Cowichan Adult Chinook Enumeration Methodology Change

Stewart Pearce and Kevin Pellett

Department of Fisheries and Oceans

Nanaimo, B.C.

&

Jeramy Damborg, Fisheries Biologist

BC Conservation Foundation

Lantzville, B.C.

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Acknowledgements

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Abstract

A total of 3,445 hatchery and 4,191 wild juvenile Cowichan River Chinook were implanted with 12 mm FDX-B PIT tags in spring 2019. One-hundred sixty-eight tags (132 adults; 36 jacks) were detected inside returning Chinook from previous tagging years at an array of 12 antennas located at the counting fence between September 10 and November 13, 2019. Secondary detection sites produced an additional 112 PIT tag detections. Of these, 39 detections (30 adults; 9 jacks) were at North Arm, 58 detections (47 adults; 11 jacks) were at South Arm, and 15 detections (5 adults; 10 jacks) were at Skutz Falls. The counting fence was operational between September 9 and October 17, 2019; during this period, 10,527 adults (88.6% wild; 11.4% hatchery origin) and 1,300 jacks (87.5% wild; 12.5% hatchery origin) were enumerated. PIT tag detections during this period indicated 69.7 percent of the population migrated past the fence while it was operational. Applying these data to a Hypergeometric Model yielded an expanded estimate of 14,889 ± SD 953 adult Chinook (*CV: 6.4%*). The natural spawning jack escapement was estimated at 3,035 ± SD 570 jacks (*CV: 18.8%*). Additionally, a total of 2,962 adults (84.0% wild; 16.0% hatchery) and 627 jacks (92.8% wild; 7.2% hatchery) were enumerated through an upgraded camera system in the Skutz Falls fishway which operated continuously between October 7 and December 19. A total of 15 PIT tagged fish (5 adults; 10 jacks) were detected during this period. Too few adult tags were detected to produce a secondary escapement estimate at Skutz; however, a secondary estimate of 1,997 ± SD 473 jacks (*CV: 23.7%*) was produced. 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 a dual full stream Passive Integrated Transponder (PIT) tag antenna array near the current DFO counting fence site. The array is able to detect tags implanted in juvenile Chinook throughout their life including adult returns. An approach using a PIT tag based mark-recapture technique 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 three 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 an upgraded camera system in the Skutz Falls Fishway based on results from 2018 pilot camera.

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 64,821 Chinook Juvenile salmon for the SSMSP (2014 n=7,048, 2015 n=15,748, 2016 n=22,790, 2017 n=10,906, 2018 n=8,255). Though not originally tagged for the purpose of this project, all returning tagged fish can be used for this project as they return in this and future years.

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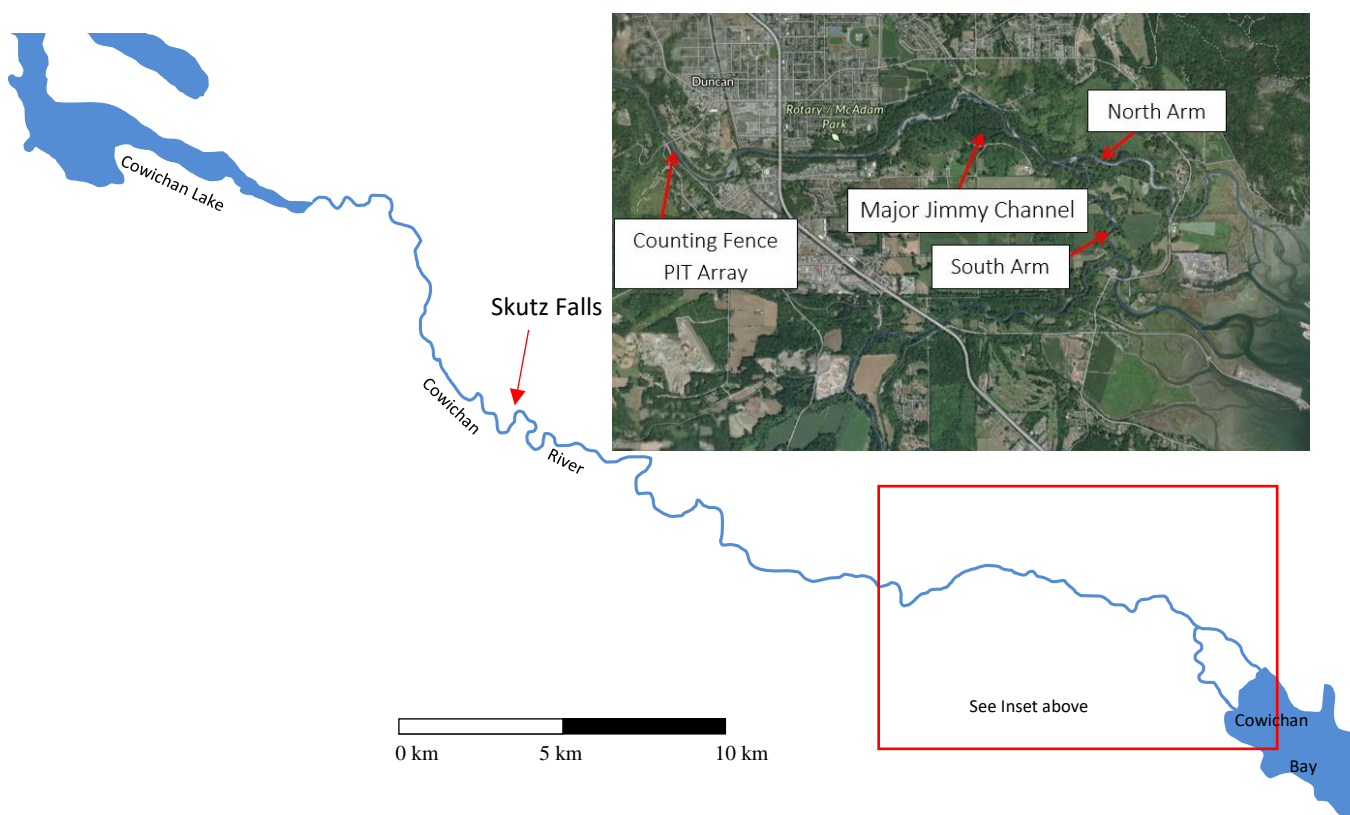
Figure 1: Map of the Cowichan River between the lake and the bay including an inset aerial image with PIT tag detection array/counting locations.

Methods

Spring Capture and Tagging

All 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 SSMSP). In years two and three (2018 and 2019) FDX-B tags were applied to all fish due to the slight advantage in noise resistance and better read range. It is anticipated that all tagging moving forward will be conducted with FDX-B tags. In 2019, tags applied in freshwater were >96% hatchery origin while those applied in the marine environment were predominantly wild (98%).

Needles and tags were pre-loaded in plastic trays[1] of 100 which also allowed for easy accounting prior to field visits as well as during tagging. Needles were inserted into tagging guns[1] 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. The cycle repeated with every fish.

Tag insertion and fish handling techniques described in the Columbia River PIT Tag Marking Procedures Manual [2] were modified slightly. As per recommendations from the DFO Veterinarian[3], the procedure for tagging was to insert the needle ahead of the pelvic girdle along the midline and inject the tag forward (Figure 2).
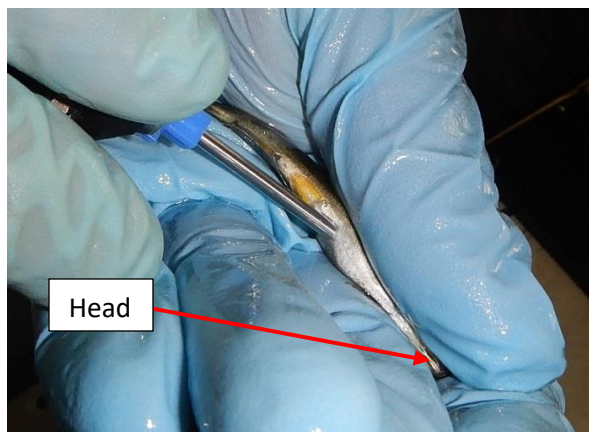
Figure 2: Photo demonstrating the tag insertion location used since 2015 as per recommendations from the DFO Veterinarian.

Hatchery Tagging

In 2019, 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) consistent with previous years. Hatchery fish were taken off food at least 24 hrs. prior, and feeding was reinstated two days following tagging. They were held in aluminum "cap troughs' until release, approximately three weeks after tagging. The day prior to release, all fish were measured for fork length and scanned. The last four digits of the PIT tag were recorded with each fork length, thus a size at release was recorded for every fish. Any mortalities

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[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

or lost tags during holding (recovered from the bottom of the tanks) were scanned and recorded. Fish were released at pre-determined locations along the mainstem Cowichan River on May 22 and 23, 2019.

Cowichan Bay Beach Seining

During spring 2018 and 2019, it was found that river temperature during juvenile Chinook out-migration often exceeded the temperature threshold specified for PIT tagging operations, while sea surface temperature in Cowichan Bay was found to remain below this threshold due to tidal mixing. Moreover, tag returns from purse seining in previous years suggested that survival of Chinook tagged in Cowichan Bay was higher than those tagged in-river, resulting in a higher proportion of returning tags. Experimental beach seining was conducted in Cowichan Bay in June 2018, which resulted in successful tagging of 2,999 juvenile Chinook. For these reasons, the proposed tagging location for wild Chinook was changed to Cowichan Bay in 2019. A notional target of 5,000 wild Chinook was set for year three in order to produce ~75 tag returns at an estimated 1.5% survival; 82% of this target was achieved as 4,191 juvenile Chinook were tagged in June 2019.

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 ¾" to ¼" stretch mesh with ½" being the most common material. Nets were deployed from a 5.5 m aluminum boat (runabout style) while a team of 2-4 people pursed the net in from the shore (Figure 3). Approximately 5-10 sets were made per day depending on catch rates and processing time.
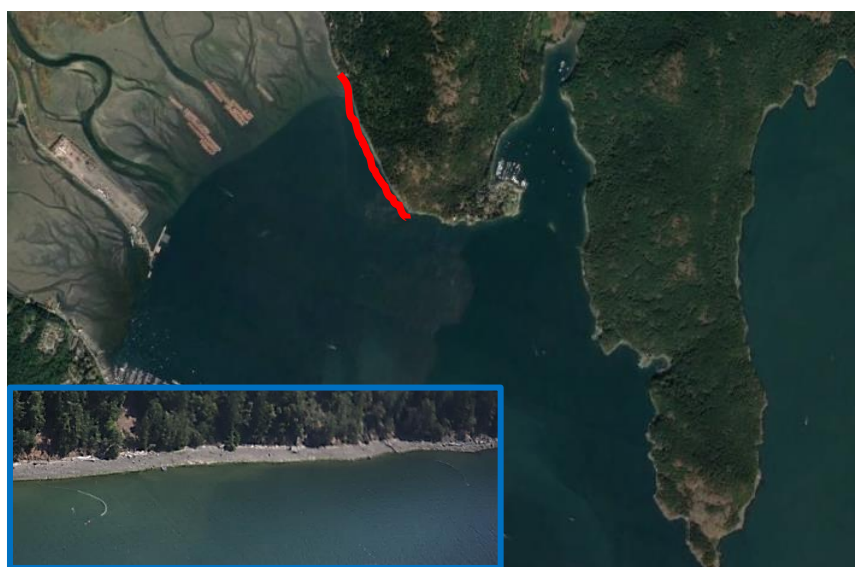
Figure 3: General area (red line) in Cowichan Bay where the majority of the juvenile Chinook were captured and tagged by beach seining in 2019. Inset; aerial view of beach seine deployments.

Once hauled in, crews would sort the bycatch (eg. jellyfish, herrring, 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 3-4 would then anesthetize, PIT tag and measure juvenile Chinook using tagging methods described as above. 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. Chinook 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 4).

Figure 4: PIT tagged juvenile Chinook holding in the recovery tank prior to release back into Cowichan Bay, June 2018.

In a typical 10 hr day, 5-10 sets were completed, with daily catch rates of approximately 200 – 500 Chinook. 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 data base.

In 2017, a 23 m commercial fishing vessel "Ocean Venture" was chartered to capture wild juvenile Chinook in Cowichan Bay by purse seine (Pellett and Damborg 2018). This work was funded by PSF and represented the last year of tagging under the SSMSP, so the vessel was unavailable in years following. However, tagged Chinook captured during purse seining operations will contribute to project results through fall 2020.

Fall Capture and Tagging

A tagging target of 250-500 mature Chinook was set to bolster mark-recapture estimates at Skutz Falls. In 2018, 276 jack and adult Chinook were captured by beach seine and PIT tagged approximately 500 m downstream of the counting fence. However, changes to fence operations in 2019 promoted fish passage through the fence without delay; as a result, Chinook did not congregate downstream of the fence like previous years which made capture difficult. Significant additional effort was required to obtain the hatchery brood quota and there were too few excess fish captured to make tagging efforts worthwhile.

As an alternative, adult Chinook captured by hook and line for a predation study in Cowichan Bay were relied upon to increase adult tag numbers. For this study, recreational fishing boats utilized traditional angling techniques (i.e., trolling and jigging) to target Cowichan River Chinook staging in Cowichan Bay and at Separation Point. Once alongside the boat, adult Chinook were assessed for hook-induced bleeding; only fish without bleeding or minimal bleeding were tagged, while the rest were released without further handling. Chinook fit for tagging were brought aboard each vessel and held in a live well (eg. cooler or fish tote) for biological data collection, which included fork length measurement, sex, origin (i.e., adipose clip status), DNA (i.e., tissue sampling), and scale sampling (Figure 5) (Atkinson and Murchy 2020). Adult Chinook were tagged in the same manner as juveniles. Once fish were sampled and tagged, they were provided time to recover in the live well prior to release.

Figure 5: Scale sample collection of an adult Cowichan River Chinook prior to application of PIT tag, September 25, 2018.

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- SSMSP; Pellett 2017). A total of 64,821 juvenile Chinook have been implanted with PIT tags through 2019 with 51% of applications in the early marine environment. 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 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 below the substrate rail for the fence panels and the other 23 m above 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 (Figure 6).
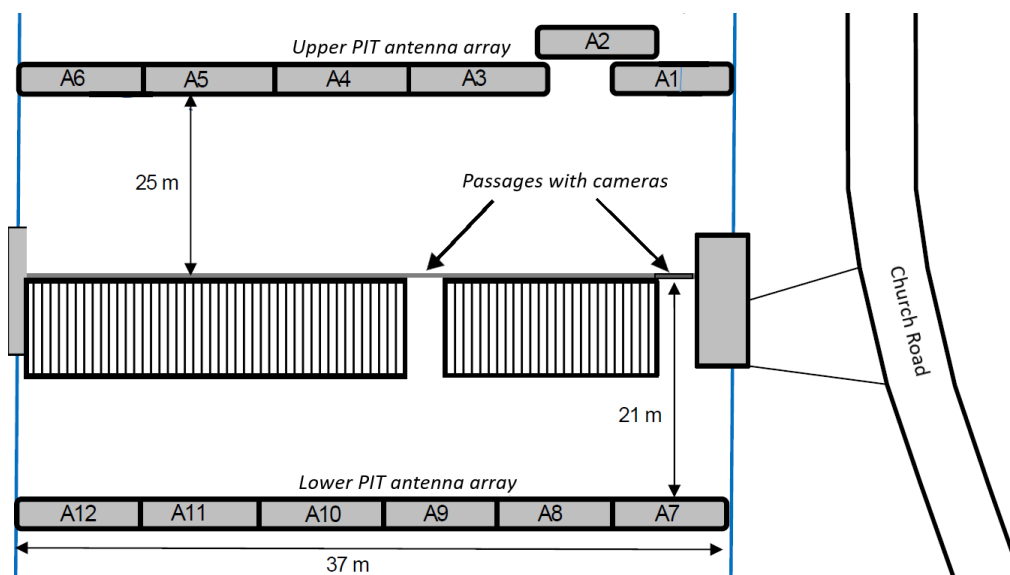
Figure 6: Plan view of the permanent PIT tag array in the lower Cowichan River relative to the seasonally operated counting fence, fall 2019.

The arrays remain operational year-round and at all flows. Tags are energized when passing 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 as well as a date/time stamp. All twelve antennas are wired in a network configuration and managed by a master controller on shore. The controller manages data from all antennas as well as operating settings (Figure 7).

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 downstream right bank. Commands can be sent to each antenna individually which is controlled with a submersed node containing a circuit board and Radio Frequency Identification (RFID) reader. Real time data and diagnostic information can be accessed remotely via a cellular modem to monitor performance.

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.

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 data base to determine the age based on tagging year. The first detection at the site (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).

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 bedload 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) as well as 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.

A secondary detection site was established in the primary fishway at Skutz Falls (Figure 9; river km 34) in order to properly estimate lower river detection efficiency. Although fish can bypass the Skutz Falls fishway at certain flows, tags detected in the fishway 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 (see "Skutz Falls Enumeration" section below for more details).

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.

Two additional PIT tag detection antennas were operated in the lower Cowichan River during fall 2019. Temporary antennas ranging from 12-15 m wide each were deployed in the North Arm (August 23 – October 16) and South Arm (August 27 – October 16; 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 north and south arm 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.

Chinook Escapement

Counting Fence Enumeration

A counting fence has been operated annually in the lower Cowichan River since 1988 to enumerate Chinook Salmon. The fence site is currently situated beside Church Road, 140 m downstream of the Allenby Road Bridge in Duncan (river km 7.0).

The fence consists of twenty-six 1.2 m x 6.1 m panels constructed of 50 mm PVC pipe spaced 100 mm on center as pickets (Figure 8). Each length of PVC passes through holes in five equally spaced 50 mm x 50 mm aluminum cross-members which space the pipes accordingly and hold them in place. The sides of each panel have 50 mm aluminum pipe in place of PVC for rigidity. Binocular clamps were attached to these aluminum pipes between each cross member and are used to connect panels together by passing individual 50 mm aluminum pipes through the clamps of adjoining panels. The ends of all pipes were capped to prevent water from entering.
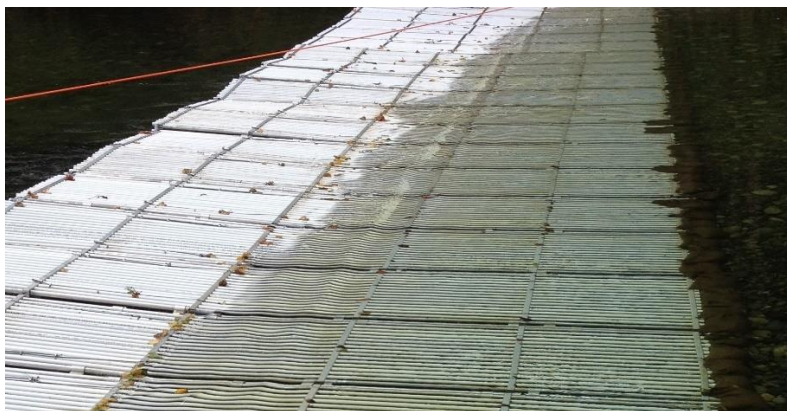
Figure 8: Close-up view of Cowichan River counting fence panels. Sandbags were placed along the bottom of the fence to ensure panels remained snug to the bottom, fall 2017.

The entire fence is anchored to a 100 mm x 150 mm square steel rail spanning the entire wetted width of the river channel (36.5 m) and is secured to pairs of 0.5 m x 0.5 m x 1.0 m concrete lock-blocks embedded into river bed at 3.0 m intervals. Square bulkheads on each bank serve as the terminus for each side of the fence in addition to providing a work platform. A 10 mm stainless steel cable runs through welded eyelets on top of the rail. Stainless steel U-connectors are spaced along this cable at 1.2 m intervals and serve as attachments for the bottom of each panel and to connect adjoining panels together. Each panel is fitted with a pair of small aluminum tubes welded to the lowest cross member which accommodate the pin on each U-connector. Lengths of 3 mm steel aircraft cable passed through the tip of these pins runs up each side of the panels to the top of the panel (i.e., above the surface of the water) where it is secured by three 50 mm stainless steel hose clamps. There are two of these cables for each panel which holds the entire fence in place. Removal of the fence simply requires removing the aluminum pipe between each panel and cutting each aircraft cable, which allows each panel to float freely and be pulled by rope to shore.

Fence operations changed considerably in 2019 from previous years. PIT tag detections indicated that narrow camera tunnels used to generate high-quality fish imagery were delaying Chinook migration. As an alternative, the fence was reconfigured to incorporate two 1.2 m wide passageways with underwater cameras (i.e., much wider passages than the previous camera tunnels). The quality of video imagery was slightly decreased with the wider passageways; however, imagery was more than adequate to identify fish to species, jacks versus adults, and origin (hatchery or wild).

One passageway was situated against the bulkhead on the Church Road (i.e., river left) side, while the other passageway was situated mid-channel (Figure 6; Figure 9). Axis Q1615 network security cameras with motion-detection capability were submerged in Videotec NXM36D0000 explosion-proof stainless steel camera housings in each opening to provide a side view of passing salmon (Figure 10). The cameras were paired with submersible 12V DC LED lights, which enabled footage to be captured at night. Additional

cameras (Barlus Underwater Camera 304) were also submerged alongside the Axis cameras to provide backup in case of failure.

Figure 9: Looking downstream at the Cowichan River counting fence, located 140 m below the Allenby Road bridge (river km 7.0), September 2019. Salmon were enumerated with underwater cameras situated in the two passageways through the fence.

Figure 10: Adult Chinook passing through the Cowichan River counting fence, September 2019.

The fence was staffed 24-hours per day throughout the season by rotating 8-hour shifts of two Cowichan Tribes Fisheries crew members. These crew provided a live, up-to-date count of all salmon species passing through the fence, which included quantifying the proportion of hatchery/wild Chinook in addition to estimating the proportion of jack Chinook. One hundred percent of Cowichan hatchery Chinook are adipose fin clipped; therefore, estimation of the hatchery component at the fence site is considered accurate due to the large sample viewed annually (i.e., thousands of Chinook). All video data were recorded and stored, which enabled a post-season review for quality assurance (Pearce and Atkinson 2020).

Fence operations are limited to a maximum flow of approximately 35 m^3/s. Typically these flows occur seasonally by mid-October requiring removal of the fence, which often coincides with the peak of Chinook migration. As a result, the fence count of Chinook represents an unknown and variable proportion of the

population each year. Therefore, fence counts are used as a sample of the population from which a PIT-tag mark rate is derived.

Skutz Falls Enumeration

Modifications to the Skutz Falls fishway (river km 33.6) continued in 2019 to establish a reliable camera system. Experimentation with cameras in 2018 suggested the fishway could provide subsample counts used for estimation of the Chinook and Coho populations, so an upgraded camera system was installed in summer 2019. An aluminum apparatus was installed in the uppermost cell of the main fishway to direct migrating adult salmon through a 30 cm x 60 cm opening (Figure 11). A replica of the camera system used at the fence was submerged in the opening, except the Barlus camera was situated in front of the opening to provide an offset head-on view of passing salmon (**Error! Reference source not found.**Figure 12**Error! Reference source not found.**).

Figure 11: Overhead view of camera apparatus used in Skutz Falls fishway (left), October 2019. The apparatus was installed in the uppermost cell of the lower fishway (right). The apparatus was lowered to the floor of the fishway and a screen was inserted overtop.

Figure 12: Adult Chinook passing through camera opening in Skutz Falls fishway, October 2019. The Axis surveillance camera provides the left view while the right view is provided by the Barlus underwater camera (i.e., same fish in both images).

Due to staffing limitations, the majority of video generated at Skutz Falls was reviewed post-season. Each salmon triggered a motion event clip, which allowed Cowichan Tribes reviewers to skip between motion events rather than view recorded video in its entirety. A PIT-tag detection antenna was installed 1.0 m downstream of the camera opening to measure detection efficiency of the mainstem array and to provide a secondary sub-sample of the mark rate in the population (Pearce and Atkinson 2020).

Other Monitoring – Hatchery Scanning and Deadpitch

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 Cowichan River 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 later on during egg takes using a hand-held reader (Figure 13).

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 wile snouts were removed from hatchery fish identified by a missing adipose fin. See Baillie et al. (2015) for further details on dead pitch methodology.

Figure 13: 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. 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 with 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. Since then a few other models have been researched and tested. For the Cowichan, the population is sampled without replacement meaning fish are only scanned or 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; therefore, it is considered the optimal model for the Cowichan Chinook data set (Equation 1).

The basic inputs to the calculations in order 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.

Equation 1: 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

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

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 fishway use by jacks).

As the alternative PIT tag-based escapement estimate relies on several new data sources it is important to understand potential biases and assumptions. Several assumptions embedded within this estimate methodology as well as the potential direction of bias relative to an escapement estimate are described in the Appendix. The list is not necessarily exhaustive but covers a variety of factors that could influence the estimate and may do so into the future depending on how the project is conducted.

Results

Spring Capture and Tagging

Hatchery Tagging

A total of 3,500 hatchery-origin juvenile Chinook salmon (AFC/CWT) were tagged on May 9 and May 10, 2019 at the Cowichan River Hatchery. Seventeen mortalities (0.5%) and 38 tag rejections (1.1%) were recorded over the following two weeks while fish were held in isolation in hatchery 'cap troughs' before release. Each fish was measured and scanned on May 22 and 23 in order to accurately capture size at release. Fork length ranged between 72 mm and 100 mm, with an average of 84 ± 4 mm (mean ± SD) (Figure 14), which was an increase from the average of 72 ± 8 mm when tagging began in 2014 (Figure 15). After accounting for tag loss and mortalities, a total of 3,445 viable PIT tagged hatchery origin Chinook were

released in 2019. Of these Chinook, 998 were released in the North Arm while 2,447 were released in the South Arm.
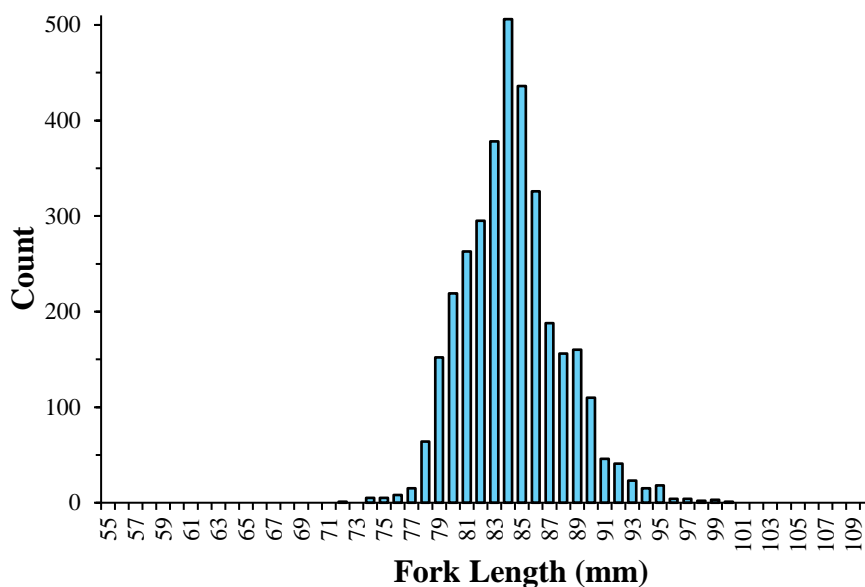
Figure 14: Size distribution of 3,445 PIT tagged Cowichan River hatchery Chinook measured prior to release, spring 2019.
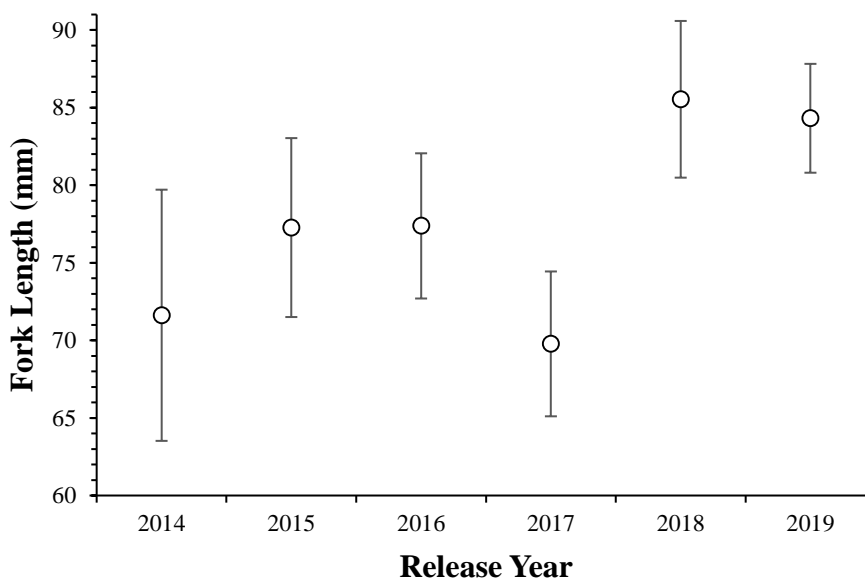
Figure 15: Average fork length of PIT tagged juvenile Cowichan hatchery Chinook between 2014 and 2019. Error bars represent one standard deviation.

Cowichan Bay Beach Seining

A total of 4,191 wild juvenile Chinook were captured, tagged and released in Cowichan Bay over six days between May 29 and 26 June, 2019 (Table 2). In addition, 40 Chinook were recaptured including 5 hatchery fish (river releases); the remainder of recaptures were from beach seining (same or previous day).

Table 2: Summary of wild Chinook PIT tagged in Cowichan Bay during beach seining operations, spring 2019.

Date	Number Tagged	Mean FL (mm)	St. Dev. (mm)
29-May	239	72	5
31-May	545	68	6
03-Jun	381	70	6
05-Jun	127	70	5
10-Jun	544	73	4
13-Jun	397	72	5
14-Jun	598	74	6
17-Jun	659	72	4
19-Jun	365	73	6
21-Jun	248	76	6
26-Jun	82	78	8

Wild Chinook comprised approximately 95 percent of beach seine catches while hatchery Chinook were measured and released untagged. They were also found to be significantly smaller on average than their hatchery counterparts at 72 ± 6 mm compared to 84 ± 4 mm for hatchery fish (*T-test; p = 0.00*) (Figure 16). Fork length of wild Chinook PIT tagged in beach seining operations has remained relatively constant between 2014 and 2019; however, minimum fork length required for tagging is 60 mm, so length of the wild population may be slightly smaller than the size presented in the figures below (Figure 17).
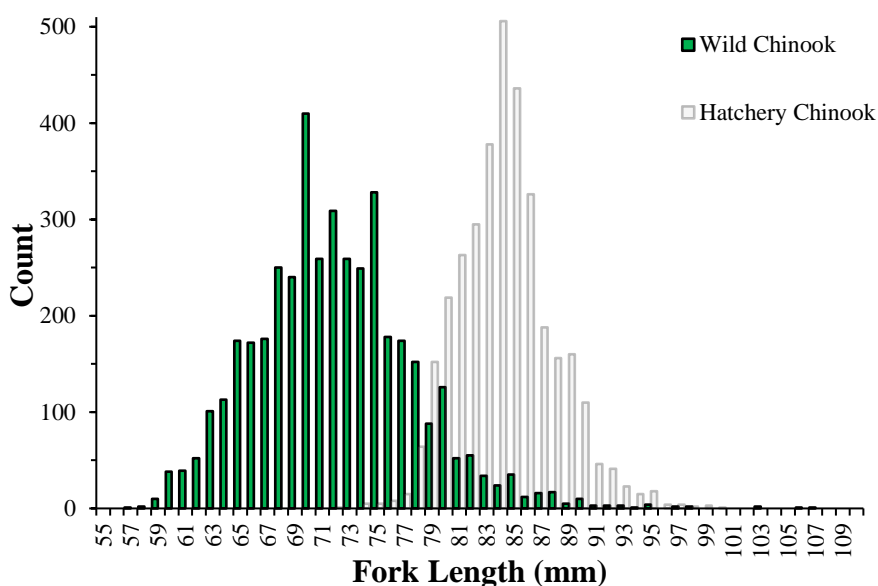
Figure 16: Size distributions of wild (n = 4,313) and hatchery (n = 3,419) origin Chinook implanted with PIT tags in Cowichan Bay, May 29 – June 26, 2019.
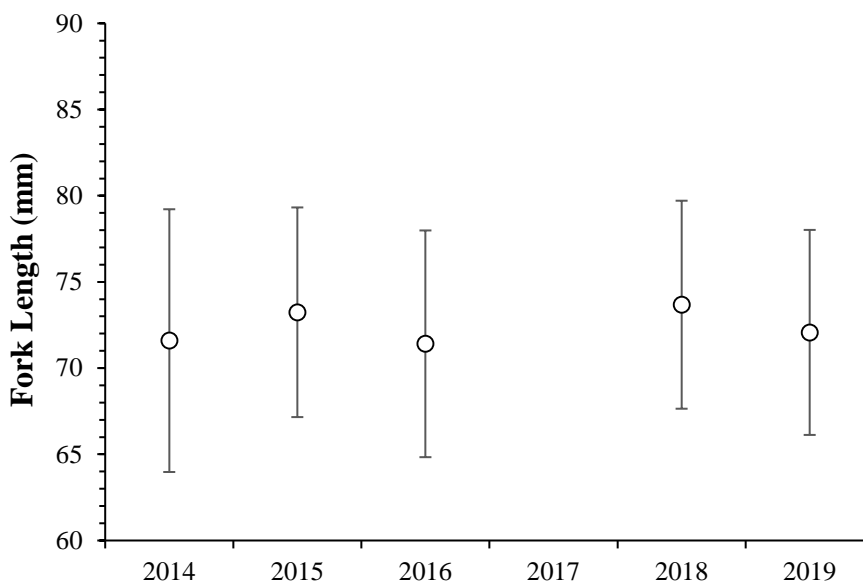
Figure 17: Average fork length of wild Chinook captured by beach seine in Cowichan Bay from 2014 to 2019. No beach seining occurred in 2017 (fish were captured by purse seine instead). Error bars represent one standard deviation.

Fall Capture and Tagging

A total of 69 adult Chinook were PIT tagged in Cowichan Bay between August 24 and September 25. Mean fork length of these Chinook was 702 mm with a SD of 76 mm. The confirmed male to female ratio was 0.7:1 while 20 percent of the fish were of unknown sex. Furthermore, 21 percent of males were adipose fin clipped (hatchery origin), compared to 24 percent of females (Atkinson and Murchy 2020). Twenty-one PIT tags from this tagging event were detected at the mainstem array at the counting fence site.

PIT Tag Detections

Counting Fence Detections

A total of 168 PIT tagged Chinook were detected on the mainstem array at the counting fence site between September 10 and November 13, 2019. Of these Chinook, 138 were tagged as juveniles while 30 were tagged as adults in the marine environment (27 in Cowichan Bay; 2 at Entrance Island; 1 at south end of Quadra Island). As observed in previous years, peak migration was triggered by increased river flow. In 2019, a modest flow increase occurred between October 2 and October 6 (7.5 m^3/s to 16.4 m^3/s), followed by a significant flow increase between October 16 and October 22 (13.6 m^3/s to 51.7 m^3/s) (Water Survey of Canada 2020). These flow increases occurred over approximately 15 percent of the Chinook migration period but 87.7 percent of tagged adults and 81.8 percent of tagged jacks passed the fence site during these periods (Figure 18). Age and origin of these Chinook are summarized in Table 3. PIT detections of the adult-tagged group suggested these fish behaved differently than the juvenile group in the early stages of the freshwater migration period; for this reason, adult-tagged Chinook were excluded from detection results at the mainstem array.
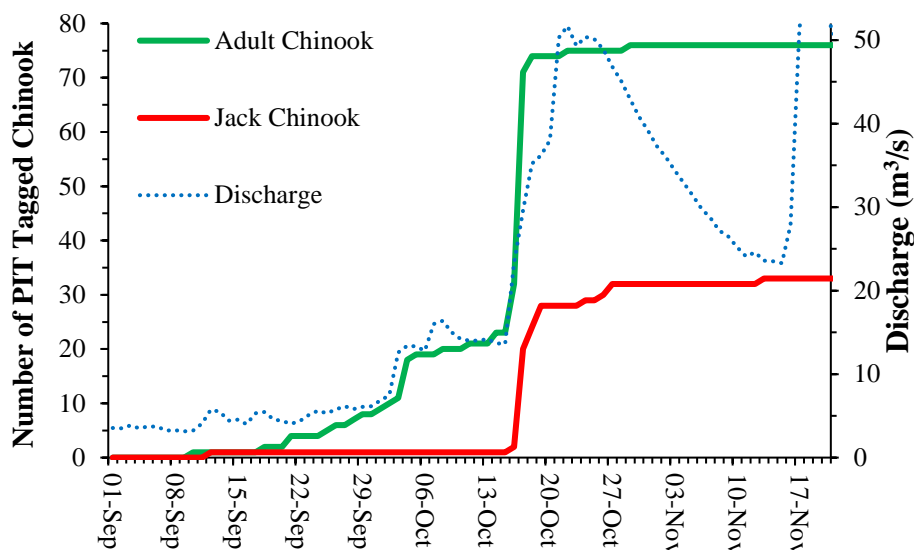
Figure 18: Cumulative detections of PIT tagged Chinook on the mainstem array at the Cowichan River counting fence site (river km 7.0), fall 2019.

Table 3: Summary of age and origin of PIT tagged Chinook detected on the mainstem array at the Cowichan River counting fence site (river km 7.0), fall 2019. Note: age was not determined for Chinook tagged as adults – they were classified as "mature" based on size (ages 3 and 4 were combined in the table); tag deployments are unequal between age class and origin – this table is simply provided to summarize detections and should not be used for comparison between groups.

Age	Tagged as Juveniles		Tagged as Adults	
	Hatchery	**Wild**	**Hatchery**	**Wild**
2	11	25		
3	10	14	6	23
4	4	74		
Total	25	113	6	23

Multiple PIT detection sites throughout the river system provided the opportunity to measure detection efficiency of all sites except Skutz Falls (Table 4). Please see "*Skutz Falls Detections"* and *"Lower River Detections"* sections below for results from these locations.

Table 4: PIT tag detection efficiency at three sites in the Cowichan River, fall 2019. MS = mainstem; number of antennas in each array in brackets. *Note: lower river antennas were removed before the end of the migration period due to high flows.

Antenna Location	Lower River Antennas (2)	Mainstem Array (12)		
		Both MS Arrays (12)	**Lower MS Array (6)**	**Upper MS Array (6)**
Unique tag IDs detected	107*	168	166	136
Tags resampled upstream	168	15	136	15
Tags missed	61	0	2	3
Detection efficiency (%)	63.7	100.0	98.5	80.0
Upstream resample location	Mainstem Array	Skutz Falls	Upper Array	Skutz Falls

One-hundred thirty-six of 168 PIT tagged Chinook were confirmed to pass the fence site (i.e., detected on the upper MS array or at Skutz Falls). Thirty-two Chinook (29 adults; 3 jacks) were detected on the lower array only; three of these were recovered in brood stock. Results from Skutz Falls indicated upper array detection efficiency was 80.0 percent, which suggested six of the remaining 29 Chinook (5 adults; 1 jack) passed the upper array undetected. Therefore, the number of PIT tagged Chinook confirmed to pass the fence site was corrected to 142 (81 adults; 34 jacks) of 168 (102 adults; 36 jacks).

Based on juvenile tag returns only, 51 PIT tagged adult Chinook passed through the fence during 2019 operations, while 30 tagged adult Chinook passed the site after the fence was removed. An additional 21 tagged Chinook were not confirmed to pass the fence site (i.e., detected on the lower array only); 18 of these Chinook were not detected again, but 3 were recovered in Cowichan Hatchery broodstock. Timing of tag detections for these remaining 18 tagged Chinook suggested that they passed the fence during operations but were missed on the upper array. Therefore, a total of 69 tagged Chinook were estimated to have passed through the fence during operations. In addition to adults, 34 tagged jack Chinook were confirmed to pass the fence site. Of these, 14 passed during fence operations while 20 passed after the fence was removed. Based on these detections, an estimated 69.7 percent of the adult Chinook return and 41.2 percent of the jack return were enumerated through the fence in 2019 (Figure 19).
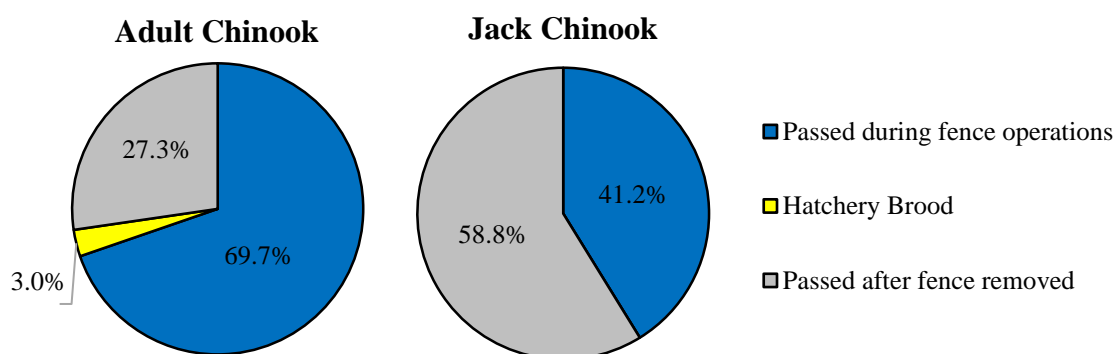
Figure 19: PIT tag detections of Chinook by age relative to operations at the Cowichan River counting fence site, fall 2019.

Skutz Falls Detections

A secondary tag detection site was operated in the main fishway at Skutz Falls between October 7 and December 14, 2019 (Figure 20). Fifteen PIT tagged Chinook were detected migrating through the fishway between October 18 and November 13; however, 66.7 percent of Chinook detected in the fishway were jacks (10/15), while jacks only represented 20.5 percent of tag returns at the mainstem array (35/170). Only five PIT tagged adult Chinook were detected in the fishway, which indicated 95.4 percent of adult Chinook either bypassed the fishway or spawned downstream of the falls.
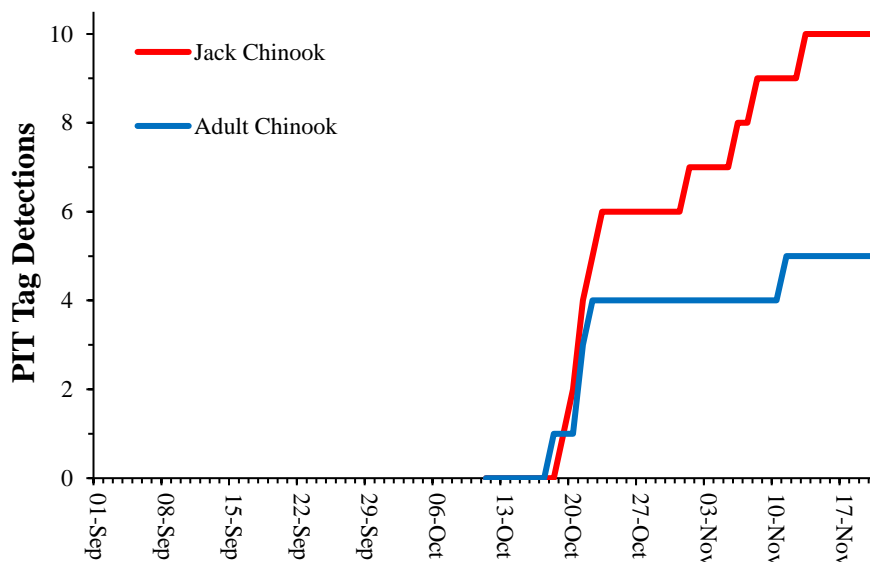
Figure 20: Cumulative detections of PIT tagged Chinook in the Skutz Falls fishway (river km 33.6), fall 2019.

North and South Arm Detections

PIT detection antennas were installed on August 23 and August 27 in the North and South Arms of the lower river, respectively (river km 1.0). These antennas operated until October 16 when they were removed due to increased river flows. A total of 73 PIT tagged Chinook were detected at the South Arm antenna and 49 at the North Arm for a total of 122 lower river tags (Figure 21). Of these, 107 were detected at the counting fence and one in brood stock while the remainder (15) were never detected again. This was broken down further into jacks and adults with survival estimates of 95.0 percent for jacks (19/20) and 86.2 percent for adults (88/102). Survival was found to be higher for adults migrating via North Arm (90%) vs South Arm (82%).
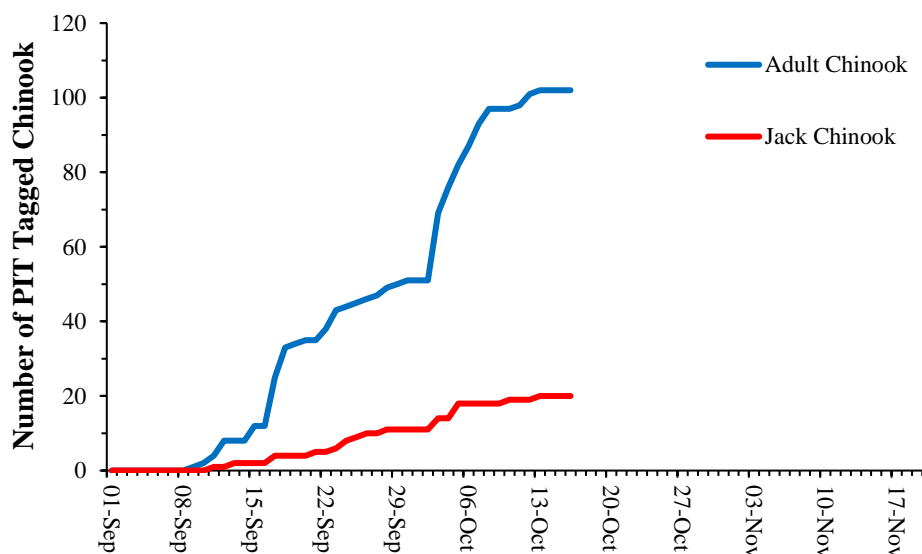
Figure 21: Cumulative detections of PIT tagged Chinook in the North and South Arms of the lower Cowichan River (river km 1.0), fall 2019. Antennas were removed October 16 due to increased river flows.

One-hundred sixty-eight tags were detected on the mainstem array which migrated by either the north or south arm channels resulting in a detection efficiency of 63.7 percent. It is likely some tags migrated through the north or south arm channels after the arrays were removed so this estimate should be considered conservative.

The majority of PIT tagged adult Chinook (61.0%) used the South Arm when entering the river, while tagged jacks were fairly evenly distributed between the North Arm (9 jacks; 45.0%) and South Arm (11 jacks; 55.0%) (Figure 22). Furthermore, detections in North Arm were absent when mainstem flow was below 7.5 m³/s suggesting lower flows did not facilitate Chinook migration.
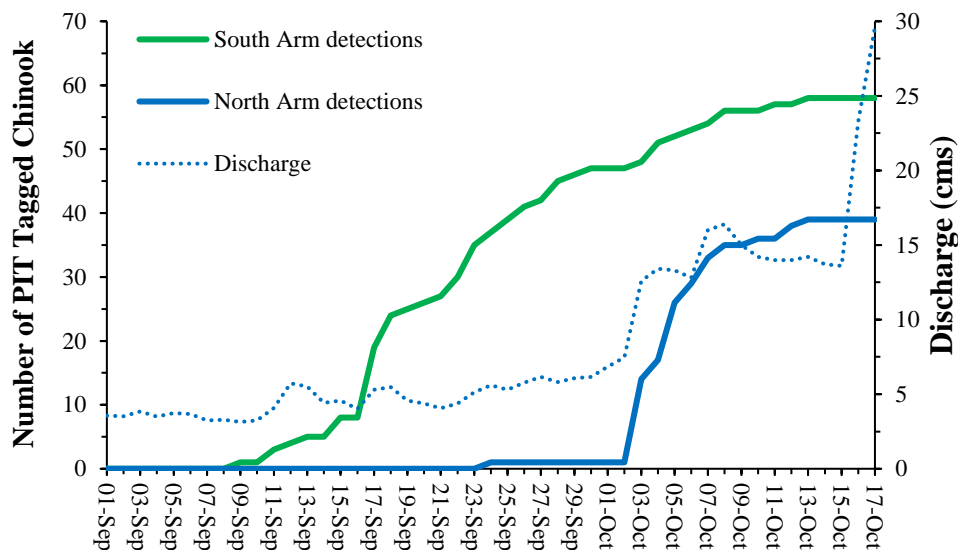
Figure 22: Cumulative detections of PIT tagged Chinook at separate antennas in the North and South Arms of the lower Cowichan River (river km 1.0), fall 2019.

Hatchery Scanning

All spawned hatchery Chinook broodstock were scanned for PIT tags. Four out of 581 Chinook (578 adults; 3 jacks) were PIT tagged for a mark rate of 1 in 145 fish. Of these tags, one was among the 16 adult tags not detected at the mainstem array. If we assume the remaining 15 missing tags were removed prior to reaching the fence then the escapement estimated at the fence represents 87.7 percent of the total freshwater return (107/122).

Run Timing

Run timing curves were generally similar between years with a dramatic increase in migration during mid-October (Figure 23). However, the mid-river fence passage was closed from September 27 to October 2 and both fence passages were closed between October 2 and 4 to promote accumulation of fish downstream of the fence; this was done to improve catch rates of Chinook brood for the Cowichan Hatchery. Despite imposing this intentional delay to a portion of the run, the proportion of Chinook enumerated through the fence prior to removal was 69.7 percent, which was greater than both 2018 (53.3%) and 2017 (42.4%). The end of the run (last tag detection) occurred on November 13, compared to November 11 in 2018 and November 8 in 2017.
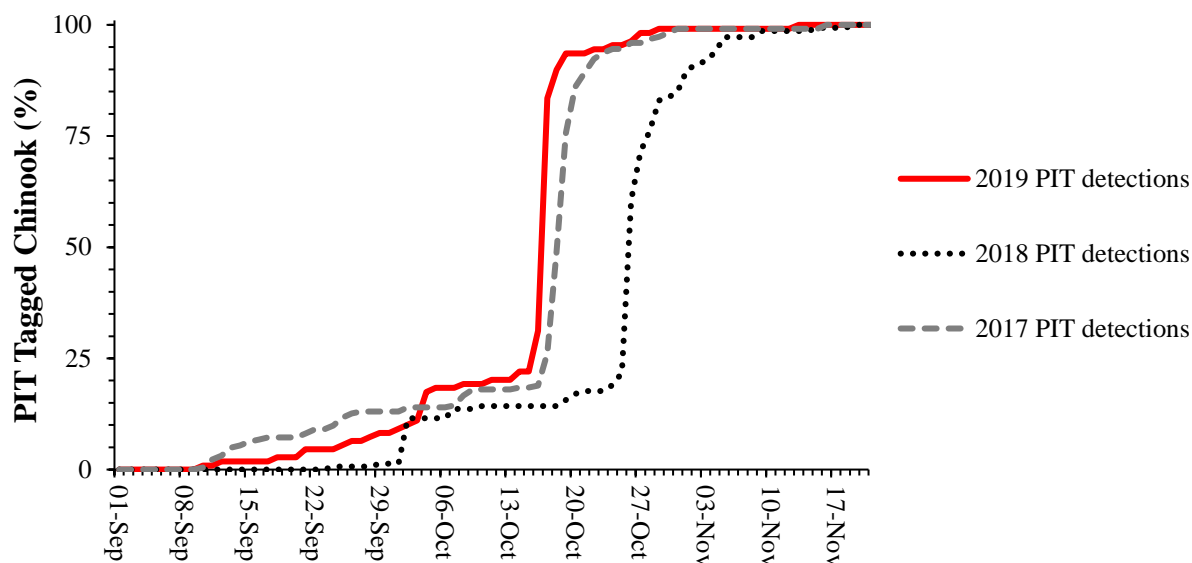
Figure 23: Run timing comparison of PIT tagged Chinook at the Cowichan River counting fence site, 2017-2019. In 2019, fence passages were partially closed between September 27 and October 2 and fully closed between October 2 and October 4 to assist with capture of Chinook brood for the Cowichan Hatchery.

Run timing curves for PIT tagged Chinook detected at each site were generated as an estimate of river entry timing and migration rate (Figure 24). Assuming equal detection efficiency across the run, detections at the lower river sites and Skutz Falls were considered unbiased in terms of enumeration activities due to the distance between those sites and the fence. Adult Chinook took 11.9 ± 9.2 days (mean $\pm$ SD) to migrate between the lower river and fence site (5.0 km migration distance), 3.5 ± 5.9 days to migrate past the fence site (lower to upper array), and 9.7 ± 8.6 days to migrate between the fence site and Skutz Falls (26.6 km migration distance). These detections indicate adult Chinook took approximately 3-4 weeks to reach Skutz Falls after entering the river with the majority of that time spent holding below the fence (Figure 25).
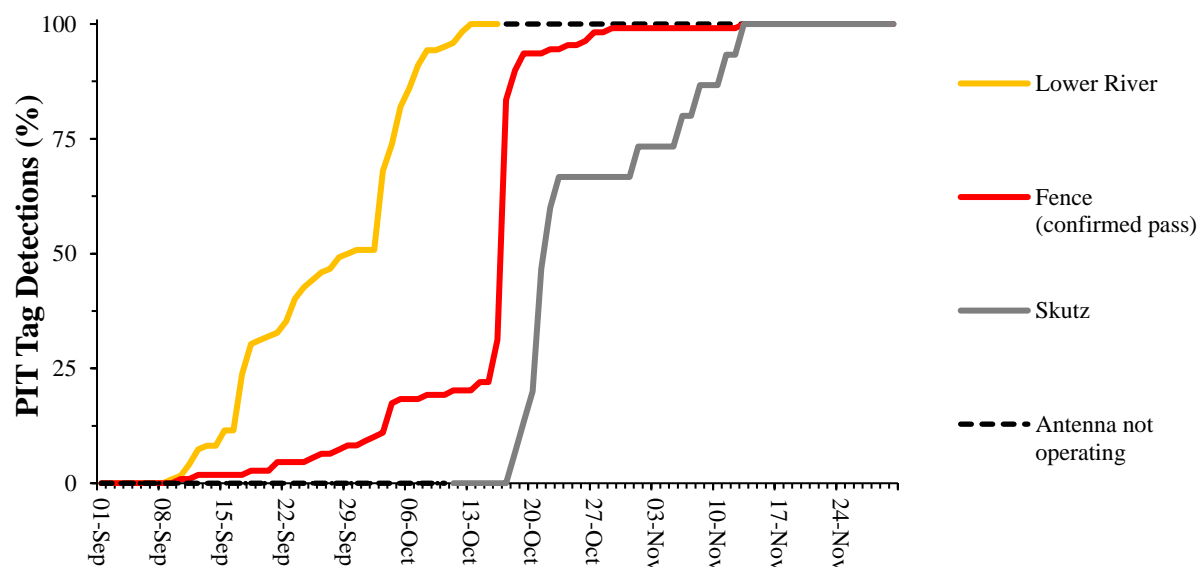
Figure 24: Run timing curves of PIT tagged Chinook detected at three sites in the Cowichan River, fall 2019. Curves are based on the date of arrival at each site, independent of fence operations.
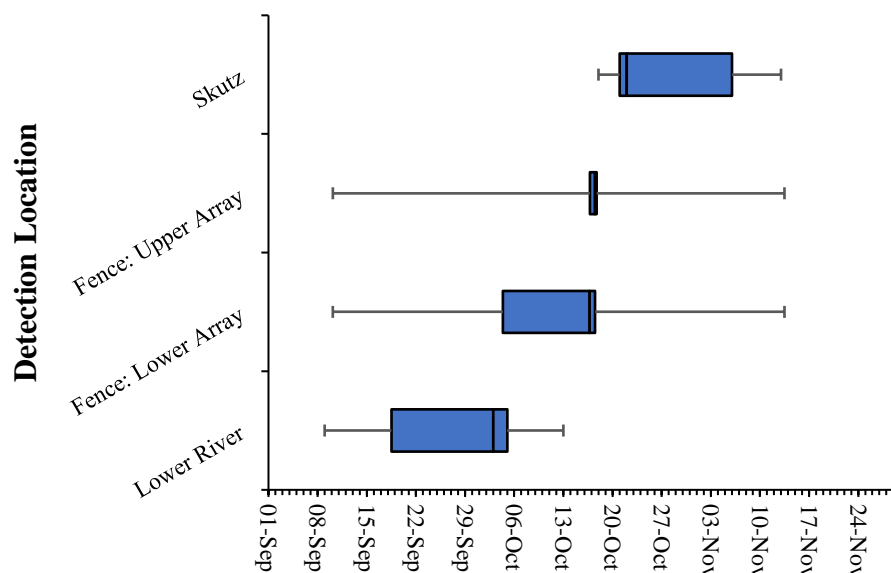
Figure 25: Migration rate of PIT tagged adult Chinook in the Cowichan River, fall 2019.

Chinook Escapement

Counting Fence Enumeration

All panels of the counting fence were installed on September 9 with the first shift starting at 16:00. No Chinook migrated on the first shift, but 9 adults and 1 jack were enumerated in the first 24 hours of operations. By the end of the first week 87 adults and 25 jacks had passed through the fence. Relative to 2018, the number of migrants in September was similar, but the majority of the run occurred earlier including two pulses during the weeks ending October 6th and 20th (Figure 26; Figure 27).
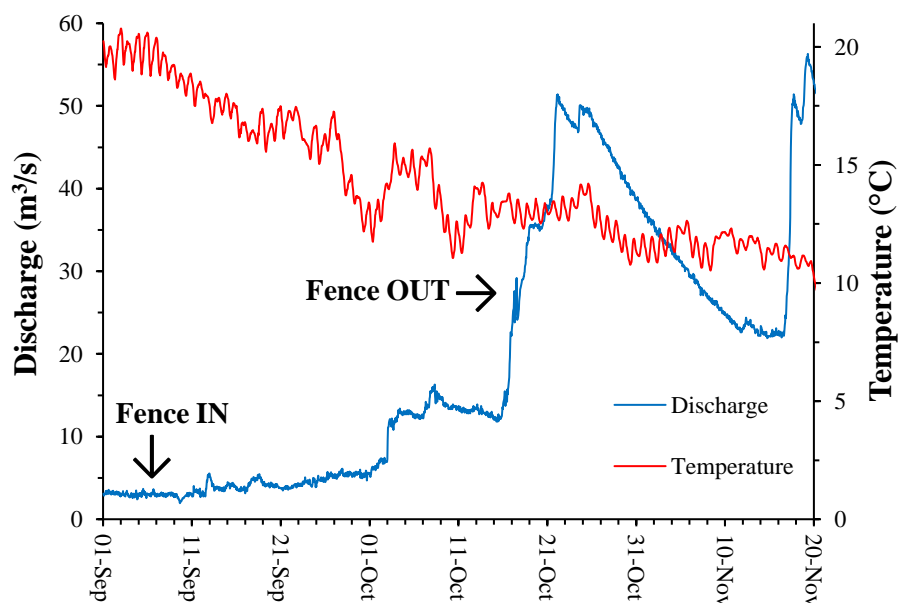
Figure 26: Discharge and temperature recorded at Water Survey of Canada station 08HA011 relative to Cowichan River counting fence operations, 2019.
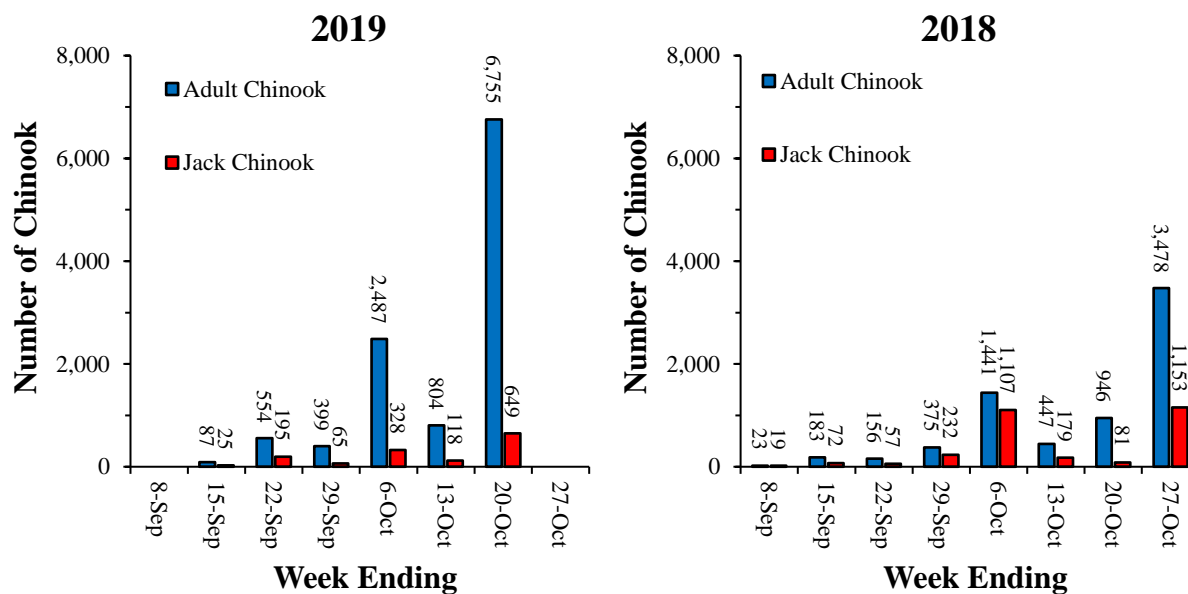
Figure 27: Summary of weekly Chinook counts in 2019 (left) and 2018 (right) at the Cowichan River counting fence. The fence was operational from September 9 – October 17, 2019 and September 7 – October 26, 2018.

A total of 11,827 Chinook (10,527 adults; 1,300 jacks) were enumerated before the fence was removed at 14:00 on October 17, 2019, when discharge exceeded the operational threshold of 35 m^3/s. Sixty-one percent of the total adult Chinook count (6,407/10,527) was enumerated in the last 30 hours of operation prior to fence removal (Figure 28). Video footage of high-volume migration periods was reviewed post-season for quality assurance of estimates (i.e., confirmation of jack/adult ratio, origin, and species composition). The overall adipose clip rate during periods of high confidence in assignment of origin was estimated at 11.4 percent for adults and 12.5 percent for jacks (n = 4,676); this was similar to clip rates observed in previous years (Figure 29).

Figure 28: Underwater view of Chinook through the counting fence in response to an increase in flow, October 16, 2019.

Adult Chinook   Jack Chinook
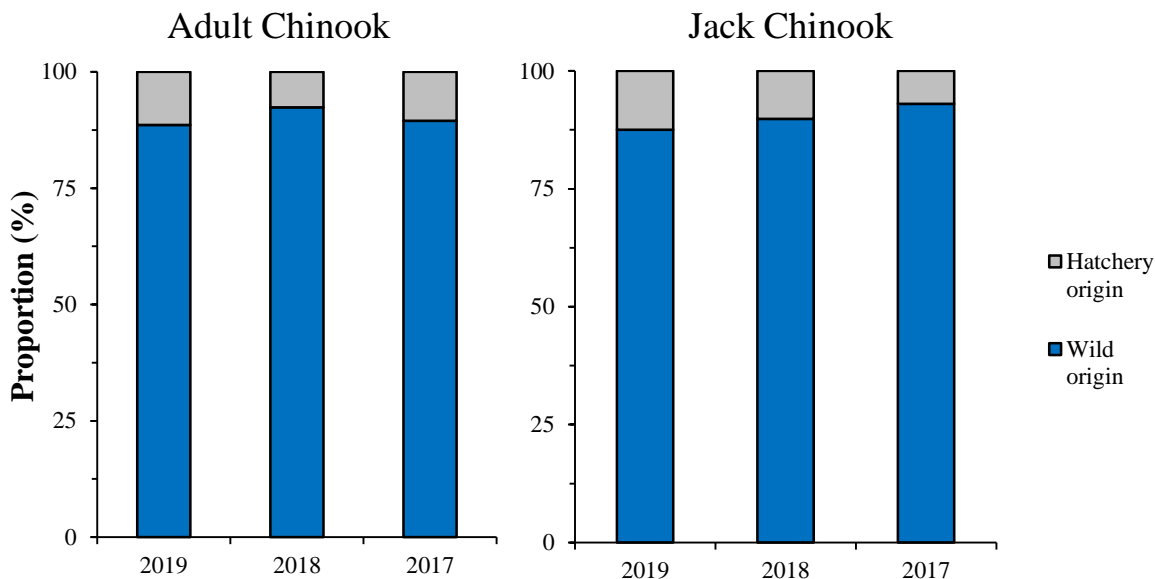
Figure 29: Origin of Cowichan River Chinook, 2017 – 2019. Origin was determined by video enumeration of adipose fin-clipped Chinook as they passed through the counting fence.

As a result of a record drought in late winter and spring 2019, a reduced summer baseflow of 4.5 m^3/s (normally 7 m^3/s) was authorized to conserve water in Lake Cowichan. Nevertheless, pumping from the lake was required in late August to sustain river flows. This was the first time in history that water storage in the lake fell below zero and pumping was required. Fortunately, a rain event occurred in mid-September which was enough to refill the lake and restore natural flow on September 17, which was ahead of peak Chinook migration timing. Average water temperature was warmer in September 2019 by 1.0°C but similar during October (0.2°C colder) compared to 2018. Flow was lower than 2018 with a rainfall driven pulse starting in early October resulting in sustained discharge of approximately 15 m^3/s until October 16, when significant rainfall resulted in flows surpassing the operational threshold of the fence (Figure 30).

Discharge (m³/s)   Temperature (°C)
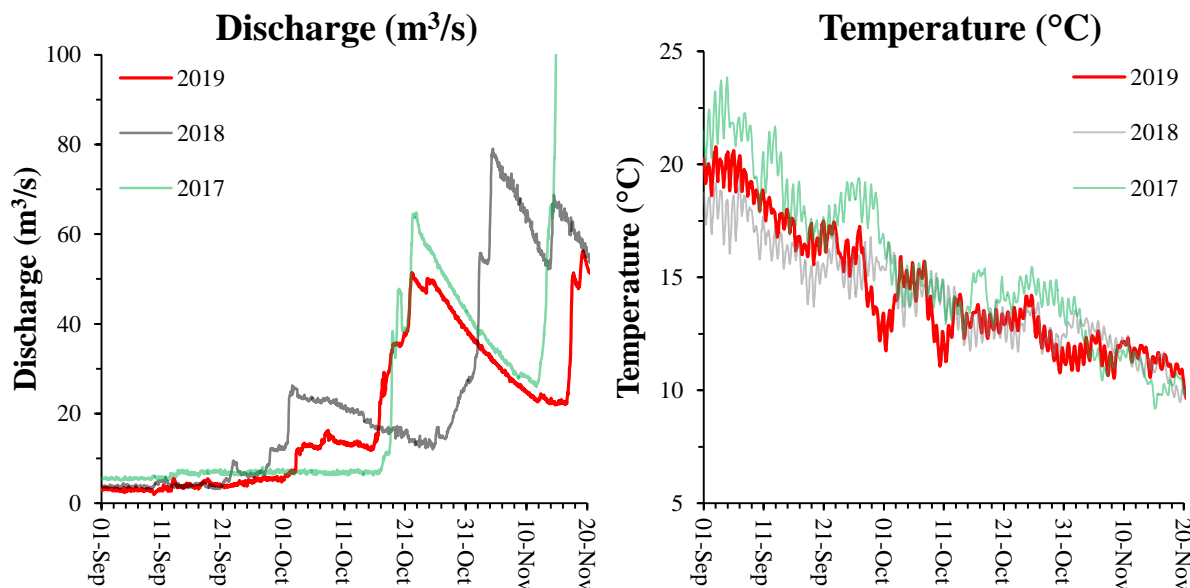
Figure 30: Discharge (left) and temperature (right) recorded at Water Survey of Canada station 08HA011 in the Cowichan River, September 1- November 20, 2017 – 2019.

Fence operations in 2019 were modified from previous years to reduce migration delays (see "*Chinook Escapement – Counting Fence Enumeration*" above). The daily count of Chinook migrating through the fence was greatest in 2019 when compared to 2017 and 2018 (Figure 31). Additionally, the number of adult Chinook enumerated through the counting fence in 2019 was the second highest on record (10,715 in 1995) since operations began in 1988; this was despite the fact that the 2019 season was 17 days shorter than the 1995 season and 11 days shorter than the average since 1988 (Figure 32).
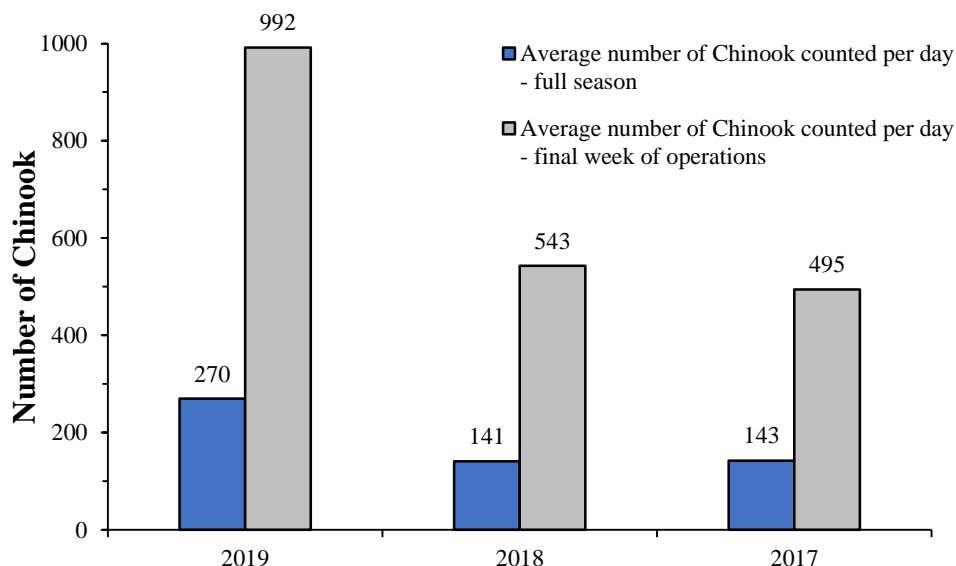
Figure 31: Average daily number of Chinook enumerated through the Cowichan River counting fence, 2017 – 2019. In 2019 fence passageways were changed from two 20 cm x 30 cm camera tunnels to two 1.2 m passageways with submerged cameras for enumerating salmon. Note: the concept of the 1.2 m passageways was piloted in 2018, but the fence was removed prior to peak migration over concerns of numerous Chinook holding for an extended period of time downstream of the fence (i.e., counts per day should have been greater).
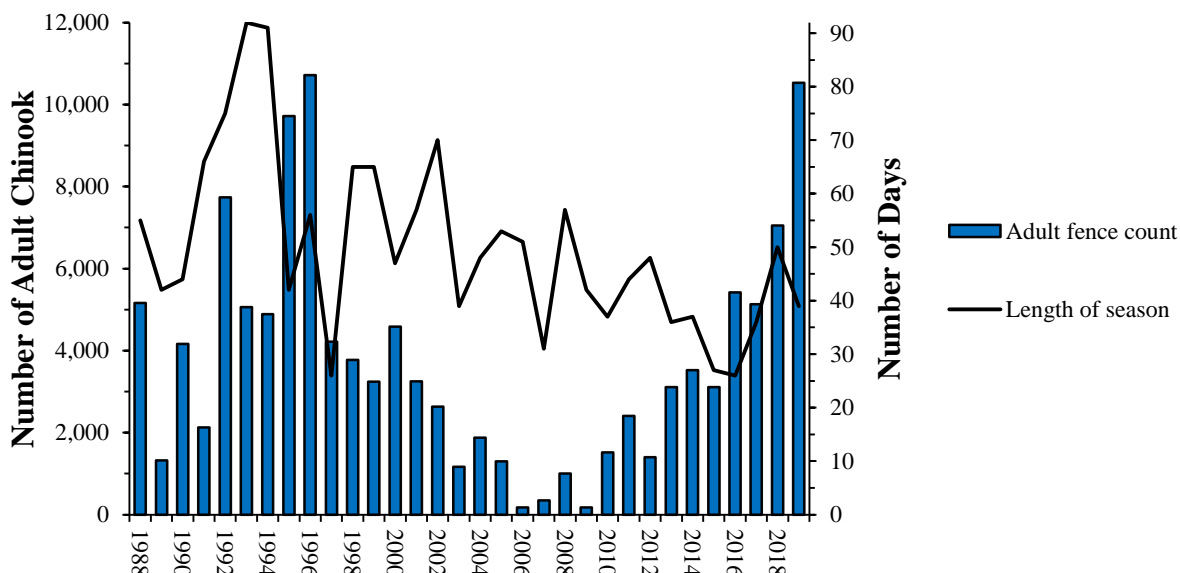
Figure 32: Number of adult Chinook enumerated through the Cowichan River counting fence versus the number of operational fence days, 1988 – 2019.

In addition to Chinook, a total of 2,556 adult Coho were counted through the fence in 2019 of which 87.8 percent passed in the last 30 hours of operation. Two-hundred five Chum were also enumerated with 97.5 percent passing in the last 30 hours. Enumeration of Chum continued through to November 29 via DIDSON producing a total estimate of 94,962.

Skutz Falls Enumeration

Estimating the PIT tag mark rate for later expansions was a primary objective at Skutz Falls in order to support population expansions. Upgrades to camera infrastructure in 2019 provided continuous footage which was recorded from October 7 to December 19. During this period a total of 3,589 Chinook were enumerated. The first Chinook were observed on October 7, but over 70 percent (2,518/3,589) were enumerated between October 16 and 25. Small numbers of Chinook continued to pass through the fishway through the end of November, with the final fish observed on December 14 (Figure 32).
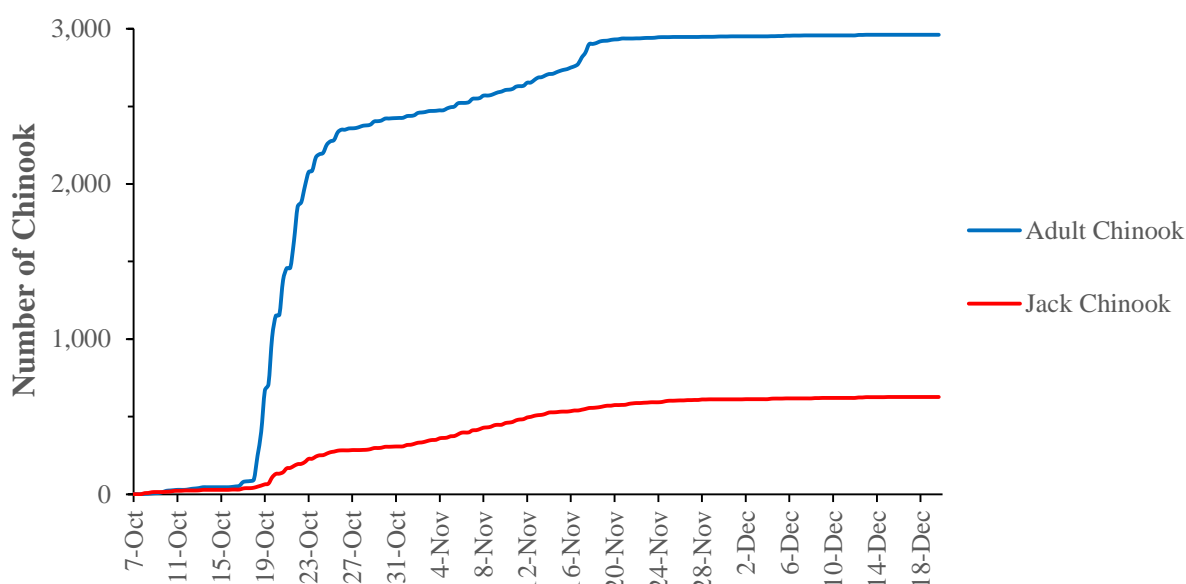
Figure 33: Number of Chinook enumerated by video in the main fishway at Skutz Falls, fall 2019.

As with the fence site, video footage at Skutz provided the ability to confidently assess the adipose fin clip rate and the jack/adult ratio of passing Chinook. Of the 3,589 Chinook assessed, 2,962 were adults (84.0% wild; 16.0% hatchery origin) and 627 were jacks (92.8% wild; 7.2% hatchery origin).

In addition to Chinook, 9,077 Coho (8,271 adults; 806 jacks) and 4,448 Chum were identified as upstream migrants. Steelhead and Rainbow Trout (*Oncorhynchus mykiss*), Cutthroat Trout (*Oncorhynchus clarki clarki*), and Brown Trout (*Salmon trutta*) were also observed migrating upstream.

Escapement Estimates

Counting Fence Estimate

A total of 69 PIT tags were detected in 10,527 adult Chinook passing through the fence between September 9 and October 17, 2019, for a mark rate of 1 in 153 adults. Furthermore, a total of 14 PIT tags were detected in 1,300 jacks passing through the fence for a mark rate of 1 in 93 jacks. The proportion of adult and jack PIT tags estimated during fence operations (69.7% adults; 41.2% jacks) were then used to expand the fence

count by the remainder of PIT tagged fish that passed the site after the fence was removed (30.3% adults; 58.8% jacks). This includes the period prior to installation (0 tags; i.e., no expansion) and incomplete or missed shifts (0 tags/0 fish). Therefore, the final expanded number of Chinook estimated to pass the counting fence site was 15,103 adult Chinook and 3,155 jack Chinook, which provided a grand total of 18,258 natural spawning Cowichan River Chinook. By comparison, input of fence enumeration and PIT data into the Hypergeometric Model resulted in an estimate of 14,889 ± SD 953 adult Chinook (*CV: 6.4%*) and 3,035 ± SD 570 jack Chinook (*CV: 18.8%*), for a grand total of 17,924 ± 1,523 natural spawning Cowichan River Chinook.

The natural spawning population was divided into age classes based on scale samples collected during dead pitch. Ages were successfully resolved from 522 of 631 Chinook carcasses; of these 522 samples, 488 were adults. Of the adults, age 4 Chinook were the most abundant, representing 63.3 percent of adult Chinook, followed by age 3 (36.3%), and age 5 (0.4%) (Figure 33). Based on results from the Hypergeometric Model, the natural adult spawning population was comprised of 9,538 ± SD 618 age 4 Chinook, 5,470 ± SD 354 age 3 Chinook, and 60 ± SD 4 age 5 Chinook. Fourteen of 432 adult Chinook (3.2%) were identified as hatchery origin by absence of their adipose fin. See Appendix 1 for more details.
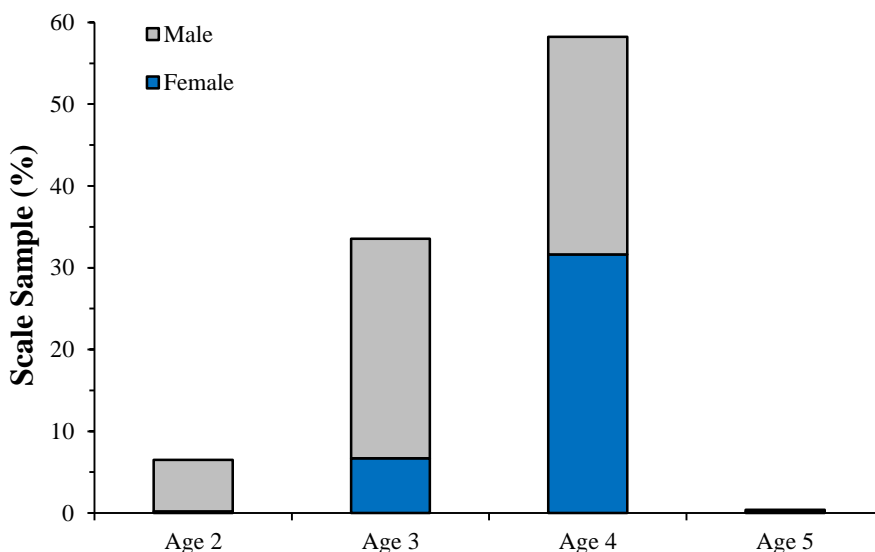
Figure 34: Age distribution by sex of Cowichan River Chinook, fall 2019. Scales were collected from 1,425 Chinook carcasses in the upper river. Of these samples, 631 were analyzed with ages of 522 Chinook successfully resolved.

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 2019 (Figure 34). Counts of age 2 fish (called jacks at the fence but typically include ~10% females) in 2017 and 2018 did not fit the recent population trend and were far more abundant than expected; however, 2019 counts of age 2 fish were more closely aligned with the long-term dataset (Figure 35). The abundance of adult Chinook has exceeded the natural spawner target of 6,500 fish (Tompkins et al. 2005) for four consecutive years while the total escapement exceeded the target in 2015.
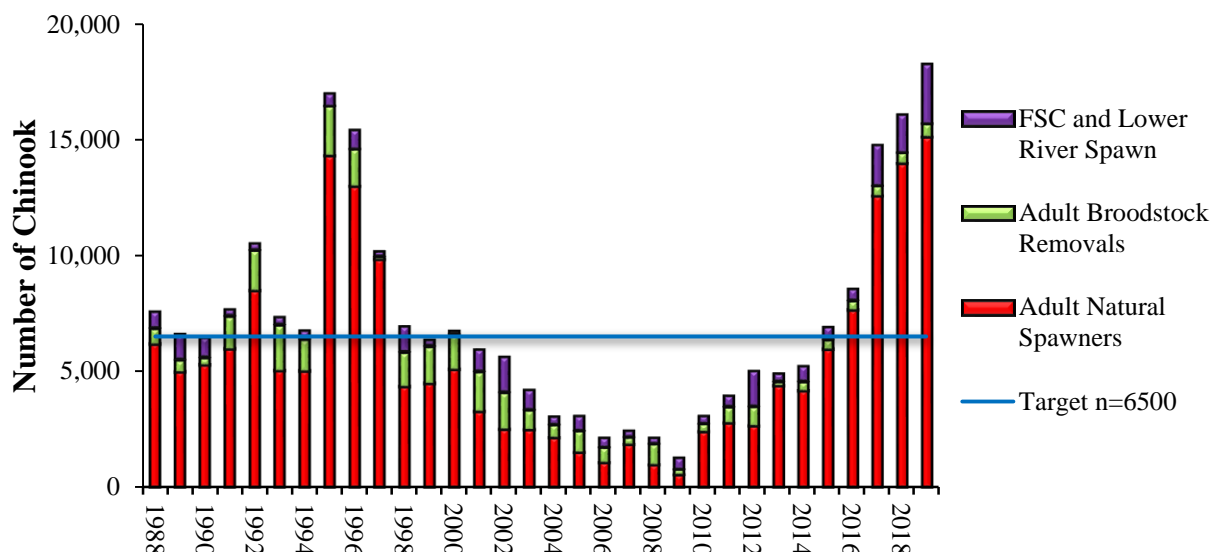
Figure 35: Summary of adult Chinook returns (ages 3-5) to the Cowichan River, 1998-2019.
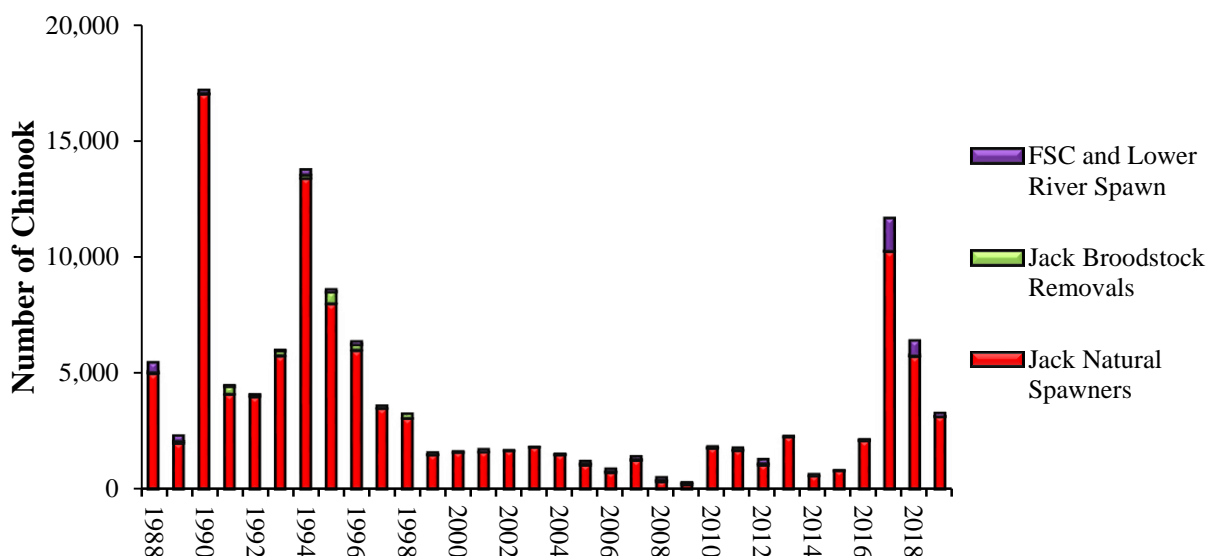
Figure 36: Summary of jack Chinook returns (age 2) Chinook returns to the Cowichan River, 1998-2019.

Skutz Falls Estimate

Only five PIT tags were detected in 2,962 adult Chinook passing through the Skutz Falls fishway between October 7 and December 19, 2019, for a mark rate of 1 in 592 adults. An additional 10 PIT tags were detected in 627 jacks for a mark rate of 1 in 63 jacks. The number of adult PIT tag detections at Skutz Falls in 2019 was insufficient for generating an adult population estimate with reasonable confidence; however, detections of jacks did provide an estimate of the jack population. Applying adult Chinook data from Skutz Falls to the Hypergeometric Model generated a CV of 36.6 percent; this result was far from the desired level of precision (CV <15%), so these results were rejected. Applying the jack data to the Hypergeometric Model resulted in an estimate of 1,997 ± SD 473 jack Chinook (*CV: 23.7%*).

Comparison to Current Methodology

The initial drive 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 m^3/s threshold which is known to significantly increase migration (Figure 36). In order to enumerate 95% of the escapement in a normal year the fence would need 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.

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 percent of the escapement was enumerated on average between 2012 and 2016 (Table 7). This is significantly different than the 78.6 percent reported in the final expansions which potentially under-estimated the escapement by 34 percent on average.
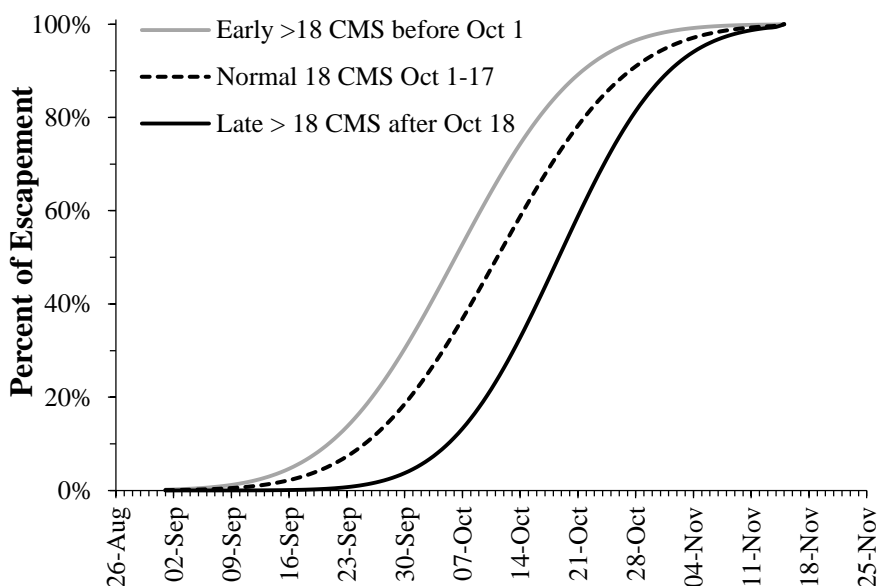
Figure 37: DFO run timing estimates for adult Chinook migration past the counting fence in the Cowichan River based on flow conditions.

Table 5: Summary of Cowichan Chinook counting fence operations, 2012-2019.

Year	Operating Period	Run Timing	Proportion Enumerated Based on Run Timing (Fig. 26)	Expansion Method	Proportion Enumerated for PIT Tag Based Estimate	Comments
2019	Sep 9 - Oct 17	Normal	67.8%	PIT tag based	69.7%	Two 1.2m passageways through fence instead of camera tunnels
2018	Sep 7 - Oct 26	Normal	88.1%	PIT tag based	50.4%	New camera boxes delayed migration, fence removed early due to migration concerns
2017	Sep 15 - Oct 18	Late	47.0%	PIT tag based	43.5%	Fence and rail rebuilt, counting box failure Oct 19
2016	Sep 19 - Oct 13	Normal	52.4%	Normal model before fence removal and Big Qualicum timing after fence	90.2%	Lost fence, rail failure Oct 13
2015	Sep 17 - Oct 12	Normal	50.3%	Early run time model 10 m^3/s threshold instead of 18 m^3/s	71.4%	Fence rebuilt
2014	Sep 16 - Oct 22	Late	62.5%	Normal model 10 m^3/s threshold instead of 18 m^3/s	80.5%	Fence underwater Oct 22, left in all winter
2013	Sep 9 - Sep 28	Early	24.1%	Dead pitch mark-recapture	60.2%	Fence underwater Sep 29, damaged but removed Oct 21
2012	Sep 4 - Oct 24	Late	69.5%	.+15% for adults only	90.7%	Fence removed Oct 25

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.

In 2019, a total of 10,527 adults and 1,300 jacks were counted through the fence which was later expanded to 14,889 ± SD 953 adults and 3,035 ± SD 570 jacks using the PIT tag based mark recapture method outlined above. A more traditional approach using run timing curves would have produced a greater expansion of approximately 15,527 adults with a lesser expansion of 1,917 jacks.

Discussion

The combined number of tags deployed in both hatchery and wild juvenile Chinook were similar to 2018 at 7,636 but below the target of 10,000 due mainly to a lower number of hatchery fish. Beach seining results in 2018 suggested that with an earlier start to the season in 2019, the tagging target of 5,000 wild Chinook would be met or exceeded; therefore, only 3,500 hatchery Chinook were tagged in order to direct extra tags toward the wild cohort. Despite these intentions, an earlier start to beach seining (in late May rather than mid-June in previous years) did not work as planned. Catch rates and fish condition were good from the start, but in early June the fish showed higher stress than was observed in previous years. As a result, tagging efforts were reduced until June 10. At that point, stress levels returned to normal and full tagging efforts were resumed. The reduced tolerance to handling and tagging was possibly attributed to catching the juveniles while they were still enduring physiological stress from transitioning to saltwater combined with abnormally high water temperatures on some days.

Fall capture and tagging of adult Chinook proved to be challenging in 2019. Modifications to the counting fence (larger passageways) had the desired effect of reducing Chinook migration delay. This prevented a buildup of Chinook downstream of the fence where broodstock was captured during recent years. Without the buildup of fish caused by the fence, more effort was required for brood collection leaving few opportunities to tag sufficient Chinook for population estimates. Closing of fence passageways was a solution to this issue, however it counteracts the objective of reducing migration delay as fish tend to initiate a long-term holding pattern once obstructed by the fence. The mortality study being conducted by UVIC offered an opportunity to overcome these difficulties; however, the number Chinook PIT tagged for this study was below the target for adult tagging. Furthermore, the proportion of these tags that reached the mainstem array was far fewer than if tagged in-river. Methods for fall capture and tagging of adult Chinook will need to be reconsidered in future years in order to obtain the goals of this objective.

PIT tag detections at the counting fence were consistent with previous years of this project. The frequency of detections increased dramatically when river discharge increased, and a significant portion of tagged Chinook passed the site after the fence was removed. Cross-referencing of tag detections between Skutz Falls and the mainstem array indicated detection efficiency of the upper array was suboptimal (<90%). These deficiencies will be investigated and addressed during the summer low flow period.

Detections at Skutz Falls continued to provide information on Chinook migration rates and fishway usage in addition to providing a measure of detection efficiency for the mainstem array. However, detections in 2019 were insufficient for the purposes of adult Chinook population estimation. Due to low flows throughout much of fall 2019, it appeared the vast majority of the Chinook population bypassed the main fishway and migrated through the falls or the secondary bypass channel. These results suggest that the PIT detection system at Skutz Falls must be expanded to incorporate the bypass channel. This should increase the proportion of the Chinook population resampled at Skutz Falls, although flows will cause the resampling rate to vary across years. Increasing the resampling rate should provide enough tag detections to facilitate a secondary population estimate to the fence.

Lower river detections provided information on river entry timing and usage of North Arm versus South Arm relative to river flows. Loss of tagged fish between lower river antennas and the mainstem array indicated mortality in the lower river was higher than expected, which may require further investigation. Installation of these antennas in future years will improve understanding of these results.

Detections of PIT tagged Chinook at three sites continued to further understandings of run timing and lower river survival rates for both hatchery and wild Chinook. The distance between the lower river antennas and the counting fence (6 km) is much less than the distance between the counting fence and Skutz Falls (26.6 km), but Chinook took fewer days to migrate between the fence and Skutz Falls than from the lower river to the fence. These results suggest that the lower river is an important staging area for returning Chinook. Increasingly high winter flows in the Cowichan have reduced heterogeneity of lower river habitat through bedload of substrate which has filled in many holding pools for Chinook (Water Survey of Canada 2020; Tim Kulchyski, Cowichan Tribes Fisheries Biologist, pers. comm.). Annual summer gravel removal may continue to be required to preserve this habitat for returning Chinook.

Modifications to the counting fence in 2019 improved operations greatly over previous years. Implementation of 1.2 m passageways with underwater cameras was essentially a synthesis of modern camera technology with the traditional fence configuration used prior to the implementation of camera tunnels. The objective of these changes was to pass more Chinook through the fence to maximize enumeration and improve confidence in population estimates while also reducing delays to migration. In comparison to tunnel imagery from recent years, underwater camera imagery was a slight compromise, however it was still more than adequate for species identification, size estimation (i.e., adult versus jack), and identification of origin (adipose clips). The fence count in 2019 was the second highest on record; although Chinook abundance in 2019 was high, this result is a testament to the efficacy of these modifications. Furthermore, estimation of origin and the adult/jack ratio were consistent with recent years which shows that camera imagery was suffice for effective enumeration. Overall, the fence modifications were beneficial to both Chinook and enumeration efforts and will continue to be used moving forward. Nonetheless, results from 2019 do not overrule the need to develop season-specific run timing curves and expansion factors.

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 in 2018. However, results in 2019 were a different story. Although an upgraded camera system in the fishway provided continuous, high-quality imagery for Chinook enumeration (a subsample of low-quality footage was used in 2018 as a pilot), comparison of PIT tag detections between years suggested that far fewer adult Chinook utilized the fishway for ascending Skutz Falls in 2019 than the previous year. This inconsistency between years suggests that river flow plays a strong role in Chinook migration through Skutz Falls. Additionally, video and PIT tag data both suggested use of the fishway is disproportionately high by jacks and adult hatchery Chinook. Results from 2019 indicated further development of the site is needed to obtain a larger, more representative subsample of the Chinook population, which is required for generating reliable population estimates.

Recommendations

Tagging targets of wild juvenile Chinook smolts may need to be reconsidered. Despite an earlier start to beach seining operations in 2019, complications with stress tolerance of juveniles resulted in delays to operations. These complications shortened the window for tagging smolts in the estuary, so only 84 percent

of the tagging target was achieved. A larger seine has been purchased for future seasons but net size was ultimately limited to the capacity of boats being used for beach seining. If the larger net does not increase catch rates, a tagging target of 4,000 wild Chinook smolts should be adopted for the remainder of the study. By contrast, no changes are recommended to hatchery tagging operations.

The PIT tag antennas were double-checked and defective equipment was repaired and replaced prior to the fall 2019 escapement season. Nevertheless, discrepancies between detections on the lower array and upper array suggested the upper array may not have been functioning at the efficiency indicated by Skutz Falls detections (which may have been a result of the small number of tags resampled at Skutz Falls). This caused issues for assigning upstream passage but the dual transect system was still able to detect 100 percent of the tags resampled upstream. These results further support the need to increase the sampling rate at Skutz Falls, because a higher sampling rate could potentially reduce uncertainties encountered at the mainstem array in addition to improving escapement estimates from Skutz Falls. An improved antenna system has been purchased for installation in the fishway prior to the 2020 season, but sampling of the bypass channel should also be considered.

In-river tagging of mature Chinook may be required for effective population estimation at Skutz Falls. Adult tagging in Cowichan Bay was insufficient for these purposes and should not be relied upon in the future but could still be considered to further supplement the number of tags in returning adult Chinook. Beach seining downstream of the counting fence should be revisited in 2020 but if catch rates are poor this objective will need to be reconsidered.

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Appendix 1

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.	Low – 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 2 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	Low – 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	Low to mod – 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 in	Low to Mod This may partially explain some of the tags which failed to pass the site as they could have been shed	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

	brood but none on the floor of the pond.	between the initial detection and passage.	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.	Low to Mod 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 could be investigated further	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 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	Mod 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.

2019 Cowichan River Chinook escapement estimate by category, age and origin.

2019				Age 2	Age 3	Age 4	Age 5	TOTAL
Natural Spawners								
	Estimated	Male		3040	4262	4324	31	**11657**
		Female		94	1065	5045	63	**6267**
		Total		3134	5327	9369	94	**17924**
		Hatchery (clipped)		392	1244	446	0	**2082**
Brood Stock				Age 2	Age 3	Age 4	Age 5	
		Male		3	133	64	0	
		Female		0	126	252	4	
		Total		3	259	316	4	**581**
		Hatchery (clipped)		0	54	15	0	**69**
Below Fence+ FSC				Age 2	Age 3	Age 4	Age 5	
***Includes all lower	Estimated	Male		160	743	754	5	**1662**
river spawners		Female		6	186	879	11	**1082**
and losses***		Total		166	929	1633	16	**2744**
		Hatchery (clipped)		21	217	78	0	**315**
Grand Totals				Age 2	Age 3	Age 4	Age 5	
		Male		3203	5137	5142	37	**13519**
		Female		100	1377	6176	77	**7730**
		Total		3303	6514	11318	114	**21249**
		Hatchery (clipped)		413	1515	539	0	**2467**
		Total Jacks		**3303**				
		Total Adults		**17946**				