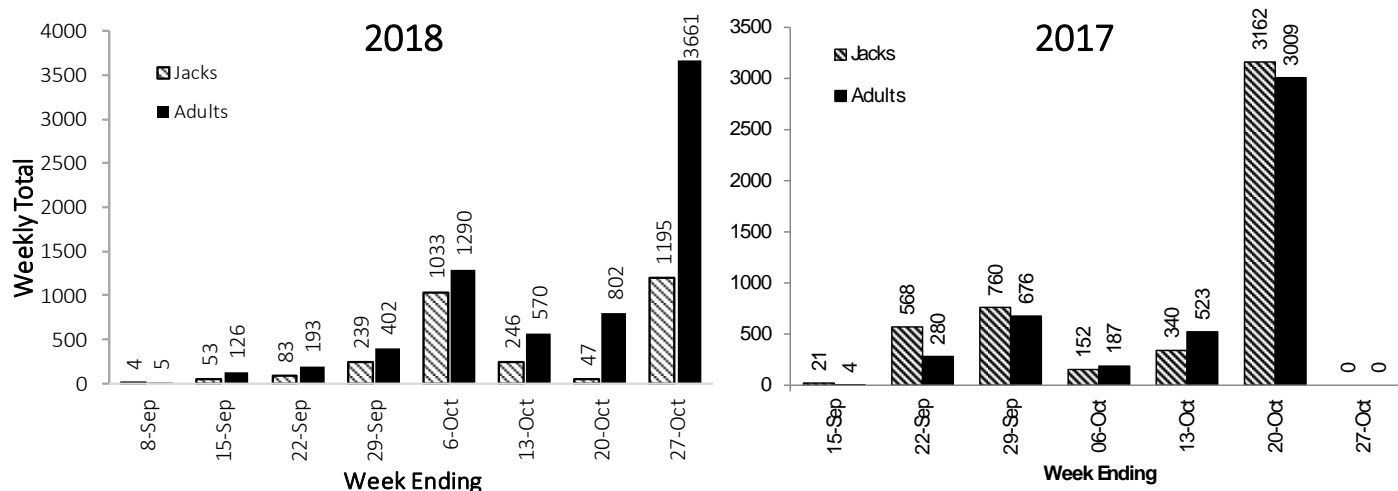


Figure 15. Summary of weekly Chinook counts at the Cowichan River fence, September 7- October 26, 2018 (left) and September 15- October 19, 2017 (right).

A total of 7,049 adults and 2,900 jacks were enumerated before the fence was removed on October 26, 2018. A large proportion of the count (25% or 2,551 of 9,949) was achieved in the last 6 hours of operation prior to fence removal. Video footage (camera and DIDSON) was reviewed post-season to confirm numbers of adults and jacks during this high volume counting period.

Water temperatures were cooler in September 2018 by 2.9°C on average and about 1.0°C colder in October compared to 2017 (Figure 16). Flow was also higher in 2018 with several rainfall driven pulses starting in late September resulting in a sustained discharge >20 m³/s throughout October.

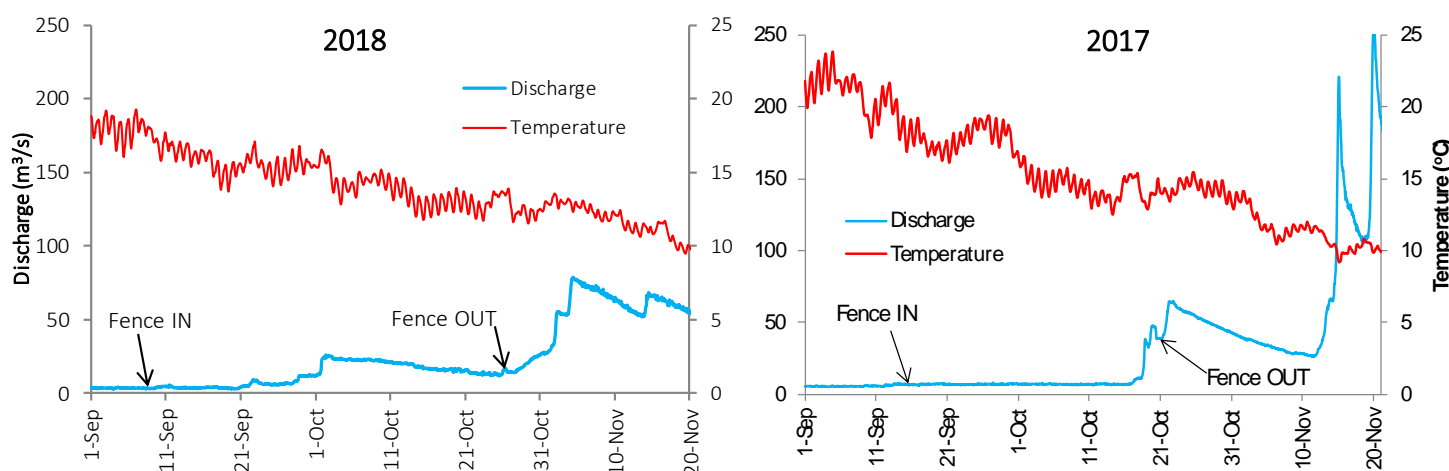


Figure 16. Flow and temperature recorded at Water Survey of Canada station 08HA011 relative to counting fence operations. Cowichan River, September 1- November 20, 2018 (left) and 2017 (right).



Figure 17. Underwater view of Chinook holding below the counting fence in response to an increase in flow, October 2, 2018.

In addition to Chinook, a total of 3,085 Coho were counted through the fence in 2018 of which 63% passed in the last 24 hours of operation. Chum were also enumerated with 2,690 fish recorded over the season including over 1,600 in the last 48 hours. Enumeration of Chum continued through to November 25th via DIDSON at river km 2.2 producing a total estimate of 181,114.

Skutz Falls Video Counts

Two underwater cameras were installed in the top cell of the Skutz Falls fish way on September 12th and operated continuously until November 25th. Footage was sub-sampled post season for both Chinook and Coho. Cameras were not able to be triggered by motion detection so the video review was time consuming and variable lighting at night reduced image quality on some days. In addition, high flows reduced transparency later in the season limiting the amount of data that could be reviewed effectively.

However, these obstacles were not unforeseen, as this was a pilot year, and the main objective was to investigate feasibility. A total of 50.5 hours of video was reviewed from the period October 29-November 1; selected based on the frequency of Chinook PIT tag detections, observation conditions and Coho abundance. This represented a sub-sample of approximately 10% of the peak migration period (Oct 25-Nov 15) and about 5% of the migration season.

A total of 1,940 Chinook were enumerated of which 408 were estimated to be adults and 1,532 jacks. Of the 320 adults that were inspected for origin, 50 were adipose clipped (15.6%) compared to 89/901 jacks (9.9%). In addition, 839 Coho and 222 Chum were identified as upstream migrants. In general Coho adults were easily separated from Chinook/Chum due to their “brighter” appearance (Figure 18).



Figure 18. Screen captures from cameras in the Skutz Falls Fishway including Chinook (left, middle) and Coho (right), fall 2018.

PIT Tag Detections

Counting Fence

There were two distinct operating periods for the fence in 2018. The original setup was similar to 2017 with fish funneling through a camera box. However, the box was twinned in 2018 to provide fish two passages to move above the fence. After a significant increase in water levels followed by an obvious concentration of fish immediately below the fence it became apparent that the new camera boxes were not able to keep up with the numbers of fish present. A decision was made to remove one fence panel and instrument the gap with underwater cameras on October 11. The removal of the panel had implications for PIT tag detections as the opening was not monitored with a PIT antenna. Additionally, antenna 3 was not operating at full capacity meaning detection efficiency was reduced for a 6 m section of the array. Unfortunately this antenna location coincided with the direct migration route for fish moving through the fence. This resulted in an approximate reduction of 50% in the observed adult mark rate from 0.92% to 0.46% (Figure 19).

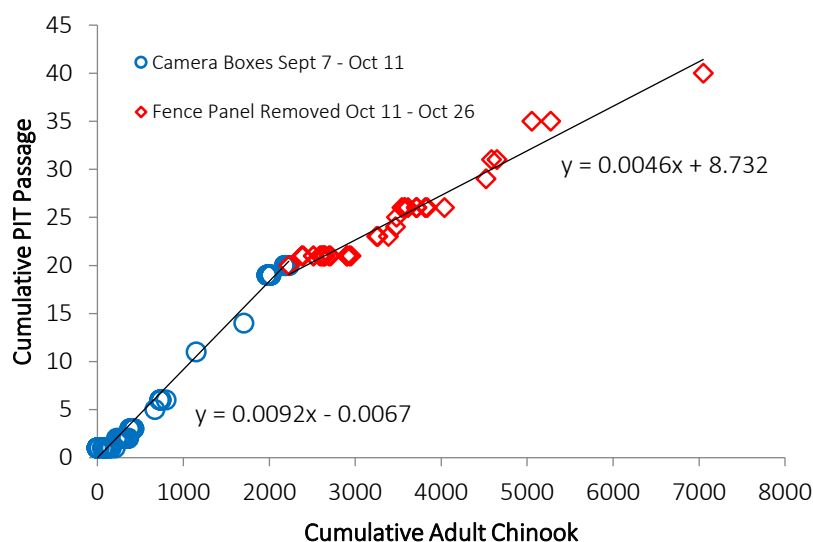


Figure 19. Comparison of PIT tag passage to adult Chinook counts (mark rate) for two operating periods at the Cowichan River fence, fall 2018. Note: Only tags from fish marked as juveniles are shown.

Although fish reverted to a holding pattern in a deep pool downstream, fish passage appeared to improve following the modifications on October 11. Migration numbers slowed for the ten days following panel removal but fish that reached the fence found their way through in short order with no additional backlogs observed.

The two camera boxes were run continuously during this period but the vast majority of fish migrated through the opening in the fence including 98.6% of Chinook adults and 98.3% of Chinook jacks in the last 24 hours of operation (n=3,400). Coho and Chum also preferred the opening which accounted for over 99% of the count for both species during this period.

Although the PIT tag detection efficiency was reduced after October 11 it appears that all tags which reached the fence were able to pass (lower array was fully functional). The adult mark rate for fish passing the fence before October 11 was 0.85% (1 in 117.6 fish) and 0.41% after. If we assume all fish which were detected on

the array after October 11 below the fence passed then the mark rate for the second stanza (Oct 11-26) increases to 0.81% (1 in 123.5). As these numbers are in close agreement and are conservative in terms of an expansion factor (maximum number of tags) we elected to combine both adult mark rates to produce an estimate of 0.823% (1 in 121.5). It was therefore estimated that 58 PIT tagged adults migrated upstream while the fence was operational in 2018.

Following removal of the counting fence, an additional 56 PIT tagged adults were detected at the site. As antenna 3 was still malfunctioning at this time all fish detected on either transect were assumed to pass. The total number of upstream migrants does not include 7 adults which were detected on the lower array before October 11 but did not pass. These could have been pre-spawn mortalities, harvested in the FSC fishery or lower river spawners.

Prior to October 11 only 1 PIT tagged jack was confirmed to migrate upstream of the fence out of 1,514 fish. Following removal of the fence panel, 4 more PIT tagged jacks migrated upstream out of 1,386 fish observed. The combined mark rate was 0.172% or 1 tag in 581.4 jacks. 22 PIT Tagged jacks were detected passing the site after the fence was removed on October 26. By the end of the season there were two tagged jacks which were detected on the lower array before October 11 but did not pass. These were assumed to be pre-spawn mortalities or lower river spawners.

When comparing the ratio of PIT tagged adults to jacks it was apparent that 2018 was very different from 2017 (Figure 20). We believe this was likely due to a combination of changes in fence operations and a low sample size of tagged jacks in 2018. Due to these factors we were not able to reliably expand jack counts at the counting fence using PIT tags.

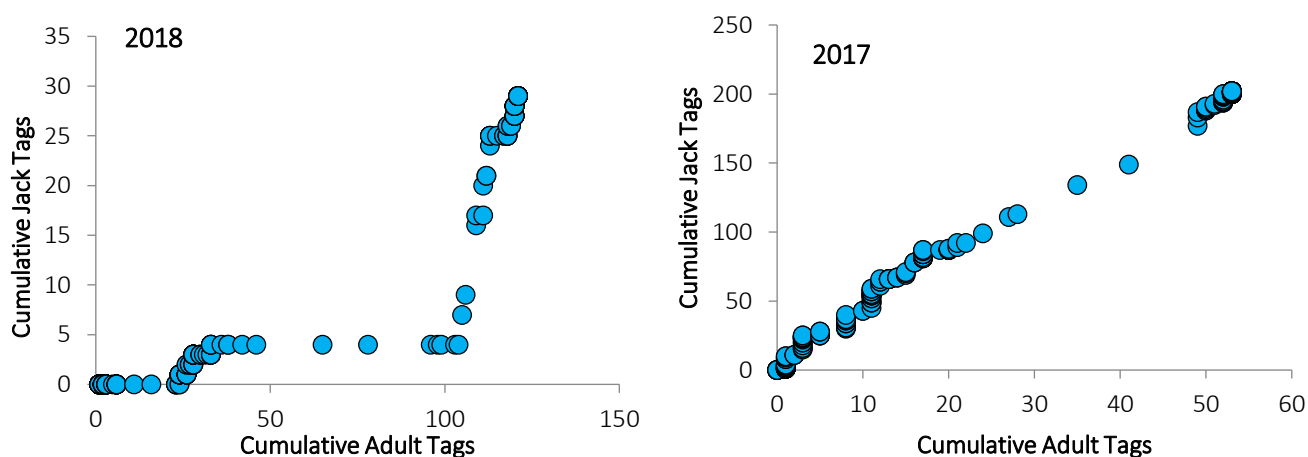


Figure 20. Comparison of cumulative detections of PIT tagged jack and adult Chinook passing the Cowichan River counting fence, 2018 (left) and 2017 (right).

Based on the above, run timing curves were generated for both jacks and adults. The first PIT tag detections at the site was an adult on August 31; approximately 7 days prior to fence installation. The second tag of the season was detected passing the site on September 17 which was considerably later than in 2017 (Figure 21).

Run timing curves were generally similar between years with a dramatic increase in migration during the third week of October. In both years, 55% of tagged Chinook migrated over a three day period. The proportion of the run enumerated through the fence prior to removal was similar at 53.3% in 2018 and 42.4% in 2017. The end of the run (last tag detection) was estimated to be November 11 in 2018 and November 8 in 2017.

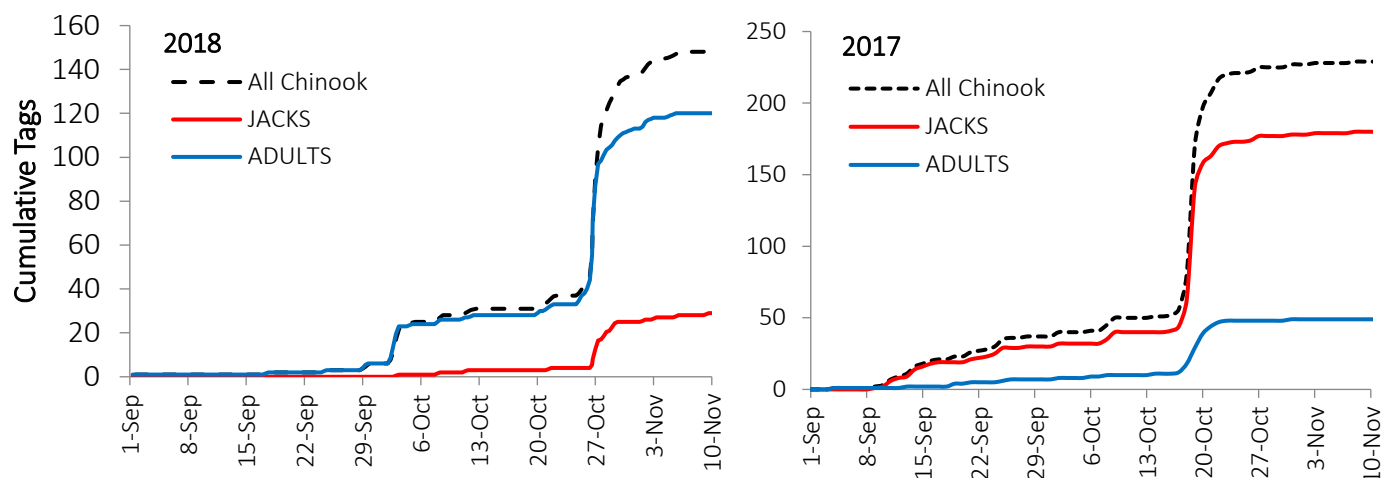


Figure 21. Run timing curves for PIT tagged Chinook based on the date of passage (detection on upstream array), independent of fence operations. Cowichan River, September 1-November 10, 2018 (left) and 2017 (right).

In addition to the 150 detections from Chinook tagged as juveniles, an additional 240 fish from the in-river tag group registered on the array. A higher fraction of the jacks (78/82 or 95%) were detected than adults (162/194 or 84%) following the tagging event ~500 m downstream. Run timing curves were generated for fish passing the fence using the criteria for the other tag group above. As tagging occurred during the first half of the migration run timing is skewed and not representative of the entire run (Figure 22). The majority of fish in this tag group migrated after the fence was removed at 14:00 on October 26 with 29% of the adults and 24% of the jacks accounted for by this time. The single largest push occurred in a 10 hour period between fence removal and midnight when 67 adults and 22 jacks (~37% of the total) were detected.

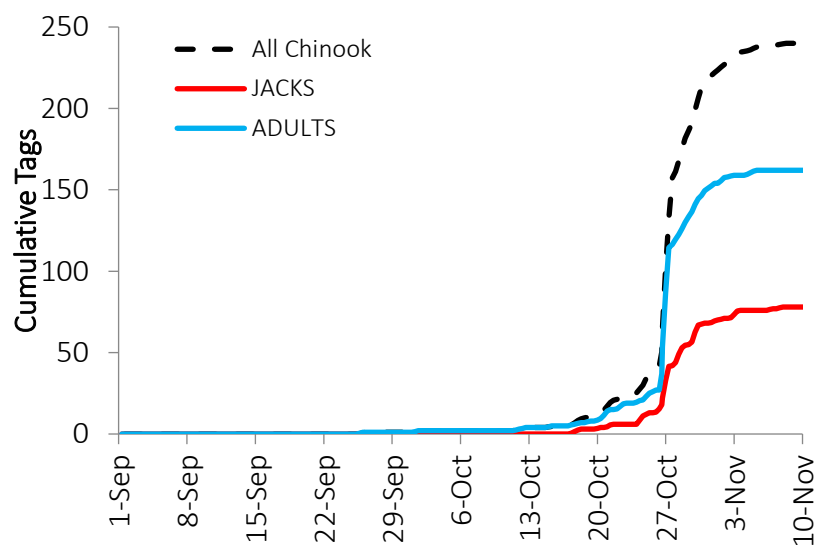


Figure 22. Run timing curves for the in-river PIT tagged Chinook based on the date of passage (detection on upstream array), independent of fence operations. Cowichan River, September 1-November 10, 2018. Note: tag application occluded during the migration period.

PIT Tag Detections – Skutz Falls

A secondary tag detection site was operated at Skutz Falls between October 10 and December 5, 2018. Chinook migrating to spawning reaches upstream of the falls were scanned for tags producing 29 detections out of the first group of 150 recorded passing through the lower river (tagged as juveniles). Jacks represented 19% of the group but 47% of the detections at Skutz Falls (14/29). All 29 were previously detected on the lower river arrays suggesting a detection efficiency of 100% while 82% (24 of 29) were properly assigned as upstream migrants (detected on upstream array). The five fish that were missed could be attributed to a poorly functioning antenna 3 which the majority of fish migrating through the open panel passed over after October 11.

In addition to the 29 fish from juvenile tagging operations, 58 PIT tagged Chinook were detected in the fishway out of the 240 fish tagged in-river that migrated upstream. Jacks had a higher probability of detection with 31/78 of the lower river migrants recovered in the fishway (37%) compared to 27/162 adults (17%). All of the 58 tags were detected at the counting fence and 48 were properly assigned as upstream migrants (83%) similar to the other tag group.

These observations suggest fish way use is not random and weighted towards jacks. This was not surprising given the disproportionate count of jacks (79%) on the sub-sample of video reviewed from the site. Therefore we elected to keep adults and jacks separated for expansion purposes to eliminate this bias.

A comparison of run timing between the counting fence and Skutz Falls detection sites revealed fish navigated the 27 km stretch in 3-4 days on average (Figure 23). Migration patterns at both locations suggest 70-90% of fish movement occurred over a 5-7 day period. Mature fish tagged in-river behaved similarly to the juvenile tag group and were the first to arrive at Skutz Falls likely due to the larger number of tags in the population.

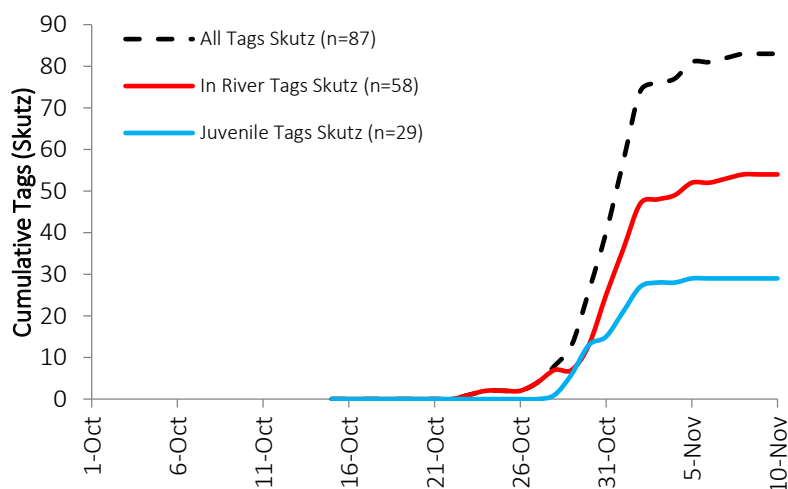


Figure 23. Cumulative daily PIT tag detections at Skutz Falls by tag group and site, Cowichan River, Fall 2018.

Estimating the PIT tag mark rate (MR) within each group for later expansions was a primary objective at Skutz Falls in order to support population expansions. During the video review period (limited to 50 hours) a total of 408 adults passed of which 3 tags from the juvenile PIT group (0.74% MR) and 7 from the in-river group (1.4% MR) were detected. Although the sample size is small these results are similar to the 0.82% mark rate observed for adults at the counting fence.

In the Skutz Falls fishway, 1,532 jacks were enumerated of which 7 were PIT tagged from the first group (juvenile) for a MR of 0.46%. a total of 21 tags were detected from the in-river tag group for a MR of 1.4%. With a total of seven jack Chinook detections at the Skutz Falls site, deriving a mark rate with counting fence detections is not possible. Too few tagged jacks were observed at the counting fence to reliably compare mark rates across sites.

Brood stock were scanned for PIT tags in conjunction with fish captured in-river prior to tag application or surplus fish returned to the river. A total of 660 adults (420 brood, 240 in-river) and 287 jacks (18 brood, 269 in-river) were manually scanned with a hand-held PIT reader. Only one tag was found in the adult brood during spawning and two tags during in-river scanning. In addition, 423 fish were scanned during dead pitch activities (335 adults, 88 jacks) but no tags were recovered. These observed mark rates were too low to produce reliable estimates and highlight the need to scan a greater proportion of the population. They also suggest tags could be missed by manually scanning fish and that larger stationary antennas routinely have a higher detection efficiency.

PIT Tag Detections – North and South Arm

A total of 43 PIT tagged adult and jack Chinook were detected at the South Arm antenna and 52 at the North Arm for a total of 95 lower river tags. Of these, 85 were also detected at the counting fence while the remainder (10) were never detected again. North and South Arm antennas detected 57% of the tags that reached the counting fence which represents an estimate of the lower river detection efficiency. If we assume the 10 missing tags were removed prior to reaching the fence then the escapement estimated at the fence represents 89.5% of the total freshwater return. All brood stock were also scanned to ensure missing tags were not due to hatchery removals.

Run timing curves for jacks and adults detected on the lower river antennas were generated as an estimate of river entry timing (Figure 24). Assuming equal detection efficiency across the run, these can be considered unbiased in terms of enumeration activities as the fence was located ~5 km upstream. When compared to the other tag monitoring sites fish took approximately one month to reach Skutz Falls after entering the river with the majority of that time spent holding below the fence.

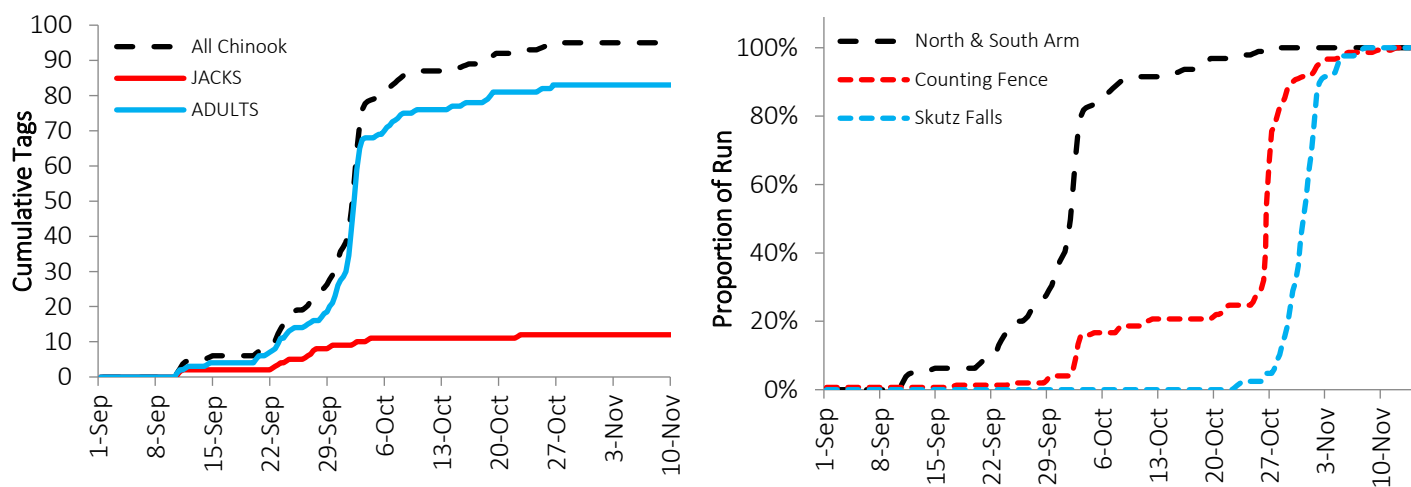


Figure 24. Run timing curves based on combined PIT tag detections on the North and South Arm arrays (left) and a comparison of run timing for all tagged Chinook at all three monitoring locations (right), Cowichan River, fall 2018.

Escapement Estimates

Counting Fence

We reported a total of 58 PIT tags in 7,049 adult Chinook passing through the fence between September 7 and October 26, 2018 for a mark rate of 1 in 121.5 (0.82 %). Unlike 2017, detections of tagged jacks were not included in the estimate as there were relatively few marks (5 in 2,900). Additionally, there was evidence of behavioral differences that justify this. An alternative approach was taken to first expand the adult count based on PIT detections then expand the jack count by the same factor. This assumes equal proportions of jacks and adults migrated before and after the fence was removed.

The PIT tag ratio estimated during fence operations was then expanded to the number of tags passing the site while the fence was not operational. This includes the period prior to installation (1 tag/122 fish), incomplete or missed shifts (0 tags/0 fish) and after removal (56 tags/6,804 fish). These estimates were added to the fence count for a grand total of 13,975 naturally spawning adult Chinook in 2018.

The proportion of fish migrating outside of the counting fence operating period was estimated at 6,926 or 49.6% of the total. The natural spawning jack population was therefore estimated at 5,754 with the fence count of 2,900 representing 50.4%. The combined natural spawning population of Cowichan River Chinook using this approach was estimated at 19,729.

The natural spawning population was divided into age classes based on scale samples collected from the spawning grounds during dead pitch. Age 3 fish were the most abundant at 9,130 followed by jacks (age 2) at 5,754. Older adult age classes were the least abundant with 4,720 4-year-olds and only 125 5-year-olds. Hatchery returns represented 10.4% of the two year olds and 9.1% of the adults although only wild origin 5-year-olds were encountered. See Appendix 1 for more details.

More robust Peterson mark recapture estimates were also derived to include an estimate of precision. Data sets were subject to several different formulas to investigate the relative difference in outputs (Table 5). The Bayesian based method produced the highest estimate at 14,348 and the binomial the lowest at 13,742 for a range of 606 across 5 models. The hypergeometric model produced the lowest CV at 9.0% with a standard deviation of 1,249 and was also the second most conservative estimate at 13,860. Given that the population is subject to sampling without replacement (fish are only counted once as they pass through the fence) and the similarity to the proportion based method above we feel this is the most appropriate method for expanding counts while including an estimate of precision.

Table 5. Summary of five different methods for estimating adult escapement in the Cowichan River using PIT tag based mark-recapture data, 2018. Models adapted from Schwartz (2006) and Webster and Kemp (2013).

Adults		Peterson Pop Estimator	Pop	Variance	SD	CV
Marks	115	Bayesian	14348	1889128	1374	9.6%
Captures	7049	Hypergeometric	13860	1560292	1249	9.0%
Recoveries	58	Binomial	13742	3120821	1767	12.9%
R/C	0.823%	Inverse Binomial	13976	3283632	1812	13.0%
		Inverse Hypergeometric	14097			

When compared to the long term data set for the indicator project (1988-present) the abundance of returning adult Chinook is following a rebuilding trend with near record levels in 2018 (Figure 25). Counts of age 2 fish (called jacks at the fence but typically include ~10% females) do not fit the recent trend and appear to be far more abundant than expected (Figure 26). Fewer jacks were observed in 2018 than 2017 but the count of 5,754 natural spawners was above the long term average. The abundance of Chinook has exceeded the natural spawner target of 6,500 adults (Tompkins et al. 2005) for three consecutive years while the total escapement of adults exceeded the target in 2015.

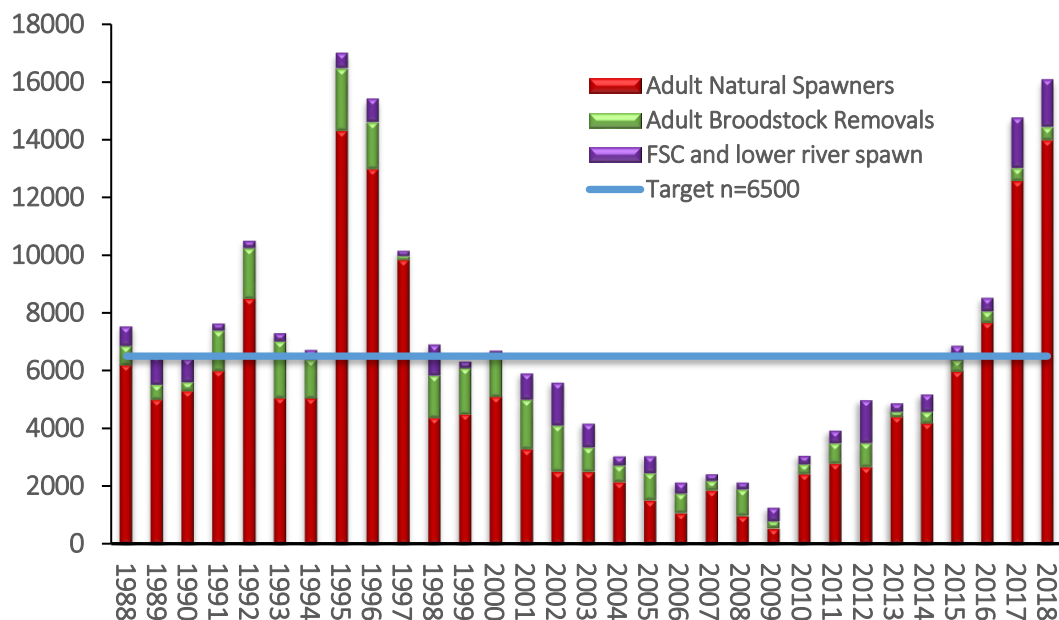


Figure 25. Summary of adult Chinook returns (ages 3-5) to the Cowichan River, 1998-2018.

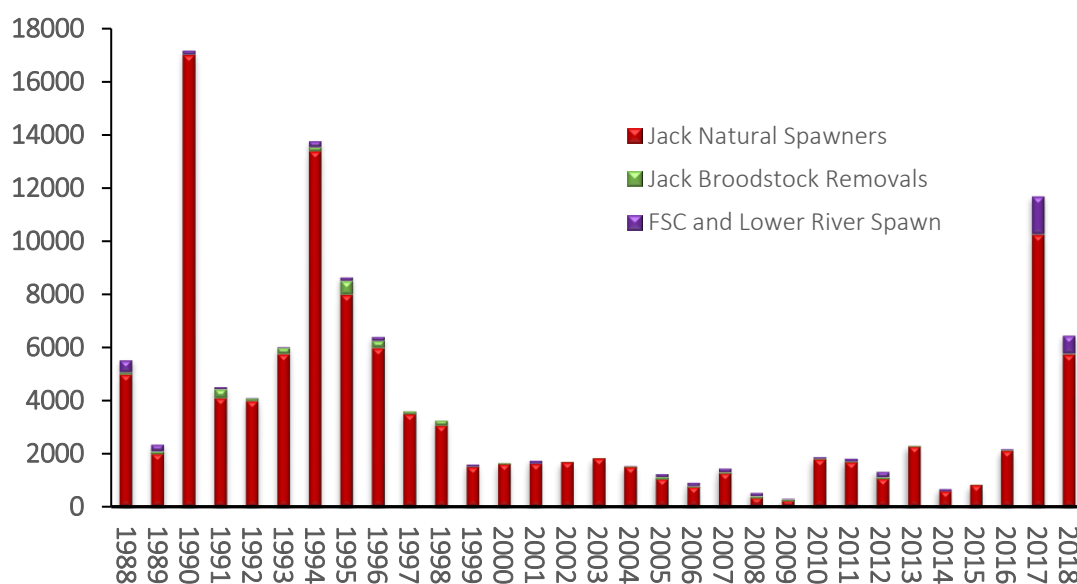


Figure 26. Summary of age 2 Chinook returns to the Cowichan River, 1998-2018.

Skutz Falls

An independent escapement estimate was also derived using preliminary camera counts and PIT tag data from the Skutz Falls Fishway. The data was processed using the hypergeometric model three different data sources: juvenile tag returns, fish tagged in river, and both combined (Table 6). Tag detections were paired with partial camera counts in order to estimate a mark rate for jacks and adults. This was expanded to the number of tags in each group that migrated upstream of the counting fence (natural spawners). Finally, an estimate of the total number of jacks and adults using the Skutz Falls fish way was estimated by comparing the ratio of tags detected during the camera counts to the total for the season.

Table 6. Summary of Chinook counts and PIT tag detections at the Skutz Falls Fishway including preliminary escapement estimates based on a hypergeometric model, fall 2018.

	Partial Skutz	Partial Tags	Total Tags	Total	Upstream	Natural		
<u>Juvenile PIT</u>	Count	Observed	Observed	Marked	Migrants	Spawners	SD	CV
Adults	408	3	15	121	115	11860	5187	43.7%
Jacks	1532	7	14	29	27	5365	1508	28.1%
<u>In River PIT</u>								
Adults	408	7	27	194	162	8332	2682	32.2%
Jacks	1532	21	31	82	78	5504	968	17.6%
<u>COMBINED PIT</u>								
Adults	408	10	42	315	277	10336	2885	27.9%
Jacks	1532	28	45	111	105	5602	864	15.4%

The number of adults counted during the video review period was relatively low at 408 or about 3% of the natural spawner estimate from the fence. Jacks were far more abundant on the video with 1,532 observations or ~27% of the natural spawning estimate. The video review period was also biased towards jacks with 62% of the combined PIT tag detections for the season occurring within the 50 hours of footage compared to 24% for adults.

Escapement estimates derived using the hypergeometric model were based on the observed mark rates from the juvenile PIT group first suggesting 11,860 adult natural spawners with a standard deviation of 5,187 and a relatively high CV of 43.7%. The precision on the jack estimate of 5,365 was slightly better with a SD of 1,508 and a CV of 28.1%.

The in-river PIT tag group produced a lower estimate for adults at 8,332 and a similar number of jacks at 5,505. The precision of these estimates improved due to a larger number of tags in the system to 32.2% and 17.6 % respectively.

A third estimate was constructed by pooling all tag detections under the assumption both groups were randomized within the population by the time they reached Skutz Falls. This produced an estimate of 10,336 natural spawning adults with a SD of 2,885 and CV of 27.9%. The estimate of natural jack spawners was 5,602 with a SD of 864 and CV of 15.4%.

Using the combined mark rates (2.45% for adults, 1.83% for jacks) we estimated that 1,714 adults and 2,468 jacks used the fishway in 2018. We then modeled the estimate as if the camera system was operational the whole season (a project goal for 2019) by using the total number of PIT detections and the estimated counts. This produced a theoretical natural spawning estimate of 11,087 adults with a CV of 13.7% and 5,675 jacks with a CV of 10.9% which are both inside the target CV of 15%.

Independent adult escapement estimates from the Skutz Falls fishway were the same as the expanded fence count in 2018. As the estimates were within 3,639 fish they were not statistically different. However, the number of adults observed on video (408) was far lower than required to produce a reliable comparison.

A comparison of jack estimates between the two sites indicated very little difference. The fence estimate of 5,754 natural spawners was similar to the combined Skutz Falls estimate of 5,602. Due to the manner the fence estimate was derived a direct statistical comparison was not attempted but these results suggest there is unlikely to be a difference.

Comparison to Current Methodology

The initial initiative for this project was based on reducing migration delays and other negative impacts to Chinook from the operation of the fence. DFO staff were initially reluctant to move away from the fence as an escapement tool given the high degree of confidence in this method. However, the fence count is only reliable if a large and/or known portion of the run is enumerated before the fence is removed. Chinook run timing for the lower Cowichan is based on fall rains that push flows over an 18 m³/s threshold which is known to significantly increase migration (Figure 27). In order to enumerate 95% of the escapement in a normal year the fence would have to operate through November 1 which extends to November 5 in a late migration year. The earlier that the fence is removed or becomes non-operational due to high flows, the lower the proportion of the run that is enumerated.

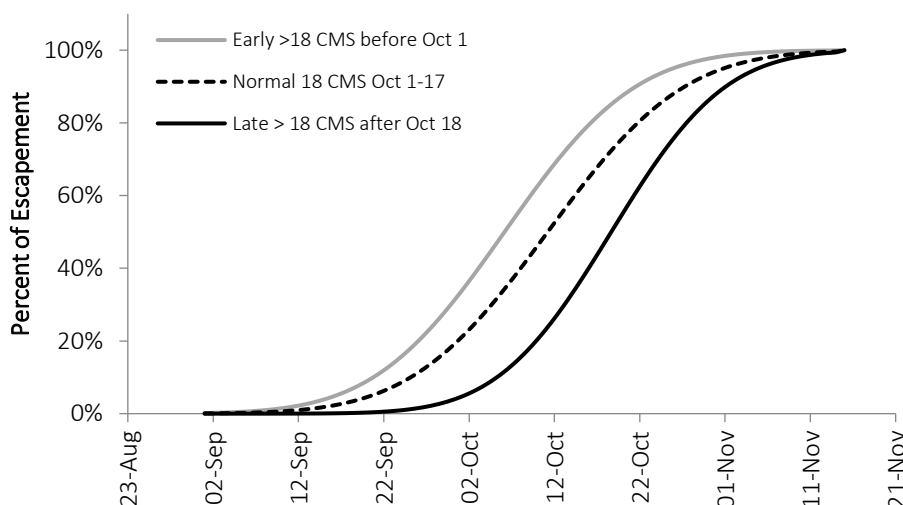


Figure 27. DFO run timing estimates for adult Chinook migration past the counting fence in the Cowichan River based on flow conditions.

A review of the previous six years of fence operations was conducted to estimate the proportion of the escapement which was enumerated. Run timing curves were selected based on seasonal flow conditions then overlaid on the operating range to account for non-operational periods. Using this approach, 51.8% of the escapement was enumerated on average between 2012 and 2016 (Table 7). This is significantly different

than the 78.6% reported in the final expansions which potentially under-estimated the escapement by 34% on average.

It should be noted that the run timing curve method relies heavily on selecting the appropriate curve for each year and is therefore not ideal. Actual run timing is often skewed by discharge or fence operations resulting in a disproportionate number of migrants later in the season. This may result in inaccurately estimating the proportion missed and suggests fence counts are not as complete as one may expect.

Table 7. Summary of Cowichan Chinook counting fence operations, 2012-2018.

Year	Operating Period	Run Timing	Expansion Factor Based on Run Timing (Figure 27)	Expansion Method For Final Estimate	Expansion Factor For Final Estimate	Comments
2018	Sept 7 – Oct 26	Normal	1.14	PIT tag based run timing	1.99	New camera boxes delayed migration, fence removed early due to migration concerns
2017	Sept 15 – Oct 18	Late	2.13	PIT tag based run timing	2.30	Fence and rail rebuilt, counting box failure on Oct 19
2016	Sept 19 – Oct 13	Normal	1.91	Normal model for before and Big Qualicum run timing for after fence	1.11	Lost fence, rail pulled out Oct 13
2015	Sept 17 – Oct 12	Normal	1.99	Early run time model 10 m ³ /s threshold instead of 18 m ³ /s	1.40	Fence rebuilt
2014	Sept 16 – Oct 22	Late	1.60	Normal time model 10 m ³ /s threshold instead of 18 m ³ /s	1.24	Fence underwater Oct 22, left in all winter
2013	Sept 9 – Sept 28	Early	4.15	Dead pitch mark recapture	1.66	Fence underwater Sept 29, damaged but removed Oct 21
2012	Sept 4 – Oct 24	Late	1.44	+15% for adults only	1.10	Fence removed Oct 25

In 2018, a total of 7,049 adults and 2,900 jacks were counted through the fence which was later expanded to 13,860 adults and 5,754 jacks using the PIT tag based mark recapture method outlined above. A more traditional approach using run timing curves would have produced a far lower expansion of approximately 8,001 adults and 3,292 jacks. The main reason for the discrepancy in expansion factors was related to fish behavior. Modifications to the counting box designed to improve passage had the opposite effect which dramatically changed the observed run timing of fish passing the fence. This highlights the need to develop season-specific run timing curves and expansion factors.

Discussion

The juvenile tagging target of 10,000 Chinook was unable to be met for a variety of reasons in 2018.

Hatchery tagging went according to plan with just under 5,000 fish tagged after accounting for mortalities and rejects. Wild Chinook capture using a lower river fence proved more difficult than anticipated with only 540 fish tagged due to design flaws and debris load. A decision to abandon in-river tagging and revert to beach seining mid-season resulted in the capture of nearly 3,000 wild Chinook. These results highlighted the need to review capture methodology prior to the next season.

Enumeration activities at the counting fence also proved challenging in fall 2018. Modifications to the video infrastructure designed to improve migration had the opposite effect. Fish reverted back to a holding pattern for much of October which skewed the observed run timing and also resulted in removal of the fence before the majority of fish had passed the site. Moreover, the delay also resulted in an in-season modification to the design of the enumeration infrastructure. This in combination with a defective PIT antenna made estimation of a mark rate in the returning population challenging.

The application of PIT tags to a portion of the returning fish in-river went well and provided valuable data at both the fence and Skutz Falls. Capture was highly effective while working with the Cowichan River Hatchery brood crew and fish responded well to tagging. The number of fish tagged using this method was more than the total return from juvenile tagging operations. However, the value of this group was limited to analysis of Skutz Falls as fish could not be considered randomly distributed in the population (tagging overlapped with migration).

However, the in river tag group was assumed to be randomly mixed at Skutz Falls due to the considerable distance from the tagging site (~27 km) and duration of time between tagging and recovery (~ 3 weeks). Results indicate that the in river tag group could be used in the future to bolster tag detections at Skutz Falls which are important for population expansions. Further work will be required to understand the utility of this group for expansion purposes at the fence. A differential rate of loss was evident within the adults of this group as only 84% were believed to move upstream of the fence compared to 95% of jacks. Detection efficiency of PIT tags due to a malfunctioning antenna 3 could be a contributing factor along with fishing (Food, Social and Ceremonial or FSC) and post-release mortality (stress).

The main objective of this project was to explore alternate methods to estimate Chinook escapement in the Cowichan River. A comparison of independent mark-recapture escapement estimates between the counting fence and Skutz Falls provided promising results. The deployment of a pilot camera system in conjunction with a PIT tag antenna in the fishway produced a sub-sample of the data suitable for a preliminary population estimate. Although the estimates between the two sites were not statistically different the confidence in the Skutz Falls number was lower due to a reduced sample size (less fish and less tags). Had a proper camera system been installed and all tag detections pooled the sample size would have been sufficient to produce a reliable estimate with a CV of 15% or less. This is encouraging given that an upgraded camera system (motion activated) will be installed for fall 2019 which should allow enumeration of most or all of the fishway migrants. The other encouraging aspect is that Chinook also migrate in the open channel alongside the main fishway as the water levels increase. It is our intention to include these migrants in the sample as modifications to the site are made which will potentially increase the sample size by 30-50%.

The lack of PIT tag detections in brood stock (1) or dead pitch (0) operations suggest efforts are best focused on locations where thousands of fish can be sampled. The recovery of zero tagged fish in the dead pitch

sample of 335 adults and 88 jacks was surprising given the mark rates observed at Skutz Falls. We would have expected 7 fish (6 adults 1 jack) to carry external pink Floy tags/internal PIT tags as well as an additional 2 adults and 1 jack with PIT tags only. Tag loss is not believed to be a factor considering fish carried two Floy tags in addition to a PIT tag so the probability of shedding all three was assumed to be very low. This does raise questions regarding the representativeness of the dead pitch sample but does support the relatively high escapement estimate compared to the previous decade average.

Recommendations

Juvenile tagging activities focused on wild Chinook smolts should be re-assessed and a more comprehensive beach seining program considered. Despite a late start in 2018 60% of the tag target was met. Had all sampling efforts been focused on beach seining from the start the capture of 5,000 fish would have been within reach. Due to significant technical challenges related to the operation of a lower river smolt fence we recommend focusing juvenile tagging efforts on an alternative method in 2019. In contrast, no changes are recommended to hatchery tagging operations.

Operational changes to the counting fence are required for fall 2019 in order to ensure the Chinook migration is not significantly impeded. Mid-season changes primarily focused on a mid-river opening in the fence appeared to dramatically improve migration. We recommend two such openings in the fence so that thousands of fish can pass within a day if required. The single opening in 2018 was proven to be effective at passing over 6,000 salmon in less than 8 hours.

The PIT tag antennas should be double checked prior to the fall and defective equipment repaired or replaced. Antenna 3 caused significant issues for estimating mark rate in the population (i.e assigning upstream passage) but the dual transect design of the system was still able to detect 100% of the tags that were encountered upstream. It is recommended that the equipment be repaired at least one month prior to fish arriving on site so any issues can be resolved during the low water period. With two large openings in the fence it will become challenging to run antennas in each in addition to the 12 permanent antennas in river. We recommend keeping operations the same for the season with no additional antennas in the fence. This will simplify fence expansions later on and allow for full stream coverage.

Skutz Falls monitoring provided valuable insights into fish behavior and the potential to develop an alternative escapement estimate. We recommend continuing with site modifications which include installation of motion-activated cameras to expedite enumeration. Efforts to monitor the secondary open channel should also be made so that the relative proportion of fish using each fishway can be estimated. This will provide clarity on the actual proportion of the population that could be enumerated at the site. Additional PIT tag detections will also be valuable to improving lower river detection efficiency estimates.

Tagging of mature Chinook in river was proven to be an effective way to increase tag detections at Skutz Falls and improve escapement estimates. We recommend continuing this activity in 2019 while maintaining or increasing tagging targets. Given the differential use of the fishway by jacks we recommend focusing efforts on adults where possible. It would also be valuable to look again for recoveries in the dead pitch program to see if the results in 2018 were anomalous or repeatable.

References

- Baillie, S.J., Matthews, I.M., Elliott, D., and McColl, B.D. 2015. Adult Chinook escapement assessment conducted on the Cowichan River during 2005, 2006, and 2007. *Can. Manuscr. Rep. Fish. Aquat. Sci.* 3079: ix + 80
- Carl, G.C. 1937. Report on the fish ladder and natural fishways at Skutz Falls, Cowichan River. Technical memo. Pacific Biological Station, Nanaimo B.C. 3 pp.
- Lister, D.B., L.M. Thorson and I. Wallace. 1981. Chinook and coho salmon escapements and coded-wire tag returns to the Cowichan-Koksilah River System, 1976-1979. *Can. MS Rep. Fish. Aquat. Sci.* 1608: xiii + 78 p.
- Pellett, K. 2017. Cowichan River juvenile Chinook habitat use assessment to direct lower river and estuary rehabilitation 2016. Technical report prepared for the Pacific Salmon Commission and Pacific Salmon Foundation, year 3 of 3. 46 pp plus app.
- Pellett, K. and J. Damborg. 2018. Cowichan Chinook Methodology Change. Technical report prepared for the Pacific Salmon Commission Southern Fund, Year 1 of 5. 27 pp.
- Schwartz, C.J. 2006. The Peterson and related estimators with applications to fisheries management. Department of Statistics and Actuarial Science, Simon Fraser University.
- Tompkins, A., B. Riddell and D.A. Nagtegaal. 2005. A biologically based escapement goal for Cowichan River fall run Chinook salmon. Canadian Science Advisory Secretariat Research Document 2005/095. 42 pp.
- Webster, A.J. and R. Kemp. 2013. Estimating omissions from searches. *The American Statistician* 67 (2): 82-89.

Appendix 1

2018 Cowichan River Chinook escapement estimate by category, age and origin.

2018						
Natural Spawners						
			Age 2	Age 3	Age 4	Age 5
	Estimated	Male	5629	5734	2173	100
		Female	125	3396	2547	25
		Total	5754	9130	4720	125
		ADULTS	13975			
		JACKS	5754			
Brood Stock						
			Age 2	Age 3	Age 4	Age 5
		Male	18	117	31	0
		Female	0	157	114	1
		Total	18	274	145	1
		ADULTS	420			
		JACKS	18			
Below Fence+ FSC						
			Age 2	Age 3	Age 4	Age 5
***Includes all lower	Estimated	Male	659	674	255	12
river spawners		Female	14	398	300	3
and losses***		Total	673	1072	555	15
		ADULTS	1642			
		JACKS	673			
Grand Totals						
			Age 2	Age 3	Age 4	Age 5
		Male	6306	6525	2459	112
		Female	139	3952	2961	29
		Total	6445	10476	5420	141
		Hatchery % (clipped)	10.5%	9.5%	8.4%	0.0%
		Total Adults	16037			
		Total Jacks	6445			
		<u>Total Return</u>	<u>22482</u>			