Tranquil Creek escapement and origin of adult Chinook salmon (*Onchorhynchus tshawytscha*) in 2019.

Prepared for:

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Executive Summary

Chinook salmon (*Oncorhynchus tschawytscha)* were captured, marked and recaptured alive on 12 occasions between September 20th, and October 12th, 2019 at Tranquil Creek, Clayoquot Sound. Captured individuals were externally tagged with both a uniquely numbered Floy tag and radio-tag. Snorkel surveys to assess spawning numbers and recover marked and unmarked carcasses occurred from August 28th to November 9th, 2019. A total of 45 adults over 460 mm post-orbital hypural length were marked with Floy tags along with 19 live recaptures. Of the 45 adults, 21 were female and 24 were male. The population was found to be demographically open with CloseTest (Stanley and Burnham, 1999; Stanley and Richards, 2005) and required an open population model to estimate abundance. The encounter history data was tested using U-CARE (Cooch and White (Eds.), 2016) and found no heterogeneity issues related to the capture or survival assumptions of the Cormack-Jolly-Seber models and thus permitted the use of the fully time-variable starting model.

Two models receiving 99.7% of the AIC support emerged from the open population mark-recapture analysis with POPAN (Schwarz and Arnason, 1996) in Program MARK (Cooch and White (Eds.), 2016). The model *{ϕ (.) P (t) Pent (t)}* received 80.7 % of the AIC support. This model shows that *apparent survival (ϕ)* was constant and was not group dependant. The model also shows both the *capture probability (P)* and *probabilities of entry (Pent)* varied with time and were also not group dependant. The second model *{ϕ (g.) P (t) Pent (t)}* received 19.0% of the AIC support. This model is the same as the first except for the identification of group differences in *apparent survival (ϕ)*. Weighted averaging of the models estimated a total of 108 Chinook salmon (SE=25.8, 95%CI 37 – 180, CV= 24%) spawners >460 mm POH in Tranquil Creek in 2019. The two groups were made up of 51 females (SE=17.4, 95%CI 17 – 85, CV= 34%) and 57 males (SE=19.1, 95%CI 20 – 95, CV= 33%).

33 adult Chinook (>460 mm POH) were externally tagged with MCFT2 coded radio transmitters. Tagged individuals consisted of 18 females and 15 males. Radio telemetry surveys tracking tagged individuals occurred from September 22nd to November 3rd, 2019. A total of 29 surveys occurred within this period. Due to emigration from the survey area and tag-loss, data from only 28 tagged adults was used to produce a survey life estimate of 16.5 days (SE= 1.22).

Examination of otoliths for thermal batch marks applied to local hatchery stocks was conducted on the six otoliths collected from carcasses recovered during snorkel surveys. Two of the six otoliths, one female and one male, were marked and found to be strays originating from the Robertson Creek hatchery. The remaining four otoliths were unmarked and are assumed to be natural-origin Tranquil Chinook.

Introduction

A modern mark-recapture (MR) experiment was conducted to estimate the number of Chinook salmon (*Oncorhynchus tschawytscha*) returning to spawn at the Tranquil Creek, Clayoquot Sound, Canada. This was part of a two-stream study initiated in 2019 to evaluate further afield the validity of a new method of indexing west coast of Vancouver Island (WCVI) escapement. Simultaneously, an area-under-the curve (AUC) estimate, parameterized with radio tag measures of survey life (residence time) and observer efficiency (O.E. or "detection probability"), was calculated for comparison with the Agency method. The AUC method is widely used by the Canadian Department of Fisheries and Oceans (CDFO) to enumerate escapement to streams along the coast of British Columbia. Snorkel and radio-telemetry surveys were conducted throughout the reaches accessible to the returning salmon.

Concern over the validity of WCVI Chinook estimates contributed to the establishment of the Pacific Salmon Commission Sentinel Stocks Program and the resultant investigations at the Burman River, Nootka Sound, from 2009-2018 to identify and validate a new index. The method is now being trialed at two other sites. The first study site is at Conuma River in Nootka Sound, where there is habitat and migration behaviours similar to the Burman River and a large hatchery population facilitating MR. The second study site, Tranquil Creek, is a much smaller watershed with very small Chinook salmon numbers returning and migration behaviour and habitat that are dissimilar to those observed at the Burman and Conuma Rivers.

The concerns of validity of the escapement estimates arise from the determination of two critical parameters when employing the AUC method: observer efficiencies and residence time (survey life). The AUC requires empirical measures of both O.E. and residence time since these parameters vary annually by species, stream, and year (Perrin and Irvine, 1990; English et al., 1992). Survey life and observer efficacy parameters were estimated by deploying radio tags. Observer efficiency was estimated by comparing the number of radio tags observed during snorkel surveys to the number of radio-tagged Chinook known to be present and alive in the study area.

The over-arching primary goal of the project was to determine if the new lower cost Discounted Survey Life (DSL) method might be applied to a small Chinook salmon population lacking freshwater migration stopover habitat in contrast to the Burman River studies from 2009-2018. The Tranquil Creek project objectives were to estimate the size of the small spawning population with: 1) a mark-recapture study meeting the Chinook Technical Committee criterion of a Coefficient of Variation (CV) of <15%, and; 2) a parameterized AUC method, as a fail-safe in case the mark-recapture study failed due to small population size, and; 3) population demographics characteristics of age, origin and sex such that a 5% change would be detected 19 out of 20 times.

Study Area

The Tranquil Creek watershed is located approximately 20 kilometers north-northeast of the town of Tofino on the west coast of Vancouver Island (WCVI), British Columbia, Canada (Figure 1). The watershed drains a total area of roughly 62 km^2 and flows south into Tranquil Inlet (Balfour and Hutchinson, 2019). Tranquil Creek is within in the Ha'houlthee (traditional territory) of the Tla-o-qui-aht First Nation. Tranquil Creek is an alluvial 4^{th} order stream and extends roughly 5.5 km inland from Tranquil Inlet (8.3 km upstream) where it is joined by its main tributary, Paradise Creek. Tranquil creek extends upstream a further 3 km where it originates from a series of small unnamed cirque lakes at approximately 430 m ASL (Eggers and Ferguson, 2018). Paradise Creek, in the smaller western valley, originates from Paradise Lake at an elevation of 850 m ASL and is the uppermost of a series of small cirque lakes (Eggers and Ferguson, 2018). The watershed is a hybrid as the creek is largely snow-melt fed in spring but by summer is only influenced by rainfall. ClimateWNA (http://www.climatewna.com/) estimates the annual precipitation at Tranquil averages over 3.3 m.

The anadromous barrier to salmonid migration, an impassable waterfall, is located approximately 6.5 km upstream from tidal water. Logging commenced in 1968 within the Tranquil watershed with the lower reaches and riparian zone logged extensively along the course of the river (Figure 2).

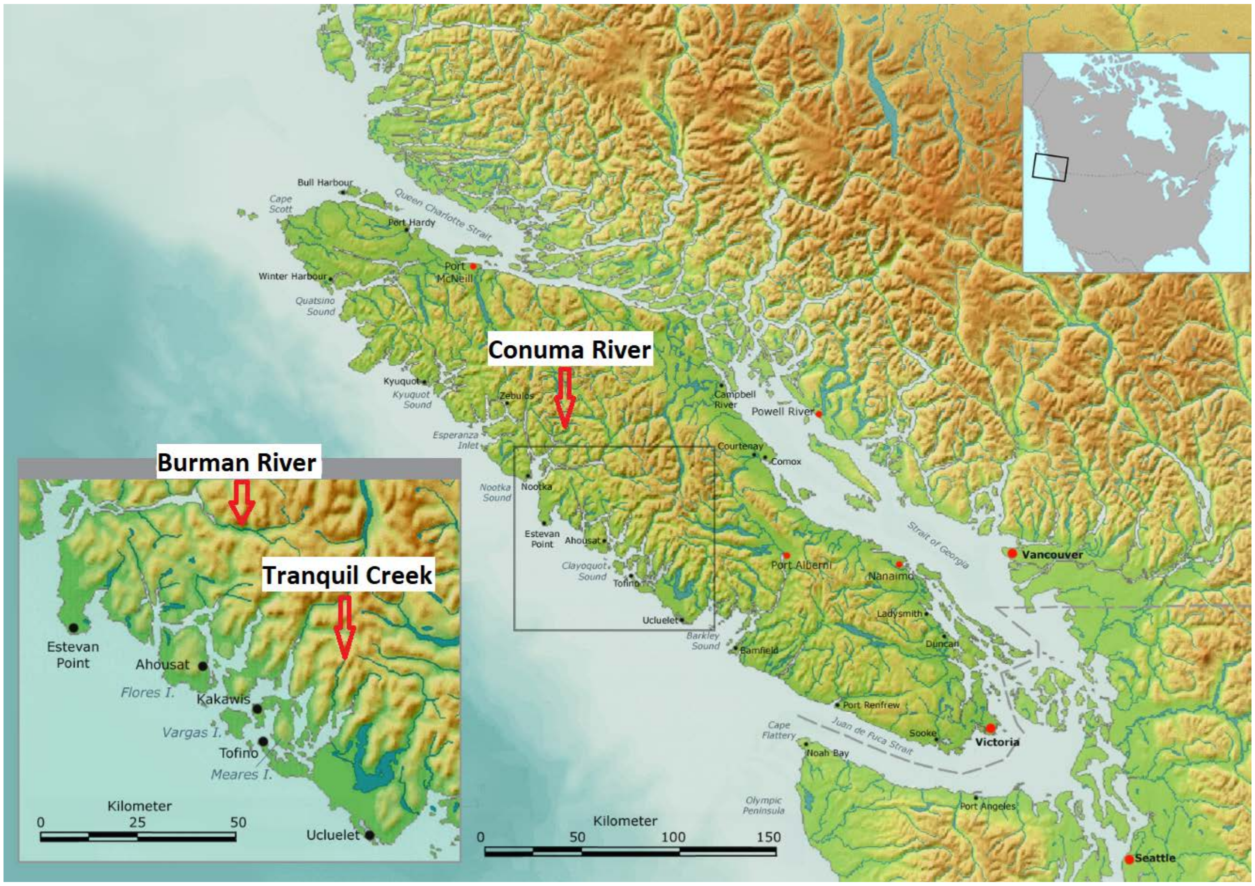

Figure 1. Locations of Tranquil Creek, Burman River, and Conuma River streams on the west coast of Vancouver Island.

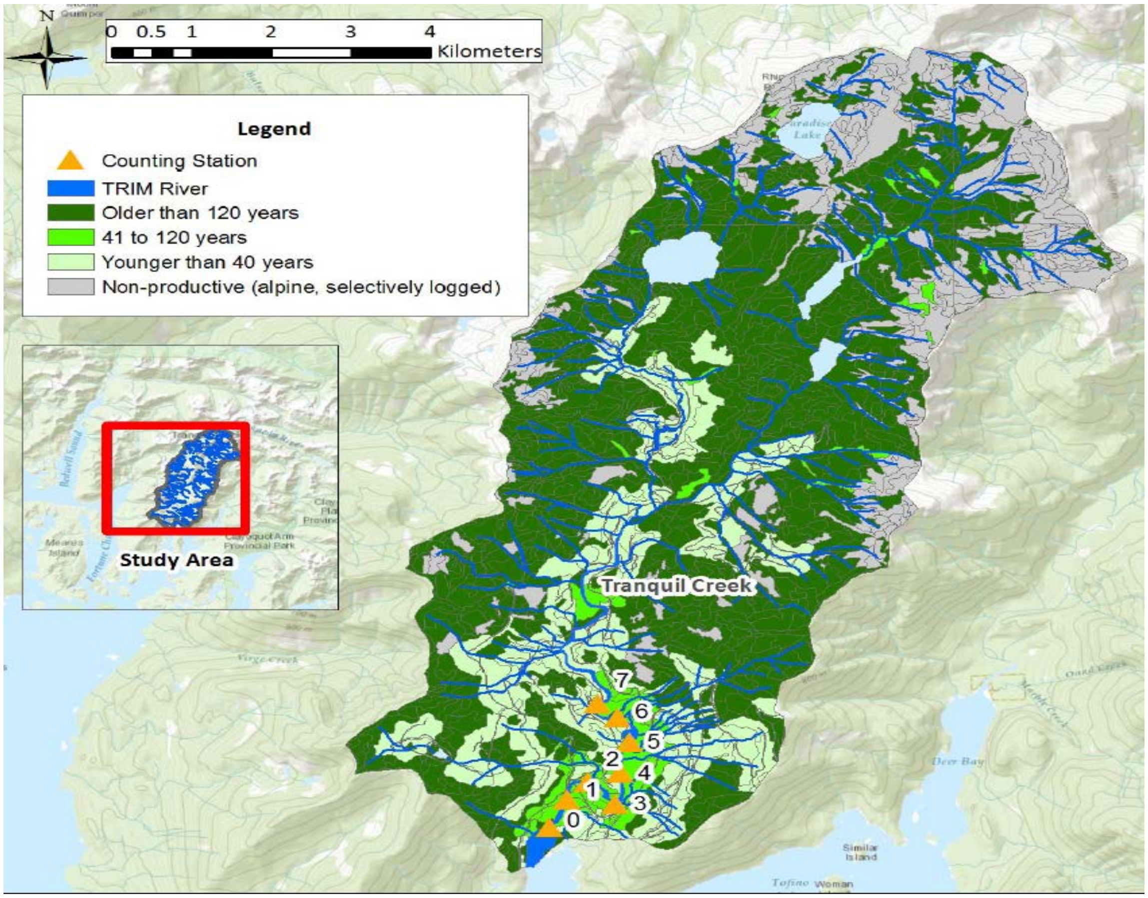

Figure 2. Land cover alterations and start of stream counting sections ("Counting Station") at Tranquil Creek, Clayoquot Sound. Date of reference for legend is 2016 (Smith & Wright, 2016).

Tranquil Creek Chinook Salmon are a coastal stock with an ocean-type life-history. The population belongs to the Southwest Vancouver Island Conservation Unit (CU) which is one of the three WCVI Chinook salmon groups currently defined by similarities among life histories, ecology and genetics (Holtby and Ciruna 2007) (Figure 3). Chinook salmon (*O. tshawytscha*) and coho salmon (*Oncorhynchus kisutch*) are observed to the anadromous barrier at Km 3.5. Chum salmon (*Oncorhynchus keta*) and the occasional sockeye salmon (*Oncorhynchus nerka*), likely strays from the nearby Kennedy sockeye population, are found in the lower reaches of the stream. Tranquil Creek also observes a winter run of steelhead trout (*Oncorhychus mykiss*). Hatchery supplementation of Chinook salmon began in 1991 and continued steadily until 2003 with an average of 116,824 released every year with the exception of 2002 when there was no Chinook release. From 1993 to 2003 the Tofino Enhancement Society (TES) implemented two hatchery release strategies: in-river releases and sea-pen reared releases. The sea-pen juveniles were held in net-pens within the Tranquil estuary to continue feeding and on average were released at 10.0 grams. The in-river releases were transferred directly from the hatchery into the lower river and were much smaller with an average release weight of 4.91 grams. Following 2003 there was a break in enhancement. Regular enhancement resumed in 2009 and did not include sea-pen rearing. The average number of age zero Chinook released from 2009 to 2017 was 37,377 with an average weight of 4.93 grams. With the exception of the releases from 1996 – 1999, none of these hatchery-raised Chinook received an external mark or coded wire wag (CWT) implant.

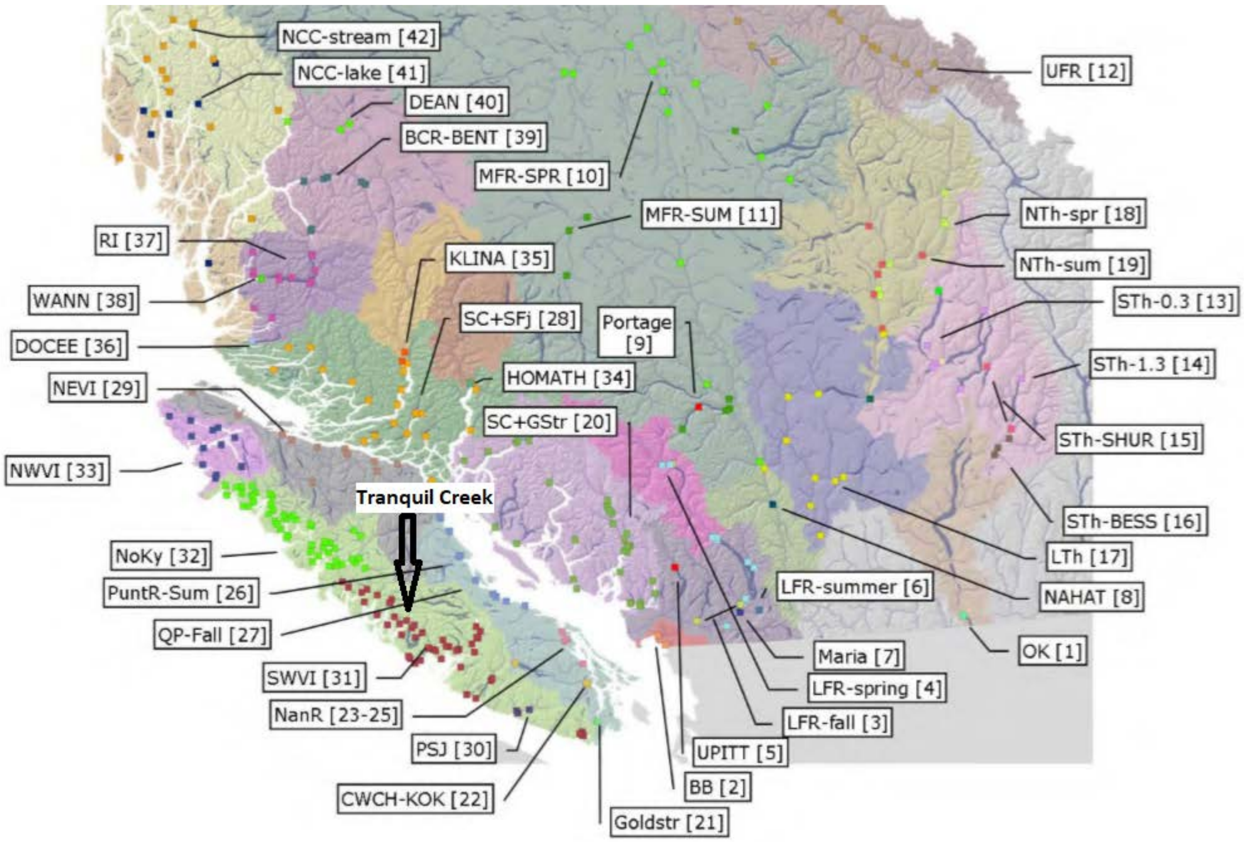

Figure 3. Location of the Tranquil Creek on the west coast of Vancouver Island (WCVI) and Chinook salmon Conservation Units (CU's) identified by Holtby and Ciruna (2007).

Methods

The primary method for population size estimation was a modern mark-recapture (MR) experiment (Velez-Espino et al., 2015) conducted with individually marked live subjects. This MR experiment was backed up with a visual area-under-the-curve (AUC) study with the key parameters estimated by radio-telemetry (English et al., 1992). The telemetry studies were undertaken for insurance against potential failure of the mark-recapture experiment due to anticipated very small population size. Population sizes estimated independently with the two different methods were compared to the traditional DFO WCVI snorkel survey-based Area-Under-the-Curve (AUC) method that employs subjective detection probability (observer efficiency) and residence time (survey life) parameters.

The sampling design enabled the option of employing either closed or open population models depending on whether or not the key assumption of closure required by the former could be demonstrated by the data with CloseTest (Stanley and Burnham 1999 Stanley and Richards 2005). An additional radio-tag study occurred simultaneously to provide information on the residency time of Chinook salmon within the Tranquil Creek survey area: the survey area being the anadromous spawning grounds that don't receive a saltwater intrusion.

Snorkel surveys

Snorkel surveys of the stream channel from km 3.5 to tidewater, counting sections seven to zero (Figure 2), occurred on 17 occasions from August 30, 2019 through November 9, 2019. Paired snorkellers counted and recorded the number of marked and unmarked Chinook salmon in each 500 m counting section along with the number of other salmon species observed. Jacks were counted separately from the adults. The marked fish were those bearing an external radio tag. Snorkellers proceeded in a downstream direction and stopped at the end of each habitat feature (i.e. riffle, pool, glide) and river section to discuss and confirm the number of fish each observed. Chinook carcasses encountered by surveyors were recovered and sampled.

Marking and tagging

Chinook salmon were captured and recaptured by beach seine deployed from a 16 foot motorized skiff at three separate pools within Tranquil Creek. Chinook captured for the first time were externally tagged with both a uniquely numbered Floy tag and a radio tag, measured for post-orbital hypural (POH) lengths to the nearest five millimeters, visually sexed, and given a tag-batch specific mutilation mark prior to being released. The mutilation marks were hole-punches at varying locations on the opercula to permit recognition in the event of tag loss. Floy tags were individually numbered with an 80 lb monofilament core secured with a size "J' Jinkai metal fishing crimp sleeve. The fluorescent-coloured tags were installed directly through the dorsal fin pterigiophores. Scale samples were also taken from every individual during their first capture for ageing.

Sampling with the beach seine commenced on September 20th, 2019 and continued until October 12th, 2019. No additional sampling occurred after October 12th. A large rain event starting October 14th produced flows and a discharge too large to continue fishing (Figure 4). Although flows subsided to a low enough level to allow for further sampling on October 23rd, the snorkel survey conducted that day found the majority (14/17) of the Chinook salmon to be located upstream of the three pools sampled.

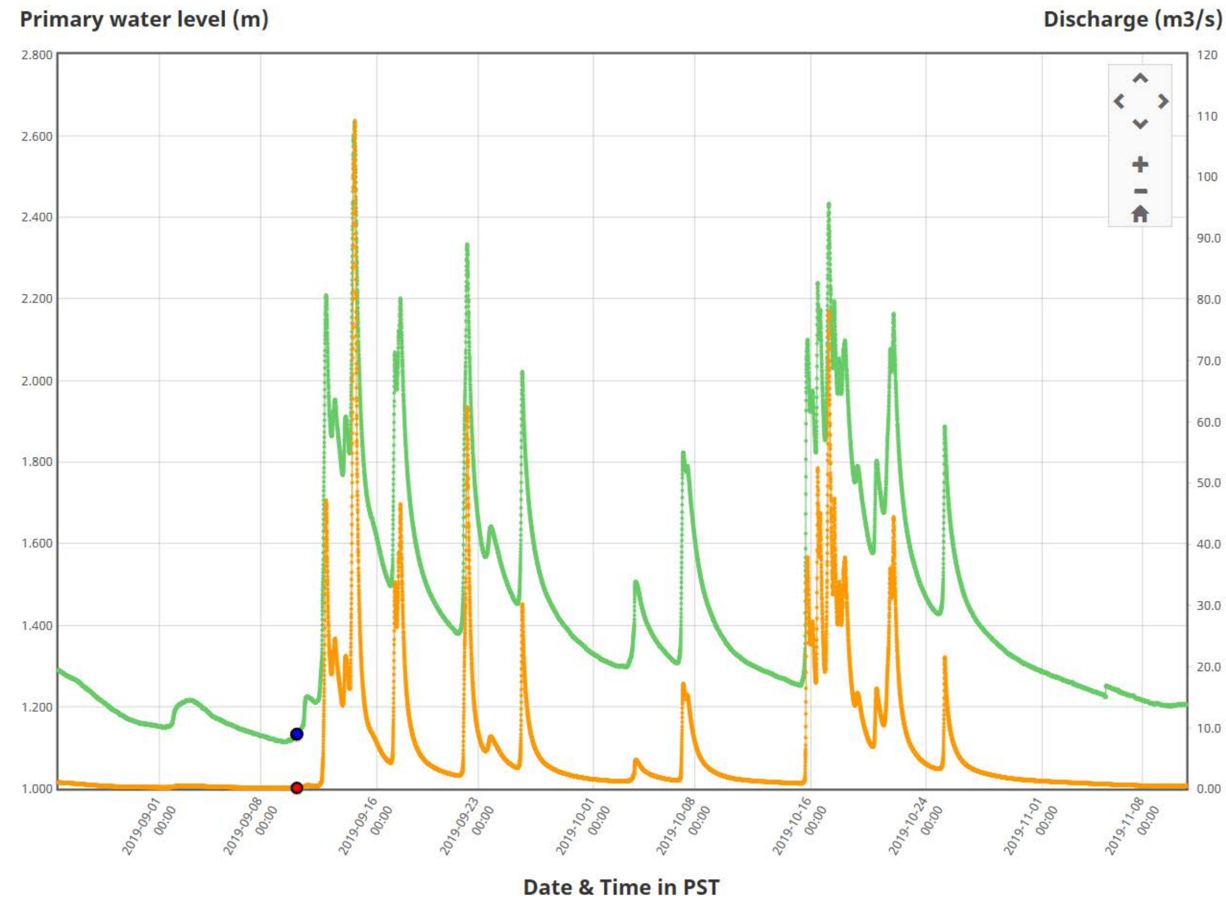

Figure 4. Tofino Creek discharge (orange) and water level (green) from August 26, 2019 to November 10, 2019.

Radio-Telemetry

34 MCFT2 coded radio transmitters with both the motion sensor and external mounting option were provided by Lotek Wireless Incorporated. The tags were mounted externally below the dorsal fin with two uniquely coded Peterson-discs attached on the side opposite of the radio tag. Each tag emits a unique radio code on one of the following frequencies: 150.20 Hz, 150.48 Hz, 150.60 Hz, 150.64 Hz, and 151.30 Hz. The individual codes emitted on specific frequencies allow for the tracking of each Chinook individually and therefore determination of their exact location within the survey area. Additionally, the motion sensor option allowed for the identification of whether the tagged individual was active (alive) or inactive (dead) as the code emitted by the inactive tag will have the number one in front after 20 hours of not detecting motion (the individual has died and no longer moved). With the limited number of radio tags, the first 34 Chinook captured received both a radio tag and a Floy tag. The remaining individuals captured for their first time received only a Floy tag with the exception of the re-deployment of four recovered radio tags on four captured Chinook on October 9th, 2019.

Radio-telemetry surveys commenced on September 22nd 2019 following the deployment of the first batch of radio tags on September 20th, 2019. During each survey, two technicians would conduct a stream walk while carrying a SRX600 radio receiver and antenna, provided by Lotek Wireless Incorporated, along the entire survey area except for the cascades and pools above the cascades just below the anadromous barrier (waterfall) in section seven. The receiver scanned through each of the five frequencies at 10 second intervals and would show the code, the channel (frequency) of the code, and the power of the signal once the tagged individuals were in range. The technicians would record the code, channel, power and which section of the creek they're in for each code detected. The time of death, when indicated by an inactive code signal, was estimated by subtracting 20 hours from the time of the first detection of the inactive code signal and then taking the mid-point in time from the previous survey. Active tags that disappeared from the survey area prior to transmitting an inactive code signal where given a death date the day after they were last detected.

Radio-telemetry and carcass recovery surveys occurred simultaneously with the snorkel surveys where technicians would accompany the snorkelers on foot. Carcasses recovered either from the bottom of the creek or found alongside the shore were sampled. Recovered carcasses were sampled for sex by dissection, otoliths, POH length, mark status and tag number, scales, categorical egg retention rates in females and DNA. Otolith recovery allows for the determination of their origin as the hatchery-raised Chinook otoliths are coded with thermal markings. Chinook without an adipose fin clip or thermal markings were assumed to be natural-origin Tranquil Chinook.

AUC Escapement Estimate

The AUC spawner escapement estimates were calculated using the average of the raw adult Chinook counts from snorkel surveys that occurred on the same day. Three separate survey life estimates were used in the calculation to produce three respective adult Chinook escapement estimates. We used the survey life estimate produced from the radio-telemetry surveys, the DFO WCVI Chinook survey life standard of 25 days and an arbitrary survey life of 21 days as a halfway point between the two estimates for comparison. The observer efficiency (O.E.) used to account for the Chinook salmon not observed by snorkel surveyors but are within the survey area was estimated by dividing the number of radio-tagged Chinook observed each snorkel survey by the number of live radio-tagged Chinook known to be in the river from the radio-telemetry surveys. These O.E.'s were applied to the average daily Chinook counts prior to calculating the area under the spawner curve.

Discounted Freshwater Life

The Discounted Freshwater Life (DFL) is the index for survey life which represents 100% of the time the Chinook are in the freshwater spawning grounds. It is defined as:

$$DFL = \frac{unadjusted\ AUC\ estimate}{mark - recapture\ population\ estimate}$$

Results

Periodic snorkel surveys began on August 30th 2019 to identify the arrival of the Chinook salmon into the survey area with zero Chinook observed during this initial survey (Figure 5). A single Chinook was observed during the second survey on September 10th. Two days later on September 12th the first freshet occurred resulting in increased discharge (Figure 4) and the first large movement of Chinook into the Tranquil Creek.

Marking commenced on September 20th 2019 once the flow at Tranquil subsided enough to allow for safe fishing. Marking finished on October 12th 2019 with a total of 12 sampling events during this period. The intervals between live sampling events were 1, 4, 3, 2, 1, 1, 2, 4, 1, 2, and 1 days from September 20th.

Starting on September 22nd 2019, regular radio-telemetry surveys occurred within the survey area following the initial radio tags being installed on September 20th. A total of 29 radio-telemetry surveys were conducted. The intervals between radio-telemetry surveys were 4, 1, 1, 1, 2, 1, 1, 1, 1, 2, 1, 1, 1, 2, 3, 2, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, and 6 days from September 22nd. The final radio-telemetry survey occurred on November 3rd following the detection of the last known active radio-tag transmitting an inactive code. The final number of Individual Encounter Histories (IEH's) used for modelling in POPAN was 45 consisting of 21 females and 24 males. The days where zero Chinook were captured were excluded from the model. Therefore, the intervals between sampling days used for the modelling was 5, 3, 3, 3, 5, 2, and 1 days from the first sampling date on September 20th, 2019.

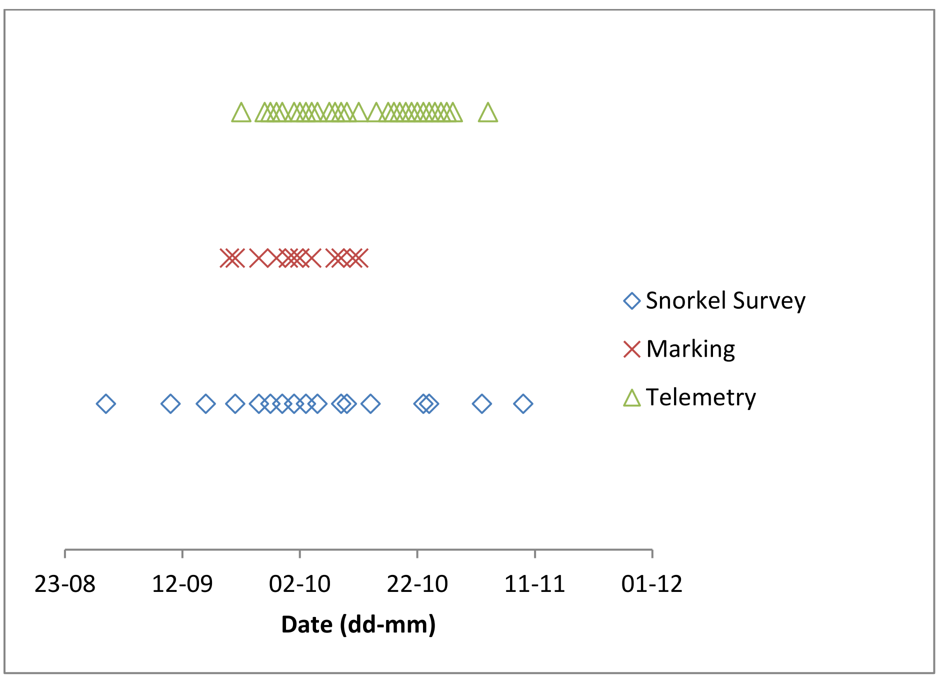

Figure 5. Timing of mark-recapture events, snorkel surveys and radio-telemetry surveys at Tranquil Creek in 2019.

Mark-Recapture

85 encounters with Chinook salmon were recorded during the live mark-recapture experiment. 11 of the 85 encounters were with jacks while the remaining 74 encounters were with adult Chinook having post-orbital hypural (POH) lengths greater than 460 millimeters. Overall, 45 adult Chinook salmon were marked with Floy tags and released. 21 of these adults were females while the remaining 24 were males. 37 of these 45 adults encountered also received a radio tag in addition to the Floy tag. 18 females, 15 males and four jacks received these radio tags. Upon each individual's initial encounter, scale samples were taken and POH lengths were recorded (Figure 6). 17 of the marked individuals were recaptured alive, some more than once, and released. These encounters were summarized as Individual Encounter Histories (IEH's). Jacks were not included in the analysis due to the extremely small sample size (six) and limited encounters.

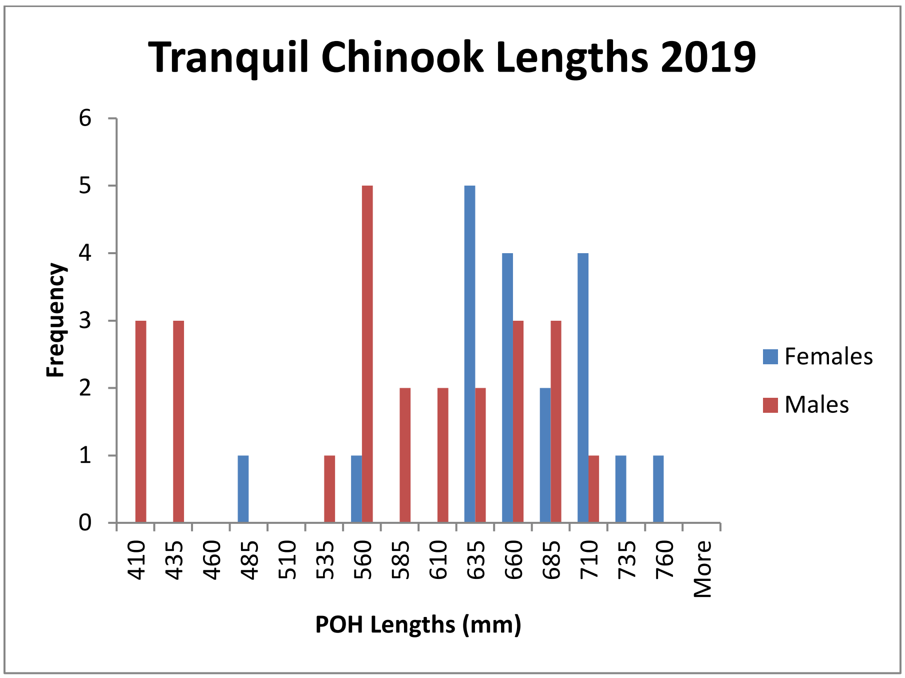

Figure 6. Post-Orbital Hypural (POH) length frequency distribution of Chinook salmon captured in Tranquil River in the Fall of 2019.

Among females, none were encountered more than four times. One was captured four times, four were captured three times, four were captured twice and the remaining 12 females were only captured once. Among males, two were captured three times, six were captured twice, and the remaining 16 were only captured once. Of the 45 adults encountered, only one had an adipose fin clip. Unfortunately this individual was not captured again nor had the carcass recovered for additional sampling.

Carcass Recoveries

A total of six Chinook carcasses were recovered during the snorkel surveys and carcass recovery/radio telemetry surveys. The recovered carcasses had their POH lengths recorded coinciding with the removal of scales, otoliths and a piece of flesh for analysis at the Pacific Biological Station by the Canadian Department of Fisheries and Oceans (CDFO). The lack of carcass recoveries can likely be attributed to two primary factors. First, the Tranquil watershed was heavily logged causing the system to experience large fluctuations in discharge as a direct result of rainfall. In layman's terms, the system is very "flashy" with river discharge increasing drastically for relatively short durations during rainfall events resulting in spawned out salmon being rapidly flushed out of the survey area and unable to be recovered. Second, the high abundance of black bears (*Ursus americanus*) observed predating on the salmon daily. However, the most common salmon species we observed being consumed by the bears were Chum due to their relatively high abundance.

Radio-Telemetry

The tagging of Tranquil Chinook with radio tags commenced on September 20th 2019 and ended on October 9th. A total of 37 tags were deployed with four of these being the redeployment of recovered tags. Of these 37, 18 were adult females, 15 were adult males and four were jacks. There were two instances where a spawned out Chinook had its radio tag get caught in the seine net and detach and was unable to be reattached due to its ragged spawned-out condition. There were another two instances where two recaptured Chinook had lost their radio-tags due to unknown reasons.

Following tagging, two of the 37 radio-tagged Chinook emigrated from the study area and were never seen again. Both were tagged on September 25th. The first to emigrate was a captured lethargic female who, following being tagged, was released and was very slow to swim away resulting in a poor release condition designation. The second to emigrate was a healthy appearing female which was released in good condition following tagging. Both of these individuals were tagged at the most downstream sampling site which is less than one kilometer away from the tidewater. As a result of tag loss and emigration from the survey area, data from 31 of the 37 radio-tagged Chinook was used to produce survey life estimates. The data suggests that the survey life of the adult Tranquil Chinook was 16.5 days and 14.3 days for jacks (Table 1).

Table 1. 2019 Survey Life estimate (days) of adult and jack Tranquil Chinook salmon.

	Mean	Standard Error	Median	Mode	Minimum	Maximum	Sample Size
Adults	16.5	1.22	18.5	19	6	29	28
Jacks	14.3	2.40	13	N/A	11	19	3

Tag-Loss

Tag loss of the Floy tags did not occur. Every recaptured individual throughout the duration of the project retained their Floy tag. The recovered carcasses also retained their tags. Although not significant, tag loss of radio tags did occur. Radio tag loss was confirmed from individuals captured with missing radio tags and further confirmed by the radio-telemetry data showing the active (live) radio signal ceasing prior to their capture. Of the 37 Chinook which received a radio tag, there were two confirmed tag losses. Both of the tag losses were from individuals tagged on September 20th: an adult male and a jack. The adult male was recaptured on October 11th yet its radio tag was last detected emitting an active "live" signal on October 9th and continued to emit an inactive signal until October 15th. The jack was recaptured on October 12th yet also had its radio signal last detected emitting a live signal on October 7th and was no longer being detected in the survey area after October 10th.

Hatchery Removals

Hatchery removal of adult male and female Chinook for broodstock from Tranquil Creek was attempted by the Tofino Enhancement Society (TES) on October 12th 2019. Unfortunately, all the adult Chinook captured had either already spawned or were not yet ready to spawn. The usual strategy of the TES is to hold the Chinook that aren't ready to spawn individually in custom-made meshed tubes at the bottom of a deep pool in the creek until they're ready to spawn. However, due to a large rain storm forecasted in the following days, no Chinook were held. Therefore, we did not observe any loss-on-captures (LOC's) that needed to be censored from the POPAN modelling.

Area-Under-the-Curve (AUC) Escapement Estimation

Beginning on August 30th 2019, a total of 17 snorkel surveys were conducted with the final survey occurring on November 9th 2019. The average of the daily raw observations from each snorkel surveyor had the daily average O.E. applied to the counts to produce a spawner curve for adult Tranquil Chinook (Figure 7). When no O.E. was estimated for a survey, the season average O.E. was applied. For example, there were no radio-tags deployed during the September 21 snorkel survey and therefore no O.E. estimated resulting in the season average O.E. of 0.656 to be applied to the raw counts. The graph was used to calculate the area under the spawner curve and was found to be 2325.7 fish·days. The unadjusted AUC was found to be 1600.75 fish·days. The unadjusted AUC produced by DFO for Tranquil Chinook in 2019 was 1596 fish·days. The number of adult Chinook was finally calculated by multiplying the adjusted area by the estimated survey life (or "residence time"). Three survey life estimates were used to produce three adult Tranquil Chinook escapement estimates for 2019 (Table 2). The first survey life applied was the estimate produced by the radio-telemetry surveys of 16.5 days which equated to an adult Chinook escapement estimate of 141. The second survey life applied was 25 days which equated to an escapement estimate of 93. A third escapement estimate was produced by using a survey life halfway between the DFO standard and the radio-telemetry estimate which was 21 days and produced an escapement estimate of 111.

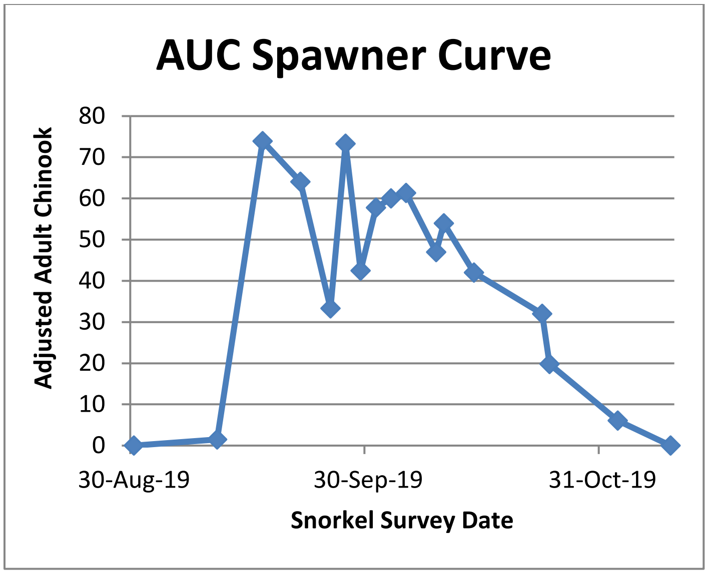

Figure 7. Tranquil Creek Chinook spawner curve. Adjusted adult Chinook are daily raw counts with applied O.E.'s.

Table 2. Tranquil Creek adult Chinook escapements using varying Survey Life estimates.

	Survey Life	**Adult Chinook Escapement Estimate**
Estimate 1	16.5	141
Estimate 2	21	111
Estimate 3	25	93

The observer efficiency (O.E.) applied to the estimates was developed from the snorkel survey and radio-telemetry survey data. In total, 15 observer efficiency estimates (Table 3) were produced from 10 snorkel survey occasions with the average O.E. between all surveyors being 0.656 (Table 4). During snorkel surveys that didn't coincide with a radio-telemetry survey, the number of radio-tags known to be in the river from the most recent radio-telemetry survey was applied. For example, on September 22nd there were four live radio tags in the survey area and the same four were live in the survey area on the 26th yet a snorkel survey was conducted on the 25th. Thus, the number of radio-tags observed on the 25th (three tags) was divided by the four live tags known to be in the river to produce an observer efficiency of 0.75.

Table 3. Snorkel surveyor Observer Efficiencies (O.E.) calculated from the number of radio tags counted during the snorkel escapement survey versus the known live-tags within the river.

Date	Swimmer	Tags Observed	Expected # of Tags	Observer Efficiency
September 25, 2019	4	3	4	0.75
September 27, 2019	2	4	10	0.40
September 27, 2019	3	5	10	0.50
September 29, 2019	1	9	10	0.90
September 29, 2019	6	7	10	0.70
October 1, 2019	1	15	20	0.75

October 1, 2019	3	12	20	0.60
October 3, 2019	3	11	20	0.55
October 3, 2019	5	11	20	0.55
October 5, 2019	6	21	28	0.75
October 9, 2019	2	21	27	0.778
October 9, 2019	4	21	27	0.778
October 10, 2019	4	20	27	0.741
October 10, 2019	5	20	27	0.741
October 23, 2019	1	2	4	0.50
October 23, 2019	4	2	4	0.50

Table 4. Seasonal mean Observer Efficiency (O.E.) estimate between all snorkel surveyors.

	Mean	**Standard Error**	**Maximum**	**Minimum**
Observer Efficiency	0.656	0.035	0.9	0.4

POPAN Modelling

The mark-recapture data was analysed using the POPAN Jolly-Seber (Schwarz and Arnason, 1996) model in Program MARK. The model {Phi (.) P (t) Pent (t)} (constant apparent survival probability, time variable capture probability, and time-dependant probability of entry into the study area) received 80.698% of the AIC weight (Table 5). The model {Phi (g*.) P (t) Pent (t)]} (group-specific constant apparent survival probability, time-dependant capture probability and entry) received 18.951% of the AIC weight while the remaining three models combined received less than 4% of the AIC weights. As shown in Table 6, the weighted average of the top two models resulted in a gross population estimate of 108 adult spawners (SE= 25.8, 95%CI 37 – 180, CV= 24%) greater than 460 mm POH.

Table 5. Summary of POPAN Jolly-Seber model (Arnason and Shwarz, 1999) results from Program MARK for Tranquil Creek adult Chinook escapement in 2019.

Model	AICc	Delta AICc	AICc Weights	Model Likelihood	Num. Par	Deviance
{Phi(.)P(t)pent(t)}	208.7624	0	0.80698	1	13	-35.0137
{Phi(g.) P(t)pent(t)}	211.6601	2.8977	0.18951	0.2348	14	-35.2523
{Phi(.)P(t)pent(gt)}	219.6558	10.8934	0.00348	0.0043	17	-37.3895
{Phi(.)P(g*t)pent(t)}	229.2238	20.4614	0.00003	0	21	-43.3023
{Phi(g.)P(gt)pent(t)}	232.6335	23.8711	0.00001	0	22	-44.1744

Table 6. POPAN open mark-recapture estimates of adult Chinook escapement into the Tranquil Creek watershed in 2019.

Parameters	**Estimates**	**SE**	**LCI**	**UCI**	**CV**
Females	51	17.4	17	85	34%

Males	57	19.1	20	95	33%
Adults	108	25.8	37	180	24%

Goodness of Fit Testing and Closure Test

The program U-CARE (**U**nified **CA**pture-**RE**capture) developed by Rémi Choquet, Roger Pradel and Olivier Gimenez (Cooch and White (Eds.), 2016) was used for the goodness of fit (GOF) testing. Testing the groups for trap dependence and transience resulted in non-significant results for all groups (Table 7) meaning that all of the assumptions of the model were met. The U-CARE "Sum of tests over groups" option was used to estimate the variance inflation factor ($\hat{C}$) through dividing the overall chi-squared statistic (χ^2) by the overall degrees of freedom (df). The $\hat{C}$ was estimated to be 0.5653 showing an under dispersion of the data. $\hat{C}$ was set to one when modelling since it's less than one (Cooch and White (Eds.), 2016).

Table 7. Summary of U-CARE goodness of fit tests for Tranquil Creek adult males and females in 2019.

Test	Group	P-value
3.SR	Females	0.337 (one-sided test for transience)
	Males	0.165 (one-sided test for transience)
3.SM	Females	0.467
	Males	0.250
2.CT	Females	0.7675
	Males	0.542
2.SM	Females	0.333
	Males	1.0

Through the program CloseTest, the Stanley and Burnham (1999) closure test was applied to the dataset to test the assumption of closure. The test resulted in a P-value of 0.000 which strongly suggests the population is not closed.

Age and Origin

Scales from every Chinook captured were collected and sent to the Pacific Biological Station (PBS) for aging. The results are not yet available and the report will be updated when the information becomes available. Otoliths and DNA were collected from six recovered carcasses and were sent to the PBS to determine of the individual's origin. Two of the six Chinook otoliths recovered were marked and were identified as originating from the Robertson Creek hatchery (Table 8). The other four otoliths were not marked and are assumed to be natural-origin Tranquil Chinook.

Table 8. Summary of otolith status and origins from carcass recovers at Tranquil Creek in 2019

Source	Sex	POH Length (mm)	Mark Status	Facility

Deadpitch	Female	620	Not Marked	-
Deadpitch	Female	670	Not Marked	-
Deadpitch	Male	610	Not Marked	-
Deadpitch	Male	500	Not Marked	-
Deadpitch	Male	520	Marked	H-ROBERTSON CR
Deadpitch	Female	710	Marked	H-ROBERTSON CR

Discounted Freshwater Life

The Discounter Freshwater Life (DFL) index was calculated by dividing the raw AUC estimate of 1600.75 fish·days by the POPAN adult population estimate of 108 fish. The estimated DFL for the 2019 Tranquil Chinook was 14.8 days (Figure 8).

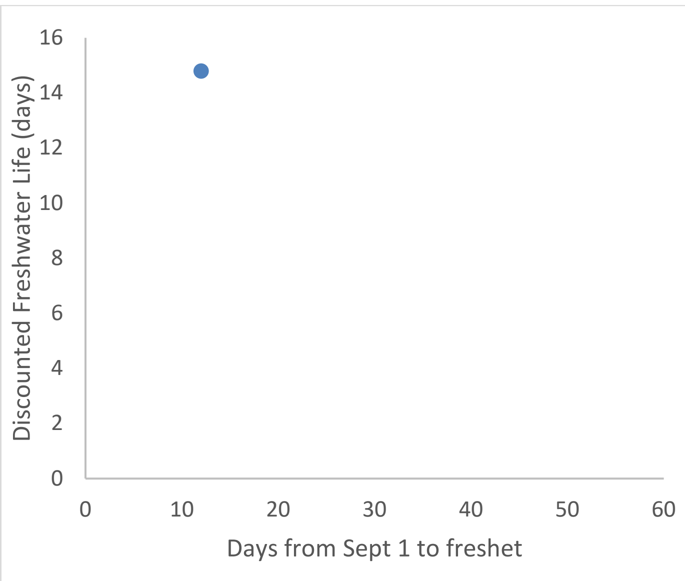

Figure 8. Discounted Freshwater Life Index for Tranquil Creek Chinook

Discussion and Recommendations

There are four assumptions underlying the Cormack-Jolly-Seber (CJS) models, and therefore the POPAN Jolly-Seber model applied in this study, that need to be met. The first is that every marked animal present in the population at time (i) has the same probability of recapture (p_i). Second, every marked animal in the population immediately after time (i) has the same probability of surviving to time (i+1). Third, marks are not lost or missed. The final key assumption is that all samples are instantaneous, relative to the interval between occasion (i) and (i+1), and each release is made immediately after the sample.

The first two assumptions are typically the most important in terms of goodness of fit (GOF) testing the model (Cooch and White (Eds.), 2016). Four tests were applied using U-CARE to examine whether the data met these assumptions. Test3.SR tests the hypothesis that there is no difference among previously and newly marked individuals captured at time *i* in the probability of being recaptured at some later time >i (Cooch and White (Eds.), 2016). Test3.SM tests the hypothesis that there is no difference in the expected time of first recapture between the "new" and "old" individuals captured at occasion *i* and seen again at least once (Cooch and White (Eds.), 2016). Test2.CT tests the hypothesis that there is no difference in the probability of being recaptured at *i*+1 between those captured and not captured at occasion *i*, conditional on presence at both occasions (Cooch and White (Eds.), 2016). Test2.SM tests the hypothesis that there is no difference in the expected time of first recapture between the "new" and "old" individuals captured at occasion *i* and seen again at least once (Cooch and White (Eds.), 2016). In summary, Test 3 deals with "survival problems" while Test 2 deals with "recapture problems" (Cooch and White (Eds.), 2016). Overall, the Tranquil 2019 adult Chinook data passed all the tests and therefore met the first two primary assumptions of the POPAN Jolly-Seber model applied to the adult Tranquil Chinook data.

The third assumption has been met as Floy tag losses were not observed during any recaptures or recoveries of marked carcasses. Marks were not missed during recaptures as prior to releasing a recaptured individual, technicians handling the fish would confirm with the technician recording the data that they have correctly written down the tag number and colour. The fourth assumption was met as all fish were immediately released upon being recaptured and having their code read. Upon their initial capture, newly encountered individuals were able to be sampled, tagged and released in less than five minutes when removed from the net. This was considered near instantaneous.

One of the traditional estimates employed for mark-recapture experiments is the Peterson estimate. However, one of the key assumptions using this method is that the population is closed. To assess whether this method could be applied, the program CloseTest was used to apply the Stanley and Burnham (1999) test for closure to the data. The results suggest that the population was not closed and therefore it would be inappropriate to apply the Peterson method to estimate the adult Tranquil Chinook escapement. This was as expected as there are numerous predators that remove the salmon from the study area and also the large number of salmon that are flushed out during large rainfall events.

As adult Chinook salmon approach their natal streams, they can be inhibited from entering the spawning grounds due to low flows and drought-like conditions. Consequently, they are forced to wait until a rain-induced freshet raises the river to a sufficient level for entry. While waiting, fat and energy reserves are consumed with longer waits requiring more energy. This will cause less energy to be available for spawning, and overall spawning ground residency, resulting in a reduced spawning area survey life. The Discounted Survey Life (DSL) index developed at the Burman River uses the relationship between the number of days from September 1 to the first freshet and annual spawning area survey life developed between 2009 and 2019. At the Burman River and in streams with freshwater migration stopover sites or holding pools, the "spawning area survey life" is a portion of freshwater life since the Chinook spend a portion of their time downstream of the spawning reaches. However, unlike the

Burman and Conuma Rivers, Tranquil Creek does not have a freshwater stopover pool where the Chinook salmon congregate and hold. Therefore the "spawning area survey life" is the "freshwater survey life" since the returning Chinook go directly from brackish saltwater into the freshwater spawning grounds. To differentiate between these two stream types, the index for Tranquil-like streams without a stopover pool is defined as the Discounted Freshwater Life (DFL) index even though both the DFL and DSL index the spawning area survey life as a function of time to the first freshet from September 1.

The project was successful at demonstrating the ability to conduct a mark-recapture experiment on a very small Chinook population, which was one of the primary goals during this trial year, but did not achieve the goal of producing an adult Chinook escapement estimate with a Coefficient of Variation (CV) of 15% or less: the Chinook Technical Committee standard. Many improvements have been suggested that, if implemented, will likely achieve increased encounters and produce an estimate that meets or surpasses the standard. The first recommendation is to have a seine net at each of the three sampling sites. The lower two sample sites aren't accessible by road which required the net to be transported to the lower sites in the boat. Transporting the net in the boat across shallow riffles and onto land to be trucked back to the uppermost site was very time-consuming. Having the net at each site will allow fishing at multiple sites in the same day as only the crew and boat will need to be transported between any of the sites. For instance, it was not possible to transport the net upstream and therefore transport from the lowermost site to the mid site or the mid site to the uppermost site was not possible. With a net at each site, this can be achieved with great ease.

The second recommendation is to not conduct a simultaneous radio tagging and radio-telemetry study. Numerous radio-telemetry surveys that coincided with the snorkel surveys were conducted this year to produce robust observer efficiency (O.E.) estimates and a survey life estimate. Removing the radio-telemetry component will result in reduced effort and time being spent on snorkel surveys, increasing the fishing effort and therefore increasing the encounters and recaptures. The increased encounters and recaptures should reduce the CV. With such a small population, radio-tagged Chinook would frequently be captured with the radio tag often becoming tangled in the net. The tags would often become lose or be removed entirely and had to be tightened or reattached. However, attaching the radio tag was sometimes not possible due to how degraded a spawned out individual would be and no longer allowed for the use of that individuals data as there was no way of determining how long they would remain in the study area. Radio tags that were tightened or reattached were no longer as snug to the body of the individual because the thrashing with the radio-tag stuck in the net would cause the pins going through the body of the fish to create larger holes. Consequently, the radio-tag loss may be underestimated and may have resulted in the survey life estimates being biased low.

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Appendix I

CLOSE TEST RESULTS

Data Input File= E:\Tranquil\Without Jacks including skunked days\Tranquil Chinook 2019 IEH's Adults Only including skunked days.INP

N hat= 47

M_t+1= 45

Occasions= 10

** 4 occasions dropped from original data (no captures)

CH Data Format= List-directed input

Stanley & Burnham Closure Test (Low p-values suggest population not closed):

Chi-square statistic= 49.09187

df= 11.

p-value= 0.00000

Otis et al. (1978) Closure Test (Low p-values suggest population not closed):

z-value= -1.29753

p-value= 0.09722

Component Statistics of Stanley & Burnham Closure Test

Component Chi-square df p-value

Tests for additions to population (Low p-values suggest there were additions)

NR vs JS	9.30989	3.	0.02544
M_t vs NM	4.09187	10.	0.94311

Tests for losses from population (Low p-values suggest there were losses)

M_t vs NR	39.78199	8.	0.00000
NM vs JS	45.00000	1.	0.00000

Subcomponent Statistics of the NR vs JS Test

(Low p-values on the j-th occasion indicates there were additions

to the population between occasions j and j+1)

Occasion	Chi-square	df	p-value
2	Insufficient data for test		
3	Insufficient data for test		
4	5.22321	1.	0.02229
5	3.79447	1.	0.05142
6	Insufficient data for test		
7	0.29221	1.	0.58881
8	Insufficient data for test		
9	Insufficient data for test		

Subcomponent Statistics of the NM vs JS Test

(Low p-values on the j-th occasion indicates there were losses

from the population between occasions j-1 and j)

Occasion	Chi-square	df	p-value
2	Insufficient data for test		
3	Insufficient data for test		
4	Insufficient data for test		
5	Insufficient data for test		
6	Insufficient data for test		
7	Insufficient data for test		
8	Insufficient data for test		
9	45.00000	1.	0.00000