2019 Elwha River Chinook Escapement Estimate Based on DIDSON/ARIS Multi-Beam SONAR Data


Photo: John McMillan

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This report is provided to Olympic National Park (ONP) by the Lower Elwha Klallam Tribe (LEKT) in partial fulfillment of the adult enumeration (task 1) of the final settlement agreement between ONP and LEKT

Executive Summary

We used an ARIS 1800 and a DIDSON (LR) multi-beam SONAR unit to monitor Chinook salmon escapement in the Elwha River on a daily basis from May 28, 2019, through September 17, 2019. We analyzed 20-minutes of each hour long file and then adjusted these raw counts for expansion to hourly counts, species composition, observer error, and filling data gaps. This process yielded a non-jack Chinook escapement estimate above the SONAR sites of 7,600 fish, with a coefficient of variation of 3.5% (95% CI 7,085 – 8,119).

We operated two SONAR sites in the Old Mainstem (OM) and the Hunt Road Channel (HRC) in 2019, as in every other year of the project. However, due to low flow in the HRC this year, less than 25 fish passed up the channel, thus data from that channel was not included in the final escapement estimate.

Fifty percent of the Chinook salmon run passed the SONAR sites by July 26 in 2019, which was a week earlier than 2015-2018 but similar to and one week earlier than 2013 and 2014, respectively. We captured the first Chinook salmon during species composition netting (May 21) which was the second earliest first capture (May 20 in 2015) and two to three weeks earlier than other years.

Our escapement estimate of 7,600 non-jack Chinook salmon is approximately 1800 fish more than the total of other Chinook salmon encounters in the watershed. A two date spawning redd survey from RKM 61.6 (near the headwaters) to the mouth occurred in early (upper river) and late (lower river) September and in combination with collections for the WDFW hatchery yielded an approximate total of 5,800 Chinook salmon.

The 2019 estimate of 7,600 fish is the highest in the 9 year history of the project (second highest 2018, 7,100) and the second highest during the available data record which goes back to 1986 (highest 1988, 8,667). The majority of fish returning as adults in both 2016 and 2017, which saw relatively low returns, experienced adverse river conditions as juveniles in 2012 and 2013 during the peak of sediment effects related to dam removal. Although in-river incubation and rearing conditions appear to be improving, it is important to note that over 95% of returning adults 2019 were of hatchery origin.

Our major recommendation moving forward is to perform more species composition sampling during the month of June, the presumed peak migration timing for summer run steelhead. An independent estimate of this distinct run would be very useful to co-managers and provide more accuracy in our Chinook salmon counts since raw SONAR targets will be counted as Chinook salmon if other species are not correctly represented in the species composition data. Finally, if channel morphology and flows continue to preclude Chinook salmon passage up the HRC, we recommend suspending operation of that site after the end of the steelhead season (mid June).

Introduction

One of the most important pieces of information for salmon fisheries managers is an accurate count of adults returning to spawn in a river system, hereafter referred to as escapement. Multiple methods have been used to estimate escapements of adults, including aerial surveys, counting towers, weirs, redd surveys, mark-recapture studies, and SONAR technology (reviewed by Cousens et al. 1982). The technology and techniques used to estimate abundance have remained basically static for all methods except SONAR, whose technology and application to escapement estimation have rapidly evolved over the last few decades (Maxwell 2008).

Single beam sonar systems have been used to enumerate fish migration in rivers since the early 1960's. Similar technology is still being used to measure escapement in a number of commercial fisheries in Alaska (Westerman and Willette 2003; Dunbar and Pfisterer 2004; Dunbar 2001, 2003; McKinley 2002), and Canada (Levy et al. 1991, Cronkite et al. 2006). More recently, SONAR technology has greatly improved counting accuracy by incorporating multiple high frequency beams, producing "movie" quality images while also providing detailed data on several other fish characteristics including direction of travel, range, length, and swimming speed (Belcher et al. 2001, 2002). The main unit in use for fisheries applications today is the **D**ual-frequency **ID**entification **SON**ar (DIDSON) and the newer version, **ARIS** (**A**daptive **R**esolution **I**maging **S**onar*)*.

Several studies have been conducted relating sonar counts of adult salmon derived from DIDSON imaging systems to other enumeration methods such as weir passage (Holmes et al. 2006), visual counts (Enzenhofer et al. 1998), and mark-recapture (Cronkite et al. 2006, Holmes et al. 2006). DIDSON counts have consistently had insignificant error when compared to the more traditional methods. It is important to note, however, that almost all of the fisheries applications of SONAR have been focused on large salmon runs that transpire over the course of only a few short weeks, which requires large technical staffs and operating budgets (eg. Lilja et al. 2008, Enzenhofer et al. 2010). In this study, we attempt to enumerate a relatively small and protracted run of Chinook salmon (*Oncorhynchus tshawytscha*) using multi-beam imaging SONAR.

This project is focused on the enumeration of Chinook salmon in the Elwha River, Washington through its entire run which occurs from late May through mid-September (see Denton et. al. 2010, 2012, 2013, 2014, 2015, 2016, 2017, and 2018 for previous years reports). The Elwha River, located on the north Olympic Peninsula in Washington State, provides a unique opportunity for fish enumeration using a multi-beam sonar system. Two dams had blocked fish passage to nearly 146 Km of main stem and tributary habitat since 1911, but removal of both dams began in September 2011 (Elwha River Fisheries and Ecosystem Restoration Act, 1992). The lower dam (Elwha) was completely removed in the spring of 2012. The upper dam (Glines Canyon) was removed by late summer 2014. In October 2014, shortly after the Glines Canyon Dam removal was complete, a large rockfall occurred in the canyon immediately downstream of the dam site near RKM 20.0 (Brenkman et al. 2019). The accumulation of rockfall debris and large boulders created a new barrier to upstream passage of adult salmonids. Rock blasting occurred in October 2015 to improve fish passage, and additional blasting in September 2016 was presumed to have eliminated the barrier (Brenkman et al. 2019). It is important to note, however, that potential passage issues for some species still exist at both sites and ongoing monitoring is occurring.

As highlighted in the Guidelines for Monitoring and Adaptively Managing Restoration of Chinook salmon and steelhead on the Elwha River (Peters et al. 2014), a critical aspect to evaluating the success and rate of recolonization of anadromous fish during and after dam removal is estimating the abundance of adults returning to the entire river system each year. A major goal of the Elwha and Glines Canyon Dam removals is to increase salmon and steelhead populations. However dam removal led to the release of large amounts of trapped sediment, which severely limited visibility in the river. This made the use of traditional enumeration methods (i.e. redd surveys) highly ineffective for specific species and time periods (Magirl et al. 2014). While limited visibility, at least during Chinook spawning, are seldom an issue at this point post dam removal, SONAR estimates have been shown to be more a more precise estimate of Chinook escapement mainly due to redd superimposition. In addition, the removal of both dams opened up access to approximately 90% of the watershed that was previously inaccessible to anadromous fish (Pess et al. 2008). Therefore, SONAR is the best technique for producing basin wide escapement estimates for anadromous salmon populations during and after dam-removal.

One of the species of most concern in the river is Chinook salmon, which is part of the Puget Sound Chinook Evolutionary Significant Unit and is listed as threatened under the Endangered Species Act (ESA) (Montgomery 2003). Estimating adult Chinook salmon returns on the Elwha River presents both a unique and common set of challenges. First and foremost within the Elwha River is the challenge of maintaining in-stream infrastructure in a constantly shifting environment due to the extreme sediment loads created by dam removal operations. Second, and applicable to many streams in the Pacific Northwest (PNW), is that the DIDSON/ARIS site requires constant maintenance, adjustment, and monitoring due to variable stream flows, particularly during snowmelt and rain on snow events. Lastly, and also like other rivers in the PNW, the Elwha River mainstem is anastomosing, displaying a forested island-braided morphology that provides multiple channels through which fish can migrate (Beechie et al. 2006). Adult Chinook salmon may migrate up one of two distinct channels that split near the mouth of the river. As a result, both channels have been monitored with two different SONAR devices, although changing channel conditions may reduce the need to monitor one of the channels during certain periods of low flow. The sediment loads and changing, multiple channels provide a unique opportunity to evaluate the ability of SONAR to estimate adult escapements, examine sources of estimation error, and advance understanding of how to improve the use of SONAR in future monitoring efforts. To that end, the objectives of this study are to: 1) provide an estimate of Chinook salmon escapement to the Elwha River; 2) provide run timing information; 3) incorporate and describe four sources of error in the estimate; 4) determine the proportion of Chinook and other species of migrating salmon in the river during the course of the run; and 5) make recommendations on how to improve the use of SONAR to enumerate adult salmon in the Elwha in the future.

Methods

Data Collection

Continually changing river conditions and two distinct stream channels (migratory pathways) in the lower Elwha River necessitated two separate SONAR installations to accurately detect Chinook salmon passage in 2019 (Fig. 1). Site selection was based on four criteria: 1) almost all fish would pass the site; 2) the location was downstream of the majority of Chinook spawning habitat; 3) the river channel was sufficiently narrow to accommodate the effective range of the sonar; and 4) fish movement was primarily directed upstream with little milling in the location of the SONAR.

Both sites were located at approximately RKM 0.8. The proportion of flow down each channel varies from year to year and the proportion flowing down the HRC channel seems to be shrinking each consecutive year. In 2019 during June and July approximately 20% of the flow went down the HRC, with the remaining 80% traveling down the OM; by August and September the proportion flowing down the HRC was closer to 10% (Mike McHenry, LEKT, personal communication). Two different SONAR units were used during the course of this study; a DIDSON LR in the HRC (long range, 0.7/1.1 MHz, provided by NOAA Fisheries) and an ARIS 1800 in the OM (1.1/1.8 Mhz, provided by Olympic National Park).

The HRC site (Fig. 2) was connected to line power ensuring a constant power supply. Depending on stream flow, the site was between 15 and 20 meters across and 1.1 meters depth in the thalweg, while the OM site was 18-22 meters wide and 2 meters deep in the thalweg. The SONAR was attached to a pole mount (Enzenhofer and Cronkite 2005) that was then mounted on a reinforced ladder. The SONAR and ladder were positioned just under the surface of the water with an average downward angle of approximately 4^{o} (Fig. 3). The goal of this placement was to ensonify the bottom of the river across the entire width of the channel in addition to clearly "seeing" the far bank (see Enzenhofer 2010 for details on aiming the beam). We constructed a weir approximately three meters downstream of the DIDSON that extended from the bank to 5 m beyond the SONAR (Fig. 3). This weir directed fish to a distance that allowed the sonar beams to spread to a sufficient vertical height so that the entire water column was ensonified, which greatly improved imagery and eliminated the possibility of fish passing underneath the beam.

The OM site was powered by a 24-volt, 200 amp hour battery bank that was continually charged by an array of solar panels. A weir was also installed at the OM site to direct upstream passage of adult fish (Fig 4). Chinook passage was recorded at the OM site from May 21 through September 17, 2019 with the exception of a four day gap from August 26 through August 29, a two day gap from September 2 through September 3, and a two day gap from September 7 through September 8 (Fig 5a). Chinook passage was recorded continuously at the HRC site from May 21 through July 22, 2019, when low water interrupted operations. Flow increases allowed two other short recording periods, August 2 and 3, and September 15 through September 17 (Fig. 5b). Due to these low water conditions almost no passage was recorded up the HRC (< 25 fish). Therefore, data from this channel was not included in the final escapement estimate.

The SONAR was also in operation prior to May 21, 2019, throughout the winter and spring of 2019 to record steelhead passage. Data, analysis, and an estimate of steelhead passage for this time period is available in the project's steelhead report (Denton et al., 2019).

Species Composition

We conducted tangle net surveys on 14 different days between May 21 and September 17 to capture live adult salmonids at 6 different sites in the lower two kilometers of the river. Effort was consistent across sampling dates. We used the tangle net data to determine both the beginning and end of the Chinook run and also to differentiate species of salmonids passing by the SONAR sites during the course of the run. Captured fish were measured for fork length and qualitatively categorized as “new” if they appeared to have been in the river for less than 2 weeks, “holding” if they appeared to have been in the river for more than 2 weeks, or “spawned out” if they appeared to have finished or initiated spawning. In an effort to only include actively migrating fish in the date specific data set, only fish categorized as “new” or “holding” were included in the species composition adjustment (Table 1). The tangle-net was approximately 20 m long and 3 m deep with a 10 cm mesh of 6# monofilament. We also used the in-stream netting data to determine a minimal threshold for SONAR measured targets to be included in the final escapement estimation by comparing the lengths of Chinook and non-Chinook salmonids, which included summer and winter steelhead, pink salmon, and several coho salmon towards the end of the Chinook run (Fig. 6).

Data Analysis

All DIDSON data was processed using DIDSON proprietary software (V5.25.26). All hour long files were subsampled by reviewing the first 20 minutes of each file, which is at the upper end of subsampling recommendations (Lilja et al. 2008). Raw data was transformed in a two step process that enabled empty periods of time to be efficiently reviewed, while highlighting fish passage events for closer inspection. Files were background subtracted, using the default parameters, to remove rocks and make it easier to discern moving objects, such as migrating fish. Subsequently, each file was transformed into an echogram using the default parameters, with the exception that all 48 beams were included rather than only the center beam. This dramatically increases the probability that any fish entering the ensonified area will be detected in the echogram.

An echogram is a graph of the data with distance from the sonar head on the y-axis and time on the x-axis. If no targets are present, the echogram will be blank. If a fish swims through the ensonified area, the echogram will have a series of targets connected along the x-axis, whose overall length correlates with the length of time it took the fish to pass through the ensonified area. The string of targets along the x-axis may trend up or down along the y-axis if the fish was swimming diagonally away or towards the sonar head during its passage. To count fish passage events, target echograms were simultaneously reviewed along with the raw video file. This enabled the reviewer to quickly scan through an echogram until a target pattern that could potentially represent a fish was encountered. Raw data was then reviewed to ensure identified targets were indeed fish.

A similar procedure was used for processing ARIS data (background subtraction, echogram formation, manual review of likely targets), except that ARIS data is processed with its own software, ARISFish (v.1.5). After determining that a pattern on the echogram was a fish, we noted several variables, including the date, time, direction (upstream or downstream), distance from SONAR head, length (mm) and observer confidence. Length was measured in millimeters using software specific procedures. The final characteristic was a qualitative value. The reviewer recorded a 1 if they were extremely confident that the target was indeed a fish passing in the specified direction or a 2 if they are somewhat confident that the target was a fish passing in the specified direction.

Escapement Estimation and Uncertainty Tabulation

Basic fish passage was tabulated by simply subtracting downstream passage events from upstream passage events (Xie et al. 2005):

$$N = U - D$$

In this equation N represents the net upstream movement of fish for a given period of time (20 minutes in this case), U is the sum of upstream fish for that time period and D is the sum of downstream moving fish for that time period.

In order to sum the upstream and downstream passage events for each 20 minute file, we first had to determine which passage events to include in our analysis, namely the minimum length threshold and which observer confidence categories. We used 600 mm as the cutoff for inclusion in the final escapement estimate this year for several reasons. First, we captured very few jack Chinook in our net sampling this year (2/119) and they were all below 600 mm. Additionally, only 2 additional Chinook salmon captured during species composition sampling were between 550 mm and 600 mm. Conversely, 50% (5/10) of the pink salmon captured were within 20 mm of 550 mm (Fig. 6). Therefore, mainly in an effort to avoid including pink salmon in our Chinook salmon estimate, we raised the length cutoff from the historical 550 mm to 600 mm in 2019. We only used passage events of observer confidence level 1 in the final escapement analysis. Less than one percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (24/3,449). Eight percent of all downstream passage events that met the length criteria were recorded as observer confidence level 2 (51/641).

Raw targets meeting the above criteria were then aggregated into channel-specific six-hour chunks, four per day. Each channel specific six hour chunk (n = 460) was then pushed through a four step adjustment simulation to determine the final escapement. This simulation used collected data to correct raw counts for the four major adjustments that make up the total escapement estimate: 1) expanding the 20 minute counts to represent full hour passage; 2) down weighting the expanded counts to reflect the proportion of SONAR targets that were non-jack Chinook; 3) adjusting the expanded Chinook counts to account for observer error; and 4) filling in any passage data for gaps in the expanded, corrected, Chinook data.

We used a simulation based approach and replicated this simulation procedure a large number of times (10,000) for each channel individually. We initialized the values in each cell (460 rows, representing each of the 6-hour chunks and 10,000 columns, representing the iterations) to the net passage based on the raw counts from the files. During each of the four steps in the adjustment procedure described below, we were able to generate updated channel specific estimates of escapement at varying temporal scales (6-hour estimates, daily estimates, and annual estimates). Each step of this process was done for each channel and then the channel data was summed to provide total estimates and a coefficient of variation (CV). To determine the coefficient of variation for the final escapement, the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates. To generate CV estimates for each of the four individual adjustment procedures, we applied each step of the procedure individually to the raw six-hour chunk counts from each channel.

20 Minute Count Expansion

Although counting 20 minutes of each hour is on the upper end of recommended sub-sampling regimes (Lilja et al. 2008), it requires treating two thirds of the total passage data as unknown. In order to expand our 20 minute counts and encompass the uncertainty inherent in the process we counted the full 60 minutes of 8 six hour chunks for the OM (Fig 7). We regressed these 60 minute counts against those predicted from the first 20-minutes of the same six hour chunks to create a vector of residuals. Each raw 20 minute count was then adjusted by multiplying by 3, and adding a randomly sampled value from the residual vector. The CV for escapement for this step was calculated by summing all 6-hour chunks for each iteration, yielding 10,000 estimates. Then, the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates.

Species Composition

In-river netting indicated that Chinook salmon were actively migrating past the SONAR sites beginning approximately on May 21, so all targets after that date were included in further analysis. In-river netting on September 17 revealed that almost all Chinook salmon in the vicinity of the SONAR sites were either spawned out or had been in the river for several weeks indicating that active entry into the river by Chinook salmon was nearly complete for the season. In addition, 21 fresh coho salmon (*Oncorhynchus kisutch)* greater than 600 mm in length were captured on the September 17 sampling event. Therefore calculation of the 2019 Chinook salmon escapement only included SONAR targets recorded through September 17.

In river netting also provided the necessary data to adjust the expanded counts to account for the number of Chinook moving passed the SONAR sites (Table 1). Because of the low numbers of “new” and “holding” fish caught during some of the sampling events, we summed fish between adjacent events to arrive at daily totals for fish caught and Chinook caught. For each channel, we simulated the proportion of Chinook on given iteration and day as:

$$p_{i,j,k} = Binomial\left(\frac{N_{i,j,k}^{chinook}}{N_{i,j,k}^{total}}, N_{i,j,k}^{total}\right) / N_{i,j,k}^{total}$$

where *i* represents the iteration (1 – 10,000), *j* indexes the 6-hour chunk (1 – 460) and *k* indexes the channel. The total number of fish, $N_{i,j,k}^{total}$, and total number of Chinook $N_{i,j,k}^{chinook}$ were available on a daily basis, so the four six-hour chunks from each day were assumed to have the same species composition.

We then adjusted each of the expanded counts for the proportion that were Chinook as a random draw from a binomial distribution:

$$X_{i,j,k}^{chinook} \sim Binomial\left(p_{i,j,k}, X_{i,j,k}^{total}\right)$$

This adjustment downweights the raw SONAR passage to just Chinook passage. This 2-step sampling is accounting for both uncertainty in the proportion of Chinook (first step) and random sampling variation (second step). The CV for escapement for this step was calculated by performing the correction directly on the net passage data as opposed to the expanded data used by the simulation. Then the counts of all 6-hour chunks were summed for each iteration, yielding 10,000 estimates. Finally, the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates.

Observer Error

It is generally recommended to account for the possibility of observer error in SONAR counts (Holmes et al. 2006). We quantified observation error by comparing counts for 8 six hour chunks between the primary technician and a more experienced, “expert” counter. Similar to the expansion procedure, six hour total passage counts by the expert counter were considered to be a measure of “actual” passage and were compared to the technicians “predicted” counts (Fig. 8). A regression line was fit to the expert versus technician data, with a forced intercept of 0. From this regression, we generated a vector of observer error residuals (similar to the 20-minute expansion described above). Each cell of the expanded Chinook matrix was then adjusted by multiplying it by the coefficient from the regression trend line and adding a random residual.

The CV for escapement for this step was calculated by performing the correction directly on the net passage data as opposed to the expanded Chinook data used by the simulation. Then the counts of each 6-hour chunks were summed for each iteration, yielding 10,000 estimates. And then the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates.

Filling Data Gaps

A number of different approaches could be used to fill in missing counts, including borrowing data from the neighboring channel or assuming return timing to follow some distribution (normal, double half-normal, etc). We used a generalized additive modeling (GAM) approach to fill in missing values, because this approach also allowed us to include uncertainty estimates (gam in the ‘mgcv’ package in R). We fit a smoothing spline over time (days), which allowed both a flexible shape of return timing, and uncertainty to increase as the spline became further away from data. For example, if a 5 day data gap exists, the uncertainty is highest on the mid-point (day 3) of the gap, and the uncertainty associated with passage during the gap would increase as the length of the gap increases. For each iteration of the simulation, we first fit the GAM to fill in the data gaps, then for each six hour chunk generated random values (using the mean and corresponding standard error from the GAM). Because our approach does not include autocorrelation in missing values, but assumes each six hour chunk to be independent, it represents upper bounds of uncertainty estimates.

Results

Between May 21 and September 17, 2019, there were a total 1,608 hours (67 days) recorded on the HRC, and 2,664 hours (111 days) recorded on the OM. At least one of the channels was monitored for 2,688 hours out of a total of 2,688 hours, or 95% of the total possible hours. During this time period 4,861 fish passage events were recorded and analyzed. The best estimate for the Chinook escapement to the Elwha River in 2019 was 7,600 fish with a coefficient of variation (CV) of 3.5% (95% CI 7,085 – 8,119) (Table 2). A total of < 20 (0% of total) Chinook went up the HRC, while the remaining 7,600 (100% of total) Chinook (CV 3.5%, 95% CI 7,085 – 7,119) went up the OM (Figure 10). In order of decreasing variance, the largest sources of error were (1) the uncertainty associated with expanding the 20 minute counts (3.0%), (2) error in the gap filling procedure (1.2%), (3) adjusting for species composition (0.9%), and (4) accounting for observer error (0.8%) (Table 2).

The SONAR data in combination with in-stream species composition netting provided detailed information on run timing. We captured the first Chinook salmon on May 21 and 25%, 50%, and 75% of the run had passed the OM SONAR site by July 11, July 26 and August 2, respectively. Daily Chinook passage was also plotted against flow (Fig. 11). The run appears to begin in earnest (after July 4) when the hydrograph began to decline after the peak of snowmelt. Additionally, by far the single largest passage day, ~1,000 fish on August 2, was associated with a spike in flow. In fact, most high passage days throughout the run were associated with flow increases.

Discussion

Our estimate of 7,600 Chinook salmon provides a robust measure of Chinook escapement to the Elwha River in 2019 for several reasons. Most importantly we recorded data from approximately 95% of the run (2,496 of 2,688 hours). Furthermore, we feel confident that we accurately recorded the beginning of the run, May 21, and collected data until near the end of the run, September 17. Minimal passage occurred during almost the entire month of June (only 9% of the run had passed the SONAR sites by June 30) and the weekly in-river netting operations indicated few Chinook were present in the river during that time period, as only 10% (13/119) of Chinook caught during the course of the run were caught in June. Species composition monitoring indicated that recently entering Chinook salmon likely stopped entering by mid September. The ability to confidently denote the beginning and end of the run is crucial to providing uncertainty estimates around our Chinook escapement number. Finally, we were able to account for several sources of uncertainty in our final estimate and provide a robust range of possible escapement totals, giving managers reliable information upon which to base management decisions. This uncertainty comes from four main sources, (1) expanding the 20 minute counts to 60 minutes, (2) filling data gaps, (3) adjusting for species composition and, (4) correcting for observer error. Each source of error is partly affected by sample size (fish sampled for species composition, 6-hour chunks sampled for observer error and expansion, missing days for gap filling), but also have unique characteristics. Overall, individual and total CV’s were similar to previous years and quite low.

As mentioned previously, only data from the OM site was used to calculate the total escapement and provide uncertainty estimates for the various corrections. Fish passage was measured in the HRC for over half of the run when flows allowed. This included from the initial Chinook salmon encounter during species composition sampling on May 21 through July 22, a time period when almost 50% of the run had passed up the OM site. It also included August 1 through 3 which included the highest single day of passage on the OM (August 2, ~1,000 fish). Nevertheless, a net total of only ten upstream passage events occurred during this period of recorded passage on the HRC. Since flows were lower during the period of time we did not record passage we assumed that no fish passed upstream during data gaps. For these reasons, we only ran the simulation model and report outputs for data from the OM channel.

The highest source of uncertainty this year was due to expanding the 20 minute counts, with a CV of 3.0%. The variation in predicted vs. actual counts this year was likely due to the very high fish passage that was recorded. We hypothesize that when fish passage is high it is more likely to be have a non-normal distribution through time. More important than the residuals causing the uncertainty is the regression equation relating the predicted counts to the actual counts which is close to 1 (0.88). This means that while there might be disagreement between individual predicted vs. actual six hour chunk counts, when taken as a whole, the predicted counts roughly equaled the actual counts.

The second highest source of uncertainty in 2019 was associated with the gap filling procedure, with a C.V. of 1.2%. We recorded data from the highest temporal period of the run this year, with a total of only 8 days of data gaps on the OM. Unfortunately, most of the gaps on the OM occurred around the high passage days in late August and early September. This was a period of time with high rates of passage over a short duration when flows came up, immediately followed by periods of relatively low passage. It is more difficult for the gap filling procedure to accurately predict passage when adjacent measured passage varies widely. Nevertheless, due to the high overall passage this year, the CV for this procedure remained low. Additionally, based on the species composition netting, roughly ~40% of the estimated passage during these gaps were likely coho salmon according to the species composition netting so reduced the total number of Chinook salmon added to the estimate and therefore also lower the CV associated with this procedure. Over several years of operation, the project has worked out most of the potential technical difficulties that contribute to data gaps. In addition, an early spring runoff in 2019, along with a descending hydrograph typically seen during the Chinook salmon season facilitated the near continuous operation of the SONAR stations.

The third greatest source of uncertainty was due to the observer error correction of 0.9%. The small CV associated with this adjustment is due to the near perfect agreement between the counts of the expert and technician as evidenced by the regression equation being almost exactly 1 and the high R^2 (.97). The project technicians have been working on the project for several years now and are experienced counters at this point in the project. Additionally, relatively low water conditions in the Elwha during the summer of 2019 enabled us to capture very good imagery with low turbidity. The milling problem of previous years (before 2018) was effectively dealt with by moving the SONAR just above the riffle crest at the bottom of the reach in late June. This produced exceptional imagery with fish passing one by one within 10 meters of the SONAR head.

The final source of uncertainty was adjusting for species composition, with a CV of 0.8%. 2019 was a pink salmon year on the Elwha and coho salmon appeared earlier in our species composition sampling than previous years (August 13). Other species migrating concurrently with Chinook salmon would generally increase the uncertainty associated with this correction. However, by increasing the SONAR measured length cut-off to 600 mm, which by default also raises it to 600 mm for inclusion in the species composition adjustment, we were able to remove most of the pink salmon from the species composition correction, thus lowering the CV. Similarly, while we captured the first coho salmon earlier than ever before, it measured only 550 mm so was not included in the species composition correction. We did not catch coho salmon in significant numbers, or more than one over 600 mm until September 17, which was also the date we determined to be the end of the Chinook salmon run. So, while there were several other species migrating concurrently with Chinook salmon this year, they were either too small to be included in the correction or very few were caught (although see below). It is important to note that increasing the SONAR measured length cutoff to 600 mm removed approximately 3.5% (4/119) of the smallest field measured Chinook from the species composition analysis. If we assume that this also resulted in not counting the smallest 3.5% of the Chinook swimming passed the SONAR, that would result in not counting approximately 250 Chinook salmon (0.035 * 7,600).

An unmeasured potential source of uncertainty associated with correctly apportioning raw SONAR targets to the proper species is the likely differential capture probability of different salmonid species. This is likely exacerbated in years with high Chinook salmon densities. Chinook salmon in the Elwha have a tendency to congregate in the lower ~1KM of the river awaiting the fall rains to move upstream and several hundred usually remain even after flows increase. This produces a situation where some sites in the lower river where species composition sampling occurs have several hundred Chinook salmon present for months at a time. Snorkel surveys have revealed that when other species of salmon are also present in these holes, they tend to hold downstream of the Chinook salmon. When the species composition sampling occurs in these locations, the first few Chinook salmon to hit the net at the top of the run usually lift up the lead line and catches drop to almost zero for the rest of the run. Techniques such as physically holding down the lead line or making a second set on the lower half of the run can ameliorate this situation to a certain extent but at species composition sites that hold hundreds of Chinook salmon other species are likely underrepresented. Additionally, some species may exhibit different migration patterns, whereby they move quickly through the lower river and are therefore less likely to be captured by the species composition protocol.

An empirical example of this can be seen with summer steelhead on the Elwha. Extensive snorkel surveys along with a robust mark resight analysis aimed at enumerating summer steelhead in the basin counted 354 adult summer run steelhead which yielded a median estimate of over 900 summer run steelhead in 2019 (95% CI, 473 – 1,935)(McMillan, et. al., in prep). The SONAR is theoretically capable of providing an independent estimate of the summer steelhead run population by simply changing the species composition input to reflect summer steelhead proportions instead of Chinook salmon proportions. However, we only captured three summer run steelhead during netting operations in 2019 on June 24, July 8, and July 17. When presented with the summer run species proportions, the simulation model produced an estimate of approximately 450 fish. While this estimate just barely falls outside the lower portion of the 95% CI range of the mark resight estimate, it is almost 500 fish short of the median estimate. This is not unexpected considering the project caught 9 summer run steelhead in 2018 from May 22 until July 8, indicating that our species composition sampling in 2019 likely missed the bulk of the summer run steelhead migration in June and therefore underrepresented them in the Chinook salmon model. Similarly, the fact that we caught the first coho salmon on August 12 and then only caught two others until September 17 indicates the possibility that we underrepresented them as well. In 2019, the consequence of the phenomenon of variable catchability of different salmonid species is the possibility that a total of ~500 raw SONAR targets that were deemed Chinook may have been summer run steelhead in the beginning of the run or coho towards the end of the run.

We compared our escapement estimate of 7,600 Chinook with other data collected in the watershed. A redd survey was conducted in early September from Godkin Creek (RKM 61.6) to the head of the Grand Canyon and then a peak redd survey was conducted from the head of Geyser Valley to the mouth in late-September. These surveys recorded 1,673 redds, which represents roughly 4,180 fish (redds*2.5) (McHenry et al. 2020). Additionally, 1,903 Chinook were collected for Washington Department of Fish and Game hatchery operations, although 614 were returned to the river including 410 females that may have constructed redds and been counted in the redd survey. This amounts to an estimate of either 6,011 or 5,601 depending on whether you assume the 410 females released to the river constructed redds and were accounted for in the redd surveys. This represents roughly 75% of our SONAR based estimate. McHenry et al. (2019) reported that 6.2% of the redds were recorded upstream of the former Glines Canyon dam indicating that, for the third year in a row, Chinook salmon were able to access the additional ~48 KM of mainstem and ~28 KM of tributary habitat that were previously inaccessible (Brenkman et. al. 2008). Although a one pass redd survey was conducted on the accessible mainstem habitat outside of the three significant canyons above Glines Canyon Dam, it is likely that additional redds went undetected particularly because the section upstream of the Grand Canyon was surveyed two week before the historical peak of spawning. Finally, in light of the fact that almost all of the recorded redds were seen downstream from the mouth of the Rica Canyon (RKM 26) redd superimposition certainly occurred, resulting in an undercount of redds.

As the Elwha SONAR project continues into the future, it is important to compare its escapement estimates and run timing information to previous years' data. The 2019 Chinook escapement estimate of 7,600 is larger than any other year of the project (second highest: 7,100 in 2018) (Fig 14). This year's return represents the second highest return since 1986 (the earliest year for which data is available) when 8,667 Chinook were estimated to have returned to the river in 1988. Most Elwha Chinook salmon outmigrate as age 0+ fingerlings and spend three to five years at sea before returning to spawn. The vast majority of Elwha Chinook are age three or four when they return as adults. Therefore, a majority of the 2018 and 2019 returning adults were spawned, incubated, and subsequently outmigrated during the fall, winter, and spring of 2014, 2015 and 2016 which saw several high flow events. While most of the sediment in the reservoirs has stabilized (Ritchie et al. 2018), it is unclear how much sediment impacts may be influencing Chinook egg incubation and survival in the mainstem at this point. Hatchery:natural proportions for the 2019 Chinook return were over 95% though, indicating that in-river conditions for natural production have been unfavorable, at least through 2016. Therefore, variability in hatchery releases is likely a major driver in adult returns three to five years later at this point in Chinook recovery post dam removal. In fact, 2011 through 2013 had average Chinook 0+ releases of ~1.1 million while 2014 through 2017 had average 0+ releases of ~2.2 million which would be returning as adults from 2017 through 2022. Natural outmigrant production, from 2014 through 2017 time period, as measured by a smolt trap in the mainstem, was only about 3% of hatchery outputs (McHenry et al. 2020). However, in 2019 approximately 571,000 natural 0+ outmigrants were estimated to have been produced in the river (McHenry et al. 2020). So while natural outmigrant production was severely limited during the peak of dam removal sediment impacts, as the river has stabilized, natural production of Chinook in the river appears to be increasing which will undoubtedly lead to more natural origin adults returning to the river in coming years.

In comparison to prior years, this year's date at which 50% of the run had passed the SONAR site, July 26, was roughly a week earlier than the last four years but one week later than 2014 and similar than 2013. In 2013, 2014, 2015, 2016, 2017, and 2018 the date at which 50% of the run had passed the SONAR was July 25, July 20, July 30, July 30, August 1, and July 30 respectively (Denton et. al. 2013, 2014, 2015, 2016, 2017, and 2018). The first Chinook salmon was captured during the in-stream netting operations on May 21, which roughly two weeks earlier than recent years except for 2015 when a Chinook was captured on May 20. So, the date of first Chinook capture has remained in early June or late May for several years but the run does not begin in earnest until July 4 and the date at which 50% of the run has past the SONAR sites moved a week earlier after remaining basically unchanged for the past 4 years (Table 3). It is interesting to note that the date at which 75% of the run had passed the SONAR sites was much earlier this year (August 2) and was fueled by a brief bump in flows in August 2. The fact that so many Chinook salmon moved upstream on a relatively small increase in flow in the middle of the run may provide some insight into how run timing and potentially spatial distribution are dependent on changes in flow. Observations of hundreds if not thousands of Chinook holding in the lower 2KM of the river throughout the month of August and into September make it clear that most of the fish are holding in fresh water for weeks before moving upstream to spawn. Information on the numbers of fish holding in salt water during this time period is not available.

Finally, the nature of the SONAR passage data in conjunction with the species composition data allows us to simply change the species and lengths of interests as inputs to the model to enumerate species other than Chinook salmon. This assumes the previously mentioned issue of equal capture probability in the species composition sampling is not a problem, which it likely is for all species but not nearly so much as summer run steelhead. Pink salmon likely have a similar residency period in the lower river as Chinook salmon, but are likely more difficult to catch in reaches with high Chinook density. Nevertheless, by changing the species composition input file to focus on pink salmon and by only considering SONAR measured targets measuring less than 550 mm, we estimate an escapement abundance of approximately 650 pink salmon to the Elwha River in 2019, with the first pink salmon being captured on July 29 and the last on September 24. Our estimate can be put in context with 24 pink redds that were recorded during the Chinook redd surveys (McHenry et. al., 2020)

Recommendations

We are pleased to report that both the total and adjustment specific CV's were low again this year indicating a robust sampling and analysis protocol. Our major recommendation relates to properly apportioning raw targets to the proper species, particularly summer steelhead since they are also a species of concern in the Elwha River and properly representing their timing and proportions in the SONAR data would yield a valuable independent estimate of this species. The best way to accomplish this goal would be to increase sampling frequency to twice a week during their presumed peak migration period, June. Sampling additional sites with lower Chinook densities is also worth investigating. Our other recommendation involves decreasing effort in an effort to cut operational costs without sacrificing accuracy or precision. Because essentially zero Chinook passage occurred up the HRC this year we recommend considering not deploying that site after the steelhead season concludes (mid-June) if the trend continues in 2020.

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Table 1. Total number of “new” and “holding” Chinook and other salmonids which measured at least 600 mm captured by date at 6 sites during in-river netting operations on the Elwha River in 2019. “Other” salmonids captured were: May and July, all steelhead; September, two pink salmon and the rest coho salmon.

Date	Chinook	Other	% Chinook
5/21/2019	1	2	33%
5/28/2019	4	1	80%
6/3/2019	1	0	100%
6/11/2019	1	0	100%
6/18/2019	0	0	NA
6/24/2019	6	0	100%
7/8/2019	7	1	88%
7/17/2019	10	1	91%
7/29/2019	14	0	100%
8/12/2019	11	0	100%
8/21/2019	28	0	100%
9/4/2019	17	2	89%
9/10/2019	9	1	90%
9/17/2019	5	21	19%

Table 2. Individual coefficients of variation for each adjustment procedure. The overall CV reflects the uncertainty incorporating all four sources of uncertainty and the individual CV estimates represent the uncertainty correction applied to the raw data to reflect the CV for each individual step.

Source of Uncertainty	OM (Total)
Expansion	3.0%
Species Composition	0.8%
Observer Error	0.9%
Gap Fill	1.2%
Overall	3.5%

Table 3. Escapement estimates, 95% confidence estimates, date of first Chinook capture during in-stream tangle netting, and date when 50% of the run had entered the river for all years of the Elwha SONAR project.

Year	Estimate	95% CI	First Capture	50% Entry
2009	3,152	2,552 - 3,752	N/A	2-Aug
2010	1,372	1,122 - 1,622	N/A	2-Aug
2011	N/A	N/A	N/A	N/A
2012	2,638	2,238 - 3,038	N/A	31-Jul
2013	4,243	3,743 - 4,743	24-Jun	25-Jul
2014	4,360	4,060 - 4,660	4-Jun	20-Jul
2015	4,112	3,857 - 4,372	20-May	30-Jul
2016	2,628	2,543 - 2,715	14-Jun	30-Jul
2017	3,083	2,818 - 3,348	13-Jun	1-Aug
2018	7,107	6,495 - 7,719	6-Jun	31-Jul
2019	7,600	7,085 - 8,119	21-May	26-Jul

Figure 1. Map of the lower Elwha. Former Elwha dam site is located at the bottom of the figure, with the Strait of Juan de Fuca at the top. White oval depicts the location of the Hunt Road Side Channel DIDSON site. The Old Mainstem site is located approximately adjacent to the upper right hand portion of the white oval.

Figure 2. Photo of the HRC DIDSON site. Note low water that precluded fish passage up this channel in 2019.

Figure 3. Ladder and pole mounted DIDSON multi-beam imaging SONAR. The SONAR is housed in the black silt box at the bottom of the pole.

Figure 4. Old Mainstem SONAR site. The SONAR is attached to the pole mount which is in turn attached to the ladder. The PVC picket weir immediately downstream from the ladder directs fish away from the bank so they pass at least 3 m from the SONAR head.

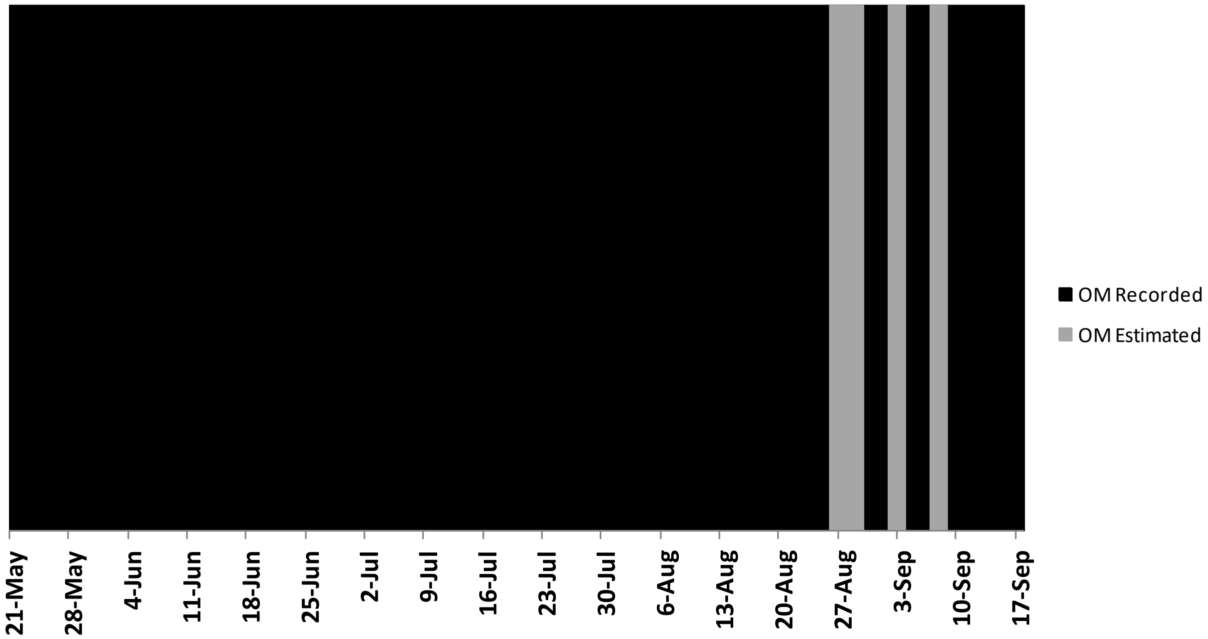


Figure 5a. Dates for which data was recorded or estimated in the Old Mainstem channel during the Chinook season on the Elwha River in 2019.

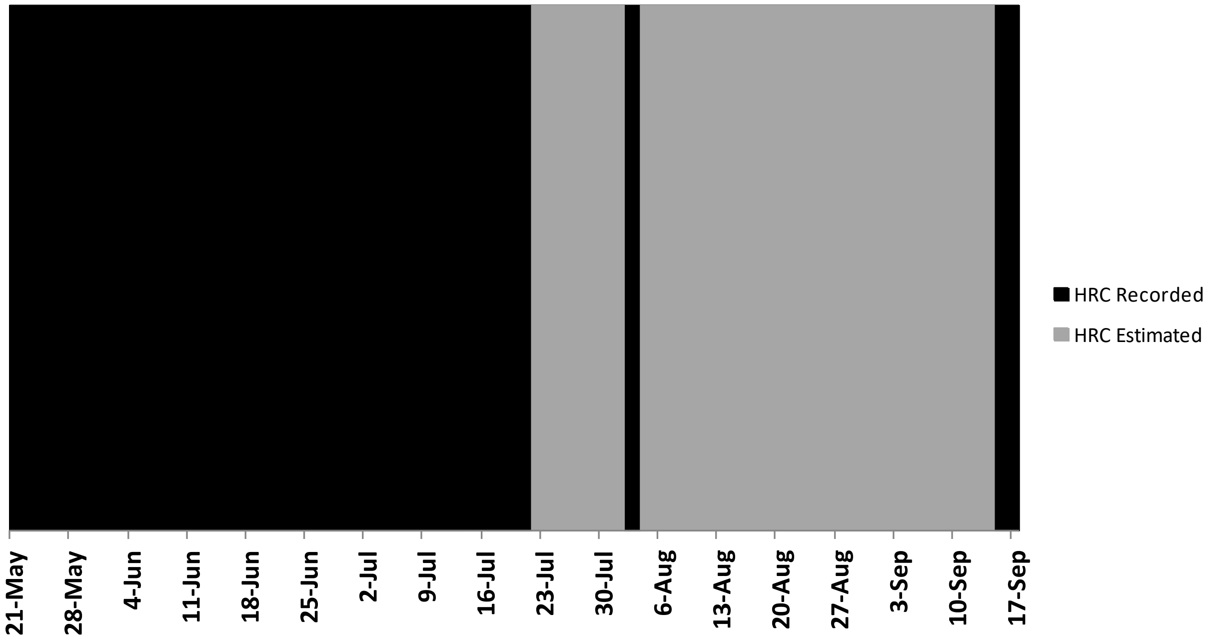


Figure 5b. Dates for which data was recorded or estimated in the Hunt Road channel during the Chinook season on the Elwha River in 2019. All missing dates were due to low water.

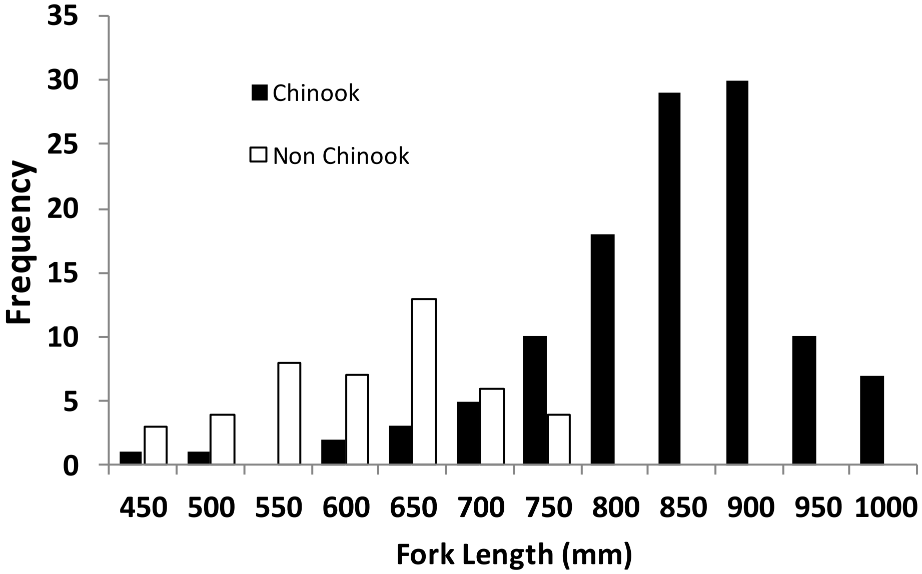


Figure 6. Length frequency histogram for all salmonids caught during 14 different sampling days between May 21, 2019 and September 17, 2019 in the Elwha River.

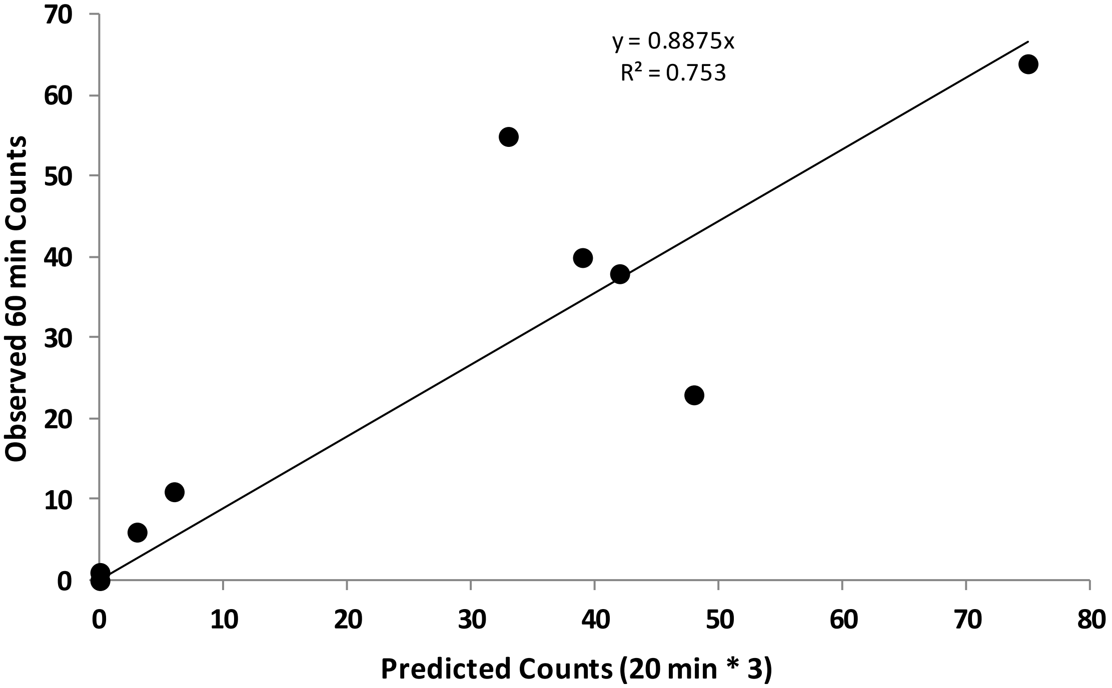


Figure 7. Predicted (20 minutes * 3) vs. observed (actual 60 minute counts) for 9 six-hour chunks of full hour counts for the Old Mainstem (OM).

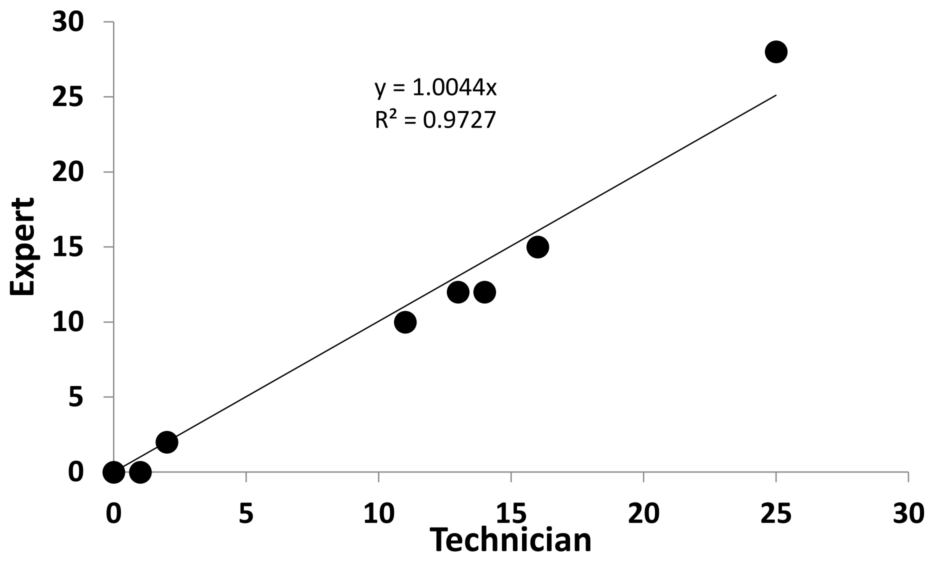


Figure 8. Total upstream passage counted by a technician and expert for 8 six-hour chunks .

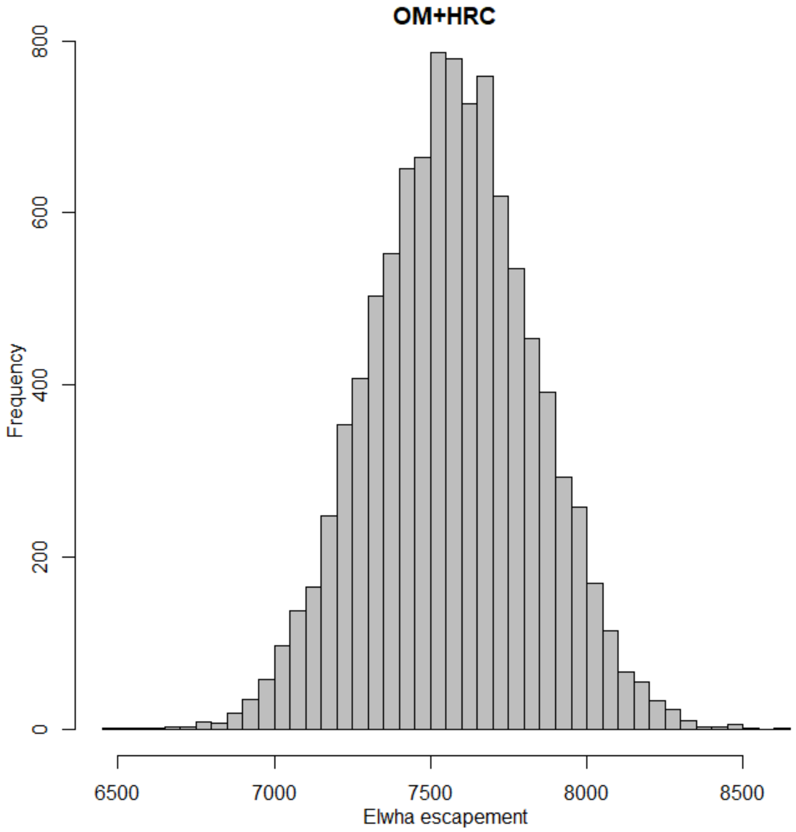


Figure 9. Old Mainstem (OM), Hunt Road Channel (HRC), and total (OM +HRC) Chinook run size estimates for the Elwha River in 2019 based on 10,000 model runs.

Figure 10. Daily Chinook passage and cumulative percent of total run for the Old Mainstem (OM), which also represents the entire run, in the Elwha River in 2019. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. Total passage estimate for the OM and the entire run was 7,600 Chinook salmon.

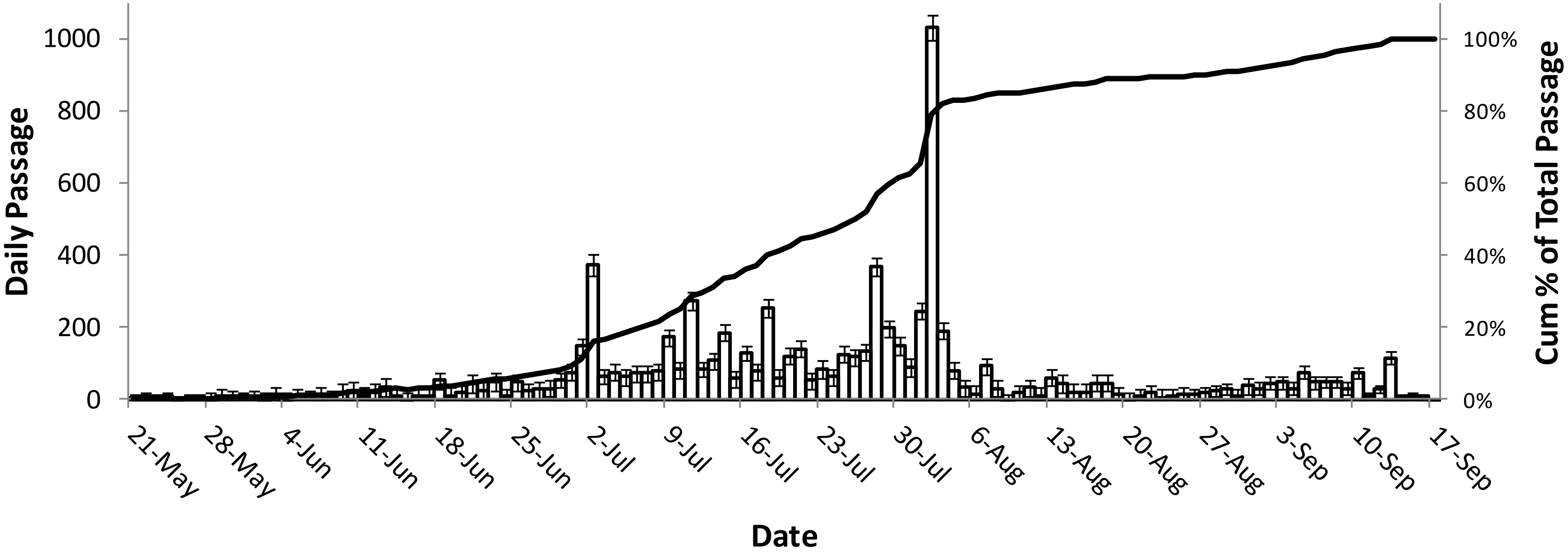
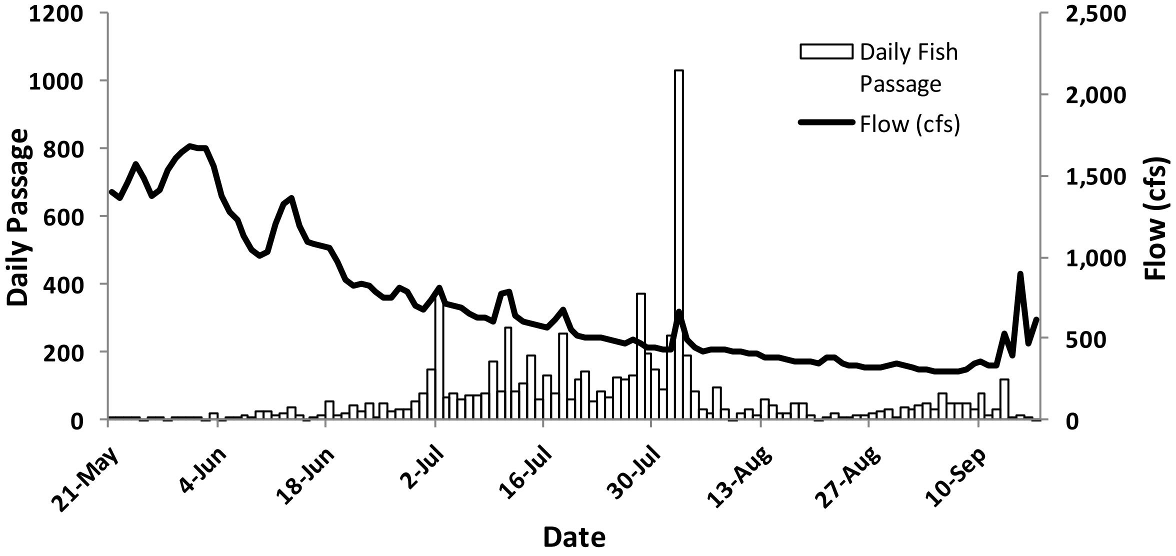


Figure 11. Daily Chinook passage and flow (cfs) for the Elwha River in 2019.



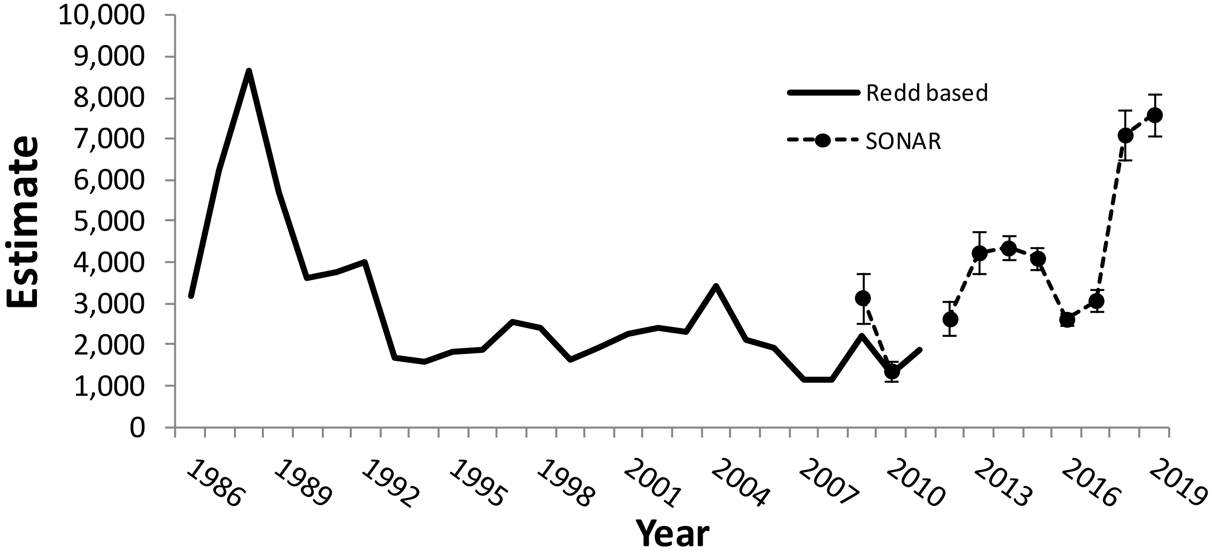


Figure 12. Historical Chinook escapement estimates from the Elwha River based on two different enumeration methods, redd counts and SONAR.