

2018 Elwha River Chinook Escapement Estimate Based on DIDSON/ARIS Multi-Beam SONAR Data



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This report is provided to Olympic National Park by the Lower Elwha Klallam Tribe in partial fulfillment of
task number 2 of contract number I40P2018C0042

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 June 6, 2018, through September 18, 2018. 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 7,107 fish, with a coefficient of variation of 3.2% (95% CI 6,598 – 7,821).

We also provide channel specific estimates of passage through the Hunt Road Channel (HRC), 531 fish (7.0% CV, 95% CI 450 – 618) and the Old Mainstem (OM), 6,576 fish (3.4% CV, 95% CI 6,131 – 7,025). In addition, we estimated coefficients of variation for each of the sources of uncertainty: species composition (1.1%), data gap fill (1.8%), observer error (2.1%), and 20 minute expansion (3.0%).

Fifty percent of the Chinook run passed the SONAR sites by July 31 in 2018, which was similar to 2015, 2016, and 2017 but 10 and 14 days later than in 2013 and 2014, respectively. We captured the first Chinook during species composition netting (June 6) one week later than the last two years, which was almost three weeks later than in 2015 (June 14 vs. May 20) and similar to 2014 (June 4).

Our escapement estimate of 7,107 non-jack Chinook salmon is about 800 fish more than the total of other Chinook encounters in the watershed. A peak spawning date redd survey from RKM 61.6 (near the headwaters) to the mouth occurred in late September and in combination with collections for the WDFW hatchery yielded an approximate total of 6,300 Chinook salmon.

The 2018 estimate of 7,107 fish is by far the highest in the 9 year history of the project (second highest 2014, 4,360) 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. A dramatic increase in the adult escapement in 2018 may portend future increases in the population as the riverine habitat moves beyond the deleterious effects of dam removal.

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 **I**Dentification **S**ONar (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 June through mid- September (see Denton et. al. 2010, 2012, 2013, 2014, 2015, 2016 and 2017 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. 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). In addition, the removal of both dams opens 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 must be monitored with two different SONAR devices. 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 2018 (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 but during June and July in 2018 approximately 35% of the flow went down the HRC, with the remaining 65% traveling down the OM; by August and September the proportion flowing down the HRC was closer to 15% (Mike McHenry, LEKT, personal communication). Two different SONAR units were used during the course of this study; a DIDSON LR (long range, 0.7/1.1 MHz, provided by NOAA Fisheries) and an ARIS 1800 (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° (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 June 6 through September 18, 2018 with the exception of a three day gap from August 25 through August 27, a three day gap from September 3 through September 5, a two day gap from September 10 to September 11 and a one day gap on September 16 (Fig 5a). Chinook passage was recorded continuously at the HRC site from June 6 through September 18, 2018, without any data gaps (Fig 5b). The SONAR was also in operation prior to June 6, 2018, throughout the winter and spring of 2018 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., 2018).

Species Composition

We conducted tangle net surveys on 12 different days between June 6 and September 18 to capture live adult salmonids at 7 different sites in the lower two kilometers of the river. 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 new entry, 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, mostly 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 captured far fewer jack Chinook in our net sampling this year and they were all below 550 mm so there was a relatively clean break in the length frequency histogram in 2018. In consideration of this, and the use of a 550 mm threshold for all previous years of the SONAR study, we selected 550 mm as the threshold of inclusion for SONAR measured targets in 2018 (Fig. 6). We only used passage events of observer confidence level 1 in the final escapement analysis. Less than three percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (96/3,251). Eleven percent of all downstream passage events that met the length criteria were recorded as observer confidence level 2 (88/758).

Raw targets meeting the above criteria were then aggregated into channel-specific six-hour chunks, four per day. Each channel specific six hour chunk 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 (432 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 9 six hour chunks for the HRC (Fig. 7a) and 25 six hour chunks for the OM (Fig 7b). 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. In previous years, we have combined 60 minutes counts across channels to adjust counts for both channels. This year we used channel specific 60 minute predicted vs. actual counts and residuals because the OM experienced significantly more passage than the HRC. Using the residual vector from the OM to add uncertainty to the HRC would have produced an unrealistically high CV because the residual for many of the predicted vs. actual counts in the OM were higher than the predicted 60 minute counts for most of the six hour chunks for the HRC. 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 June 6, so all targets after that date were included in further analysis. In-river netting on September 18 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, one fresh coho salmon (*Oncorhynchus kisutch*) greater than 550 mm in length was captured on both the September 13 and 18 sampling event. Therefore calculation of the 2018 Chinook salmon escapement only included SONAR targets recorded through September 18.

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:

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

where i represents the iteration (1 – 10,000), j indexes the 6-hour chunk (1 – 432) and k indexes the channel. The total number of fish, $N_{i,j,k}^{\text{total}}$, and total number of Chinook $N_{i,j,k}^{\text{chinook}}$ 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:

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

Thus, 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 28 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 June 6 and September 18, 2018, there were a total 2,520 hours (105 days) recorded on the HRC, and 2,304 hours (96 days) recorded on the OM. At least one of the channels was monitored for 2,520 hours out of a total of 2,520 hours, or 100% of the total possible hours. During this time period 4,794 fish passage events were recorded and analyzed. The best estimate for the Chinook escapement to the Elwha River in 2018 was 7,107 fish with a coefficient of variation (CV) of 3.2% (95% CI 6,598 – 7,821) (Table 2). A total of 531 (7% of total) Chinook (CV 7.0%, 95% CI 450 -618) went up the HRC, while

the remaining 6,576 (93% of total) Chinook (CV 3.4%, 95% CI 6,131 – 7,025) went up the OM (Figure 9). 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 (1.8%), (3) accounting for observer error (2.1%), and adjusting for species composition (1.1%) (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 June 6 and 25%, 50%, and 75% of the run had passed the SONAR sites by July 17, Jul 31 and August 29, respectively. Twenty five percent, 50%, and 75% of the run had passed the HRC by July 7, August 1, and September 10, respectively, and by July 18, July 31, and August 27 for the OM, respectively (Figs. 10, 11, and 12). Daily Chinook passage was also plotted against flow (Fig. 13). The run appears to begin in earnest (after July 4) when the hydrograph began to decline after the peak of snowmelt. Additionally, a late push of over 1,000 fish in early September occurred immediately before and during a doubling of the flow.

Discussion

Our estimate of 7,107 Chinook salmon provides a robust measure of Chinook escapement to the Elwha River in 2018 for several reasons. Most importantly we recorded data from approximately 96% of the run (4,824 of 5,040 hours). Furthermore, we feel confident that we accurately recorded the beginning of the run, June 6, and collected data until near the end of the run, September 18. Minimal passage occurred during almost the entire month of June; the weekly in-river netting operations indicated few Chinook were present in the river during that time period. Additionally, species composition sampling revealed approximately one third of the large bodied fish moving upstream in June were likely summer run steelhead (analysis of summer run steelhead data is presented in the projects steelhead report, Denton et. al. 2019). Species composition monitoring indicated that fresh Chinook 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, since the number of Chinook that pass the SONAR sites outside of these dates is largely unknown. 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) correcting for observer error, (3) gap filling and (4) adjusting for species composition. 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, but still quite low.

The highest source of uncertainty this year was due to expanding the 20 minute counts, at 3.8%, 2.4%, and 3.0%, for the HRC, OM, and both channels combined, respectively. Because the number of fish migrating up each channel was so disparate this year we used channel specific 60 minute counts. This was in an effort to deal with the fact that many of the residuals from the OM predicted vs. actual counts were actually higher than the total fish passage from the HRC. This would result in unrealistically high variation when expanding the HRC 20 minute counts. Additionally, for the OM, we used several

more 60 minute counts than previous years in order to smooth out the increased variation in the predicted vs. actual counts as compared to previous years. The wider 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 basically equal to 1. 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 was due to the observer error correction, at 13.2%, 1.7%, and 2.1%, for the HRC, OM, and both channels combined, respectively. The small CV associated with this adjustment indicates that while there may be a bias from the technician to the observer, that bias is consistent throughout the six hour comparison as evidenced by the high R^2 of the regression (.95). 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 2018 enabled us to capture very good imagery with low turbidity. The milling problem of previous years was effectively dealt with by moving the SONAR just above the riffle crest at the bottom of the reach in mid July. This produced exceptional imagery with fish passing one by one within 10 meters of the SONAR head. Similar to the expansion correction, this year's high fish passage rates produced several relatively high residuals from the technician vs. expert regression, particularly for six hour chunks with the highest fish passage. We only used six hour chunks from the OM to perform this correction, leading to a relatively high CV in the HRC because so few fish were counted in that channel as compare to the OM.

The third highest source of uncertainty in 2018 was associated with the gap filling procedure, at 0.0%, 1.9%, and 1.8%, for the HRC, OM, and both channels combined, respectively. We recorded data from the highest temporal period of the run this year, with zero gaps on the HRC and a total of only 9 days of data gaps on the OM. Unfortunately, most of the gaps on the OM occurred around the high passage days in early September. This was a period of time with very 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. 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 2018, which seems to becoming the norm, along with a descending hydrograph typically seen during the Chinook season facilitated the continuous operation of the SONAR stations.

The final source of uncertainty was adjusting for species composition, at 3.8%, 0.8%, and 1.1% for the HRC, OM, and both channels combined, respectively. 2018 was a non-pink year on the Elwha and coho salmon appeared later in our species composition sampling than previous years (September 13), leading to almost all of the fish captured being Chinook, thereby reducing the CV. The greatest number of non-Chinook captured netting operations were summer run steelhead throughout June and

into early July. However, this was a time of limited overall upstream passage so the presence of non-Chinook targets in the river did not have much effect on the CV of the species composition correction. If more non-Chinook fish greater than 550mm are encountered during the sample period, there will be a higher CV associated with the species composition correction.

We were able to deal with last year's issue of milling Chinook and the potential to mistake actively migrating coho at the end of the season for Chinook by moving the OM SONAR into fast moving water immediately upstream of the riffle crest at the downstream end of the reach. This produced imagery of fish that were actively migrating. The upstream passage of ~1,400 fish in early September immediately before our first capture of a coho salmon in our netting operation raises the possibility that some of those fish were actually coho, but we failed to characterize that in our netting operations. If that were the case, the run size estimate for Chinook could be several hundred fish lower. However, the fact that we only caught 2 non-jack coho during the two net sampling events in the weeks after the flow increase (September 13 and 18) makes the upstream passage of several hundred coho during that time period unlikely. A snorkel survey in early October from RKM 2 to the mouth revealed hundreds of adult coho but they were almost all concentrated in the lower ~500 meters of the river, adding further evidence to the unlikelihood that hundreds had moved well upstream a month earlier. Finally, other than summer run steelhead at the beginning of the Chinook run (June through early July) and a few coho at the end of the Chinook run, we did not capture any other non-Chinook salmon this year. We usually encounter several sockeye salmon and even a few even year pink salmon during our netting operations. In fact a snorkel survey of the lower 2 KM of river on July 26 revealed two sockeye salmon and the WDFW hatchery collections also recorded two sockeye salmon. There were obviously some non-Chinook salmon in the river that our netting protocol failed to capture, likely due to the very high numbers of Chinook in the river.

We compared our escapement estimate of 7,107 Chinook with other data collected in the watershed. A one-time peak redd survey was conducted in mid-late September from Godkin Creek (RKM 61.6) to the mouth. This survey recorded 1,601 redds, which represents roughly 4,003 fish (redds*2.5) (McHenry et al. 2019). Additionally, ~2,300 Chinook were collected for Washington Department of Fish and Game hatchery operations, although 500 males were returned to the river but they obviously would not have constructed any redds so would not be accounted for in the redd survey. This amounts to approximately 6,300 fish, or within 800 fish (9%) of our estimate. It is important to note that the male to female ratio of the WDFW hatchery collected fish was ~2:1 indicating the 2.5 fish/redd multiplier was likely low this year. McHenry et al. (2019) reported that 13.8% 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. Finally, in light of the fact that most all of the recorded redds were seen downstream from the mouth of Rica Canyon (RKM 25.7) 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 2018 Chinook escapement estimate of 7,107 is far greater than any other year of the project (second highest: 4,360 in 2014) 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 four years at sea before returning to spawn. Therefore, a majority of the 2018 returning adults were spawned, incubated, and subsequently outmigrated during the fall, winter, and spring of 2014 and 2015, after most of the physical effects of dam removal had subsided (Ritchie et al. 2018). While hatchery:natural proportions from this year's run are not available yet, it is important to note that, to date, the vast majority (~95%) of adult Chinook returning to the Elwha have been of hatchery origin and would be less effected by in-stream physical conditions. Although it is possible that improved estuary conditions may increase survival rates of both hatchery and naturally produced juveniles.

In comparison to prior years, this year's date at which 50% of the run had passed the SONAR site, July 31, was similar to the last three years but two weeks later than 2014 and five days later than 2013. In 2013, 2014, 2015, and 2016 the date at which 50% of the run had passed the SONAR was July 25, July 20, July 30, July 30, and August 1 respectively (Denton et. al. 2013, 2014, 2015, and 2016). The first Chinook salmon was captured during the in-stream netting operations on June 6, which was similar to 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 has remained basically unchanged for the past 4 years (Table 3).

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 only recommendation is to actively review the SONAR data (particularly the OM) in mid-late July to determine if fish are milling in front of it. Quickly moving the SONAR downstream to faster water this July greatly aided the efficiency and accuracy of our counts this year. With a forecasted run of ~10,000 Chinook in 2019 avoiding milling will be paramount to producing an accurate count.

Acknowledgments

The species composition sampling was aided by the help of numerous helpers in the field, namely Todd Bennett and Steve Corbett from NOAA's NWFSC; and Roger Peters and Jeff Johnson from the U.S Fish and Wildlife Service. The DIDSON SONAR was loaned to the project by NOAA's Northwest Fisheries Science Center and the ARIS SONAR was loaned to the project by Olympic National Park. Olympic National Park provided funding for the 2018 Chinook SONAR project.

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Table 1. Total number of “new” and “holding” Chinook and other salmonids which measured at least 550 mm captured by date at 7 sites during in-river netting operations on the Elwha River in 2018.

“Other” salmonids captured were: June all steelhead (presumed summer run), September all coho.

Date	Chinook	Other	% Chinook
6/6/2018	3	2	60%
6/13/2018	3	1	75%
6/27/2018	5	1	83%
7/10/2018	12	2	86%
7/17/2018	8	0	100%
8/1/2018	16	0	100%
8/13/2018	26	0	100%
8/21/2018	26	0	100%
8/30/2018	24	0	100%
9/6/2018	19	0	100%
9/13/2018	15	1	94%
9/18/2018	5	1	83%

Table 2. Channel specific individual coefficients of variation for each adjustment procedure. The overall CV reflects the uncertainty incorporating all four sources of uncertainty for each channel, 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	HRC	OM	Combined
Expansion	2.4%	3.3%	3.0%
Species Composition	3.8%	0.8%	1.1%
Observer Error	13.2%	1.7%	2.1%
Gap Fill	0.0%	1.9%	1.8%
Overall	7.0%	3.4%	3.2%

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



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 showing the picket weir and the ladder on which the DIDSON is mounted.



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.

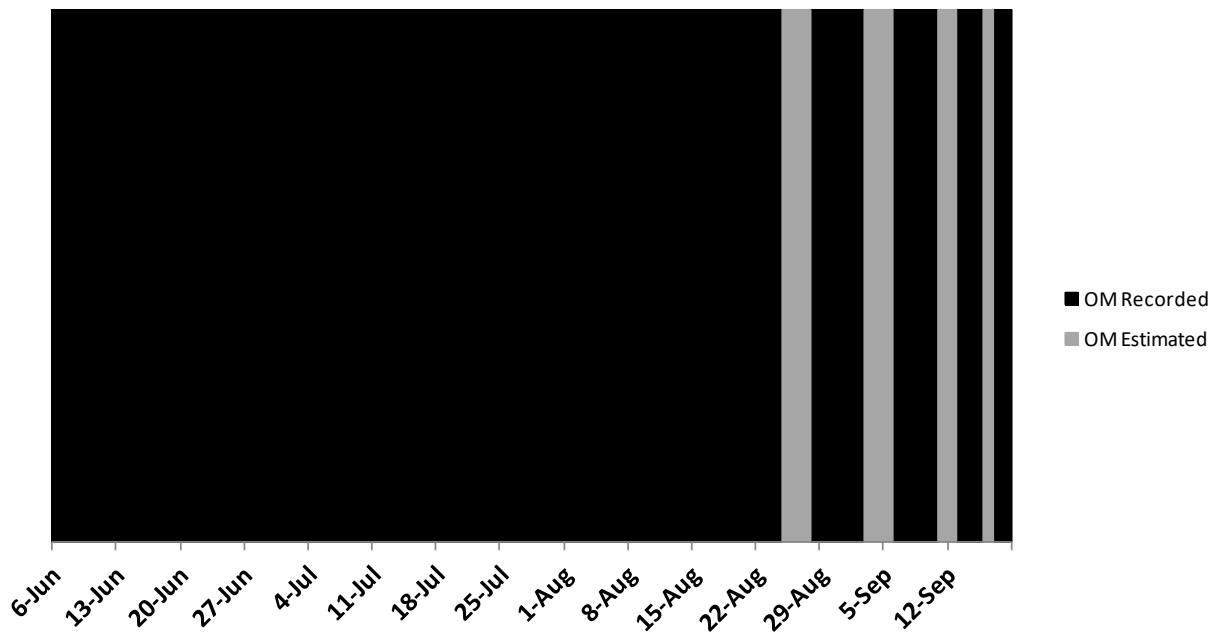


Figure 5a. Dates for which data was recorded or estimated in the Old Mainstem channel during the Chinook season on the Elwha River in 2018.

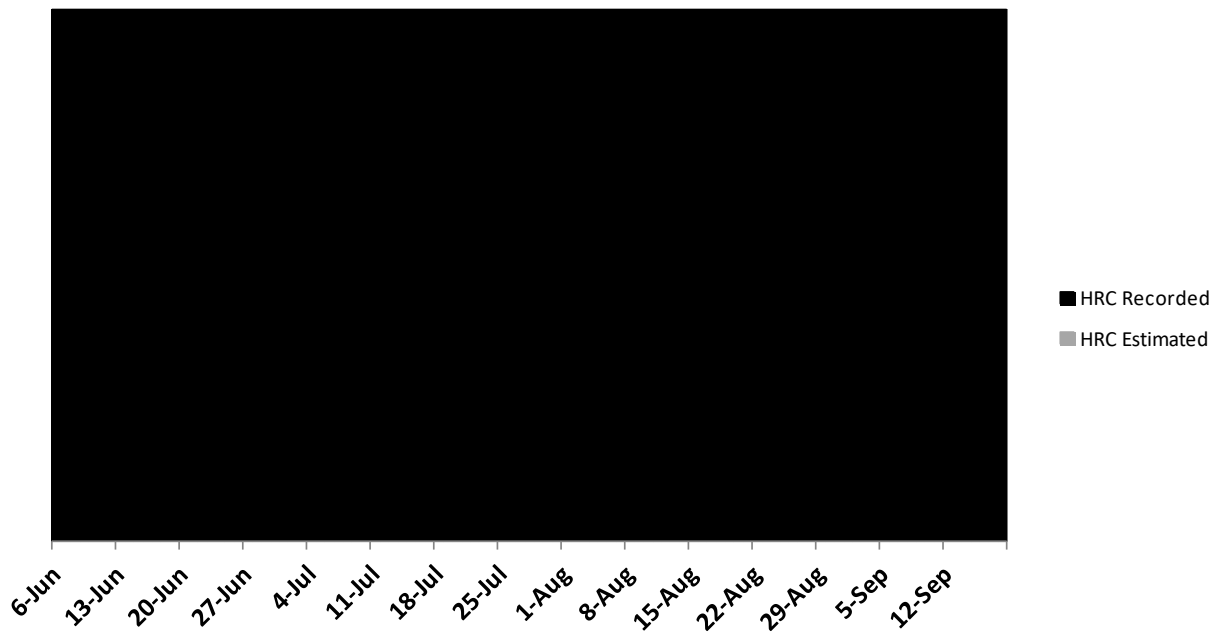


Figure 5b. Dates for which data was recorded or estimated in the Hunt Road channel during the Chinook season on the Elwha River in 2018. No dates were estimated for the Hunt Road Channel in 2018.

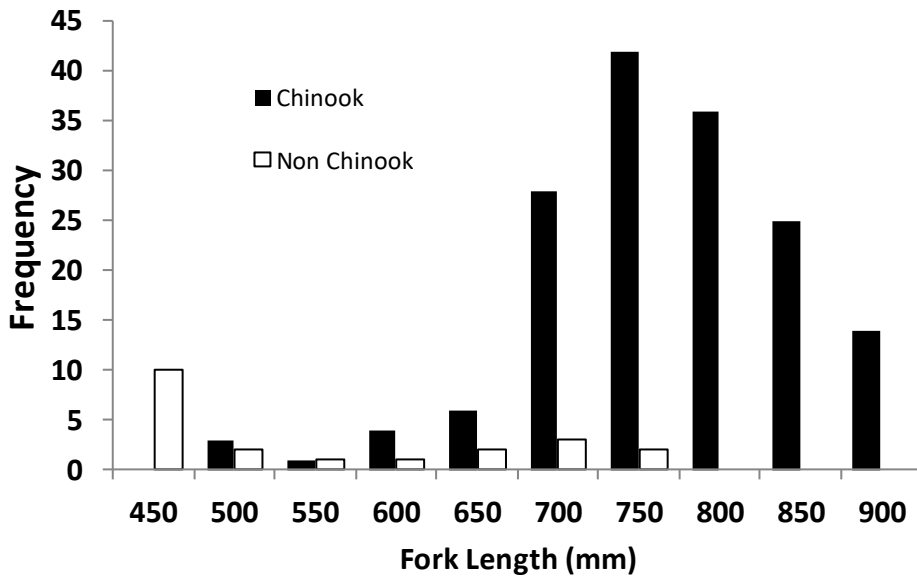


Figure 6. Length frequency histogram for all salmonids caught during 12 different sampling days between June 6th, 2018 and September 18th, 2018 in the Elwha River.

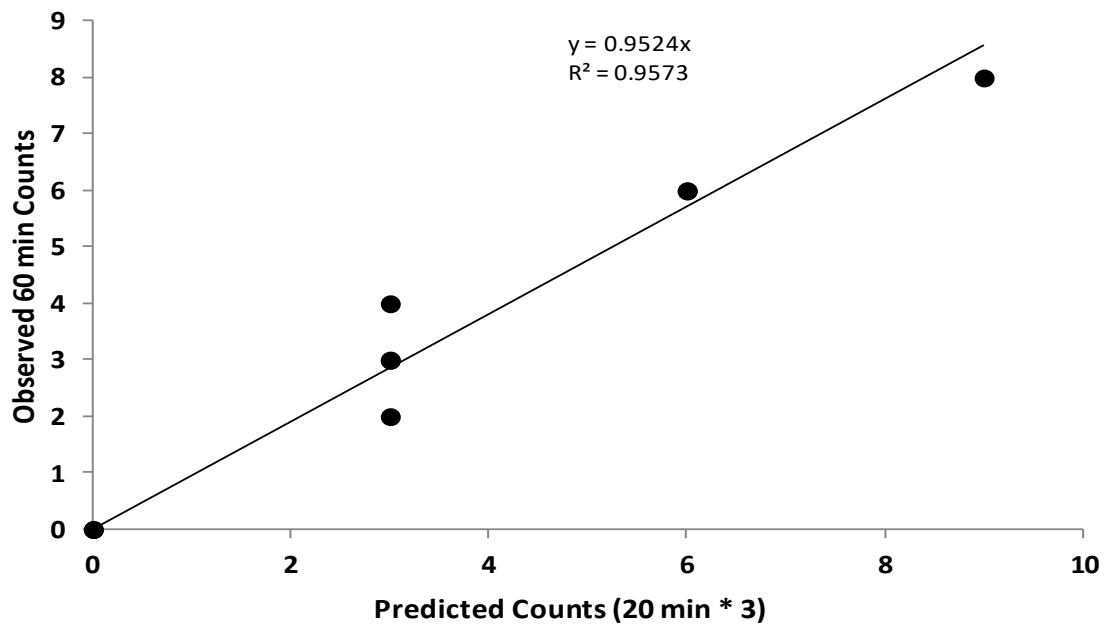


Figure 7a. Predicted (20 minutes * 3) vs. observed (actual 60 minute counts) for 9 six-hour chunks of full hour counts for the Hunt Road Channel. There are two points at (0,0), (3,3), and (6,6).

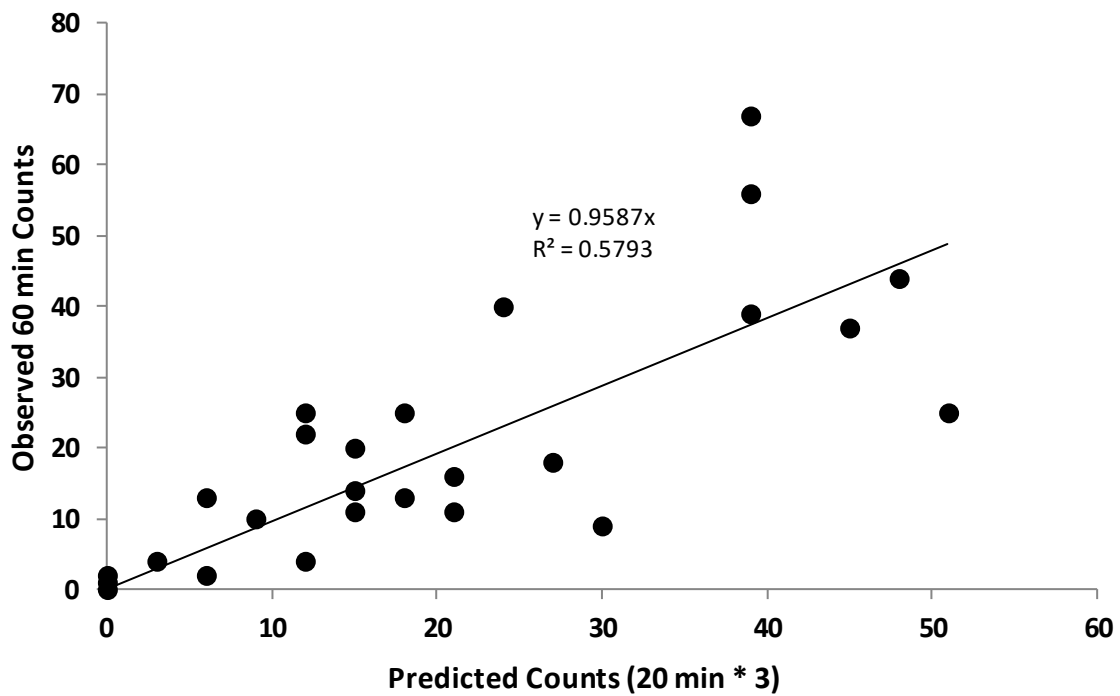


Figure 7b. Predicted (20 minutes * 3) vs. observed (actual 60 minute counts) for 25 six-hour chunks of full hour counts for the Old Mainstem.

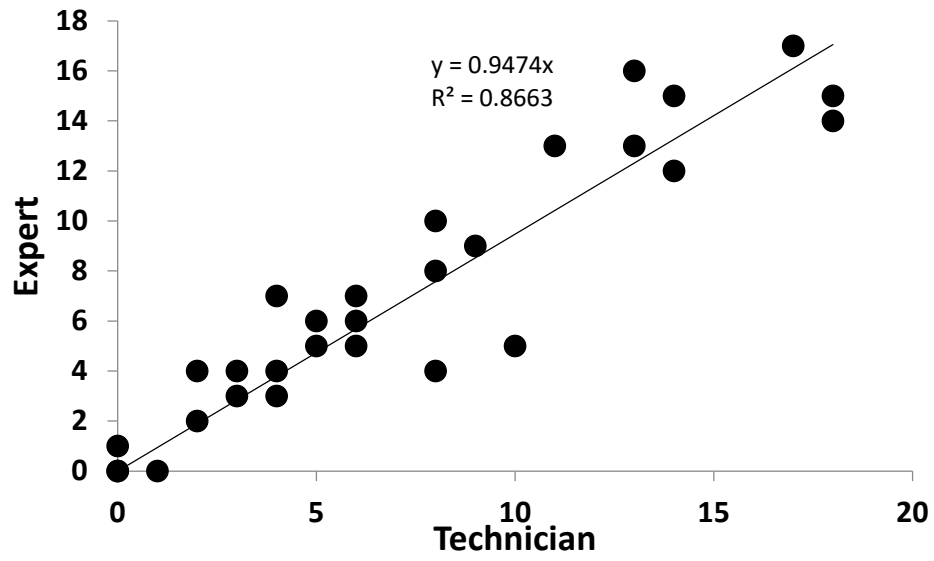


Figure 8. Total upstream passage counted by a technician and expert for 28 six-hour chunks .

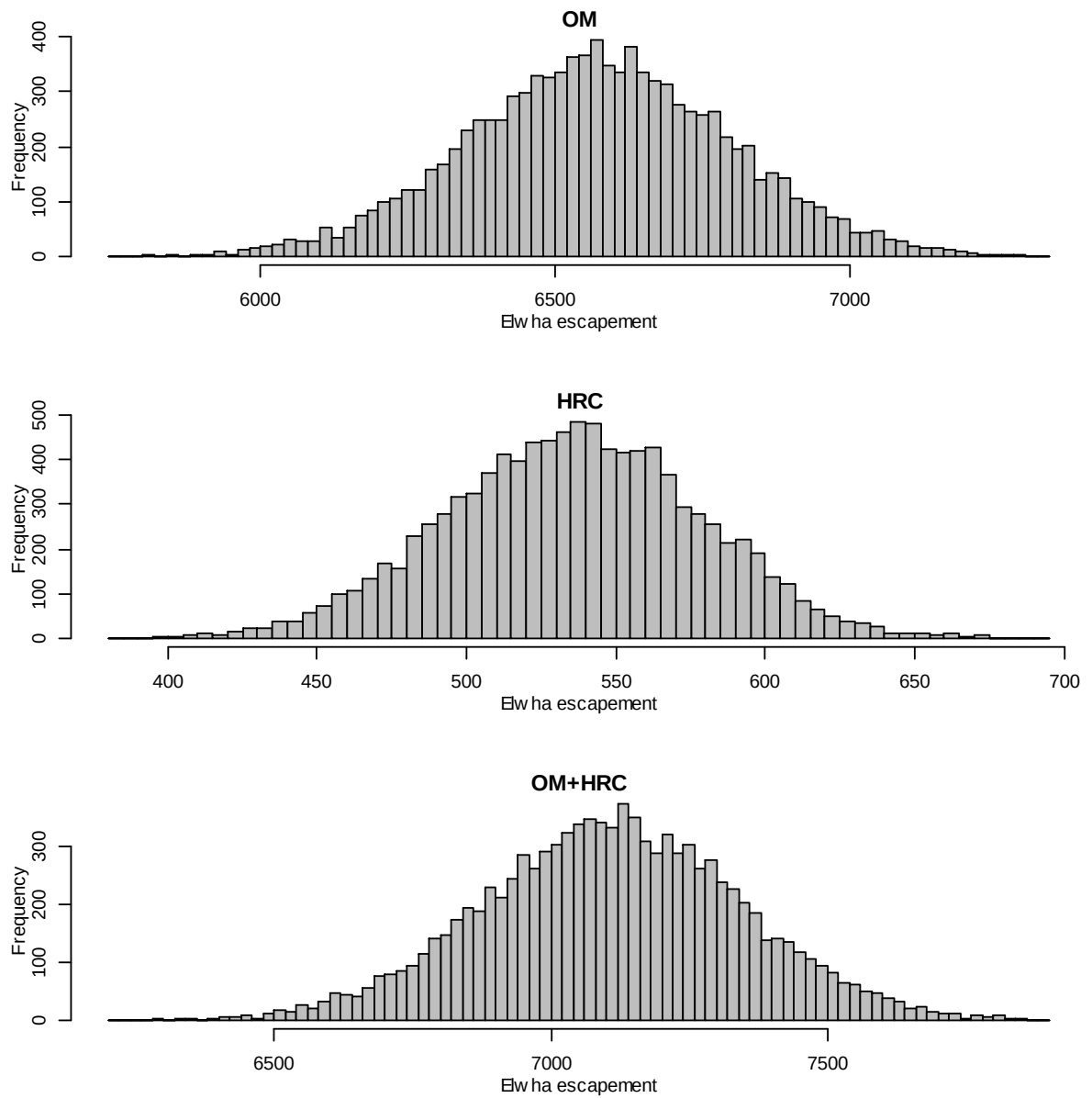


Figure 9. Old Mainstem (OM), Hunt Road Channel (HRC), and total (OM +HRC) Chinook run size estimates for the Elwha River in 2018 based on 10,000 model runs.

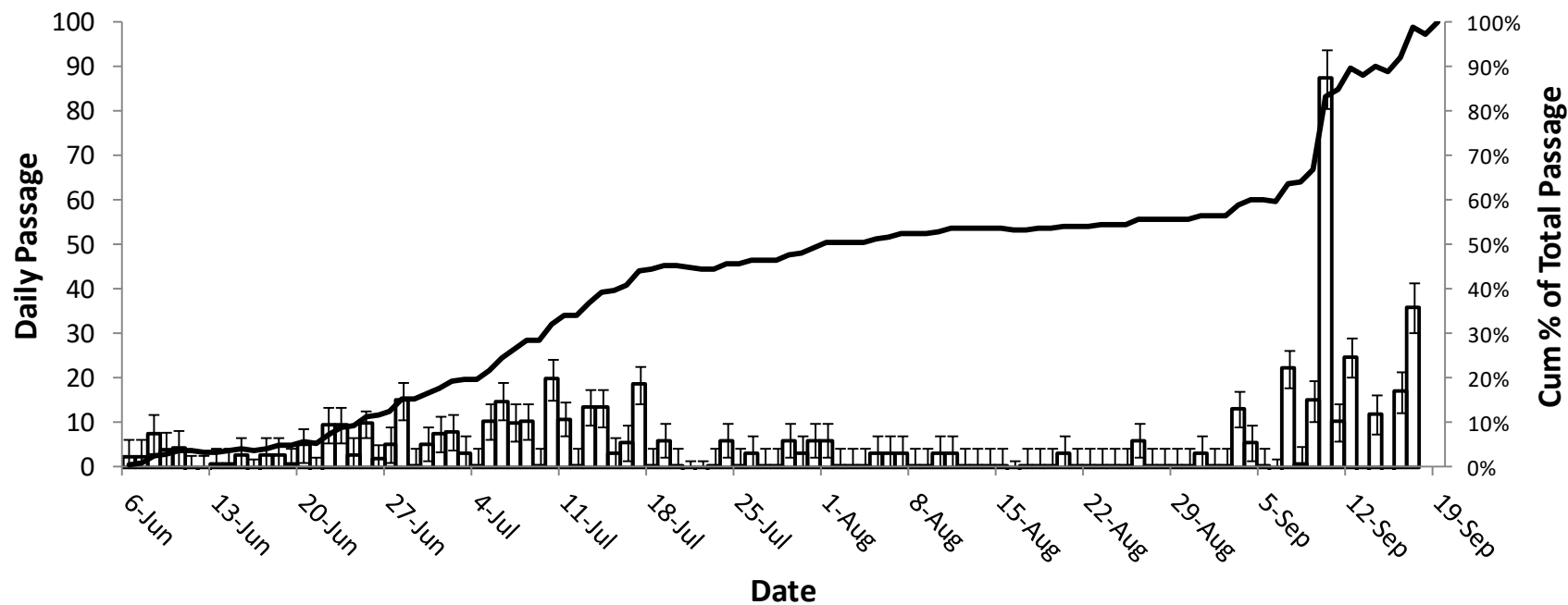


Figure 10. Daily Chinook passage and cumulative percent of total run for the Hunt Road Channel (HRC) of the Elwha River in 2018. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. Total passage estimate for the HRC was 531 Chinook salmon.

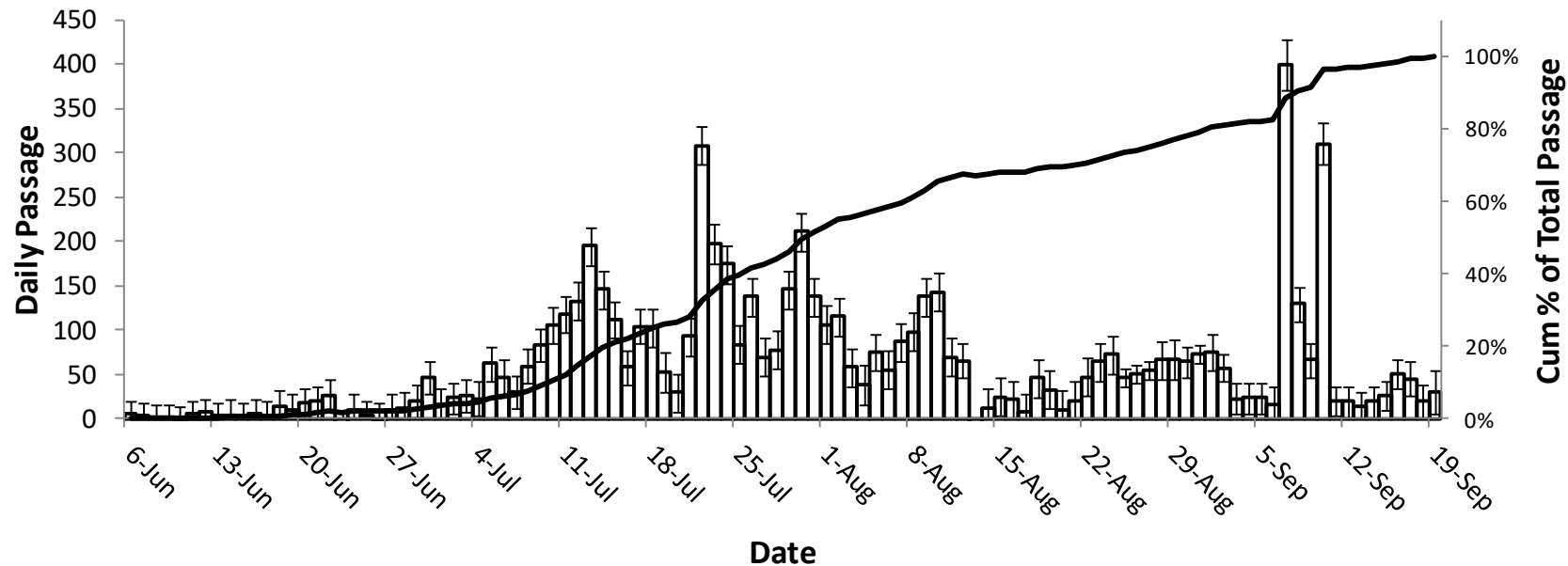


Figure 11. Daily Chinook passage and cumulative percent of total run for the Old Mainstem (OM) in the Elwha River in 2018. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. Total passage estimate for the OM was 6,576 Chinook salmon.

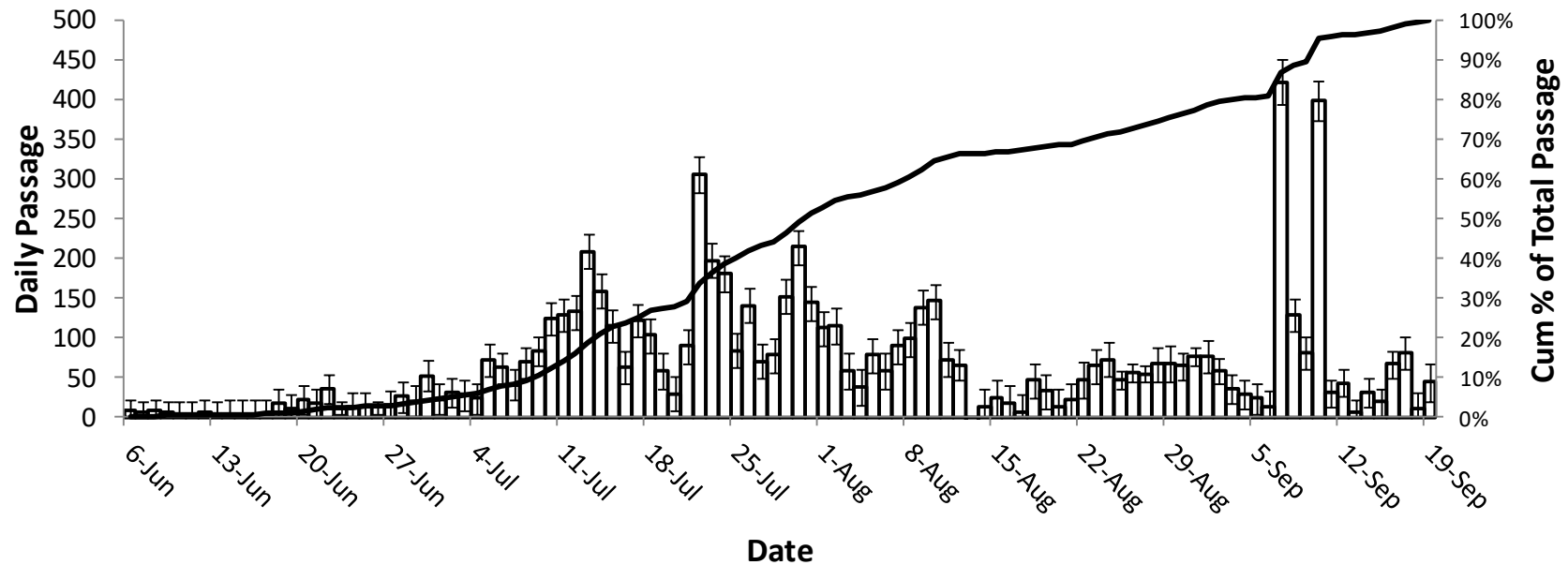


Figure 12. Daily Chinook passage and cumulative percent of total run for both channels combined (HRC and OM) in the Elwha River in 2018. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. The total passage estimate was 7,107 Chinook salmon.

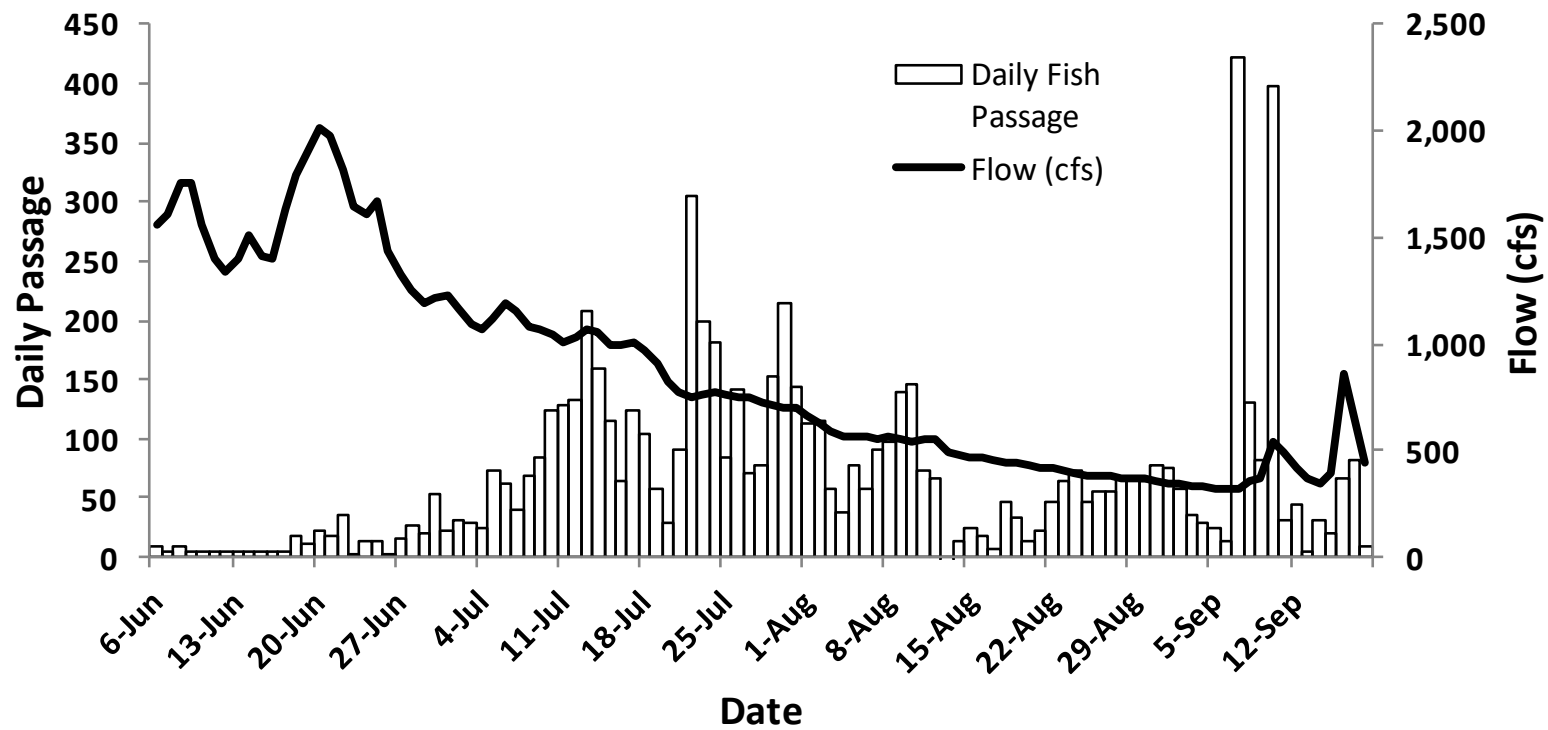


Figure 13. Daily Chinook passage and flow (cfs) for the Elwha River in 2018.

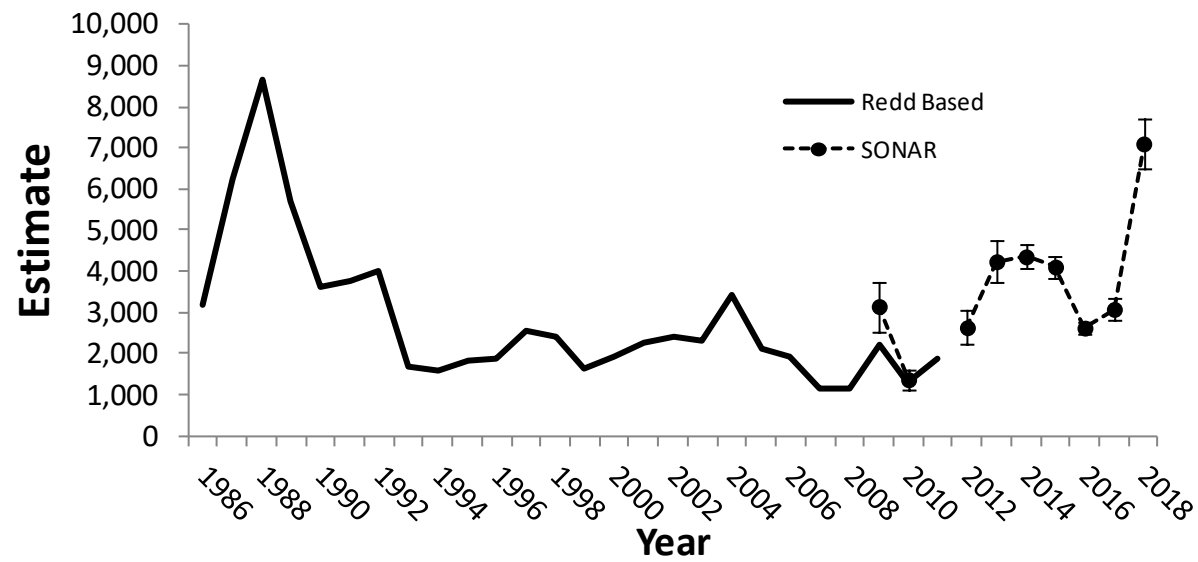


Figure 14. Historical Chinook escapement estimates from the Elwha River based on two different enumeration methods, redd counts and SONAR.