

2021 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 by the Lower Elwha Klallam Tribe in partial fulfillment of action item 1 (adult enumeration) for Elwha monitoring activities

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Executive Summary

We used an ARIS 1800 and a DIDSON (LR) multi-beam SONAR unit to monitor Chinook salmon escapement in the Elwha River daily from June 7, 2021, through September 20, 2021. 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 2,630 fish, with a coefficient of variation of 5.6% (95% CI 2,330 – 2,830).

We operated two SONAR sites, one in the Mainstem (formerly called the Old Mainstem) and one in the Hunt Road Channel (HRC) in 2021, as in every other year of the project. However, due to low flow in the HRC this year, approximately only 60 fish passed up that channel. Fish passage from that channel was included in the final escapement estimate but we did not adjust it for error or produce a CV for it.

Fifty percent of the Chinook salmon run passed the SONAR sites by July 30, which was a week later than 2019 but similar to 2015-2018 and 2020. We captured the first Chinook salmon during species composition netting on June 7, which was about the median date of first capture since 2013 (June 5).

Our escapement estimate of 2,630 non-jack Chinook salmon is approximately 500 fish more than the total of other Chinook salmon encounters in the watershed. A peak spawning redd survey from RKM 56 (near Carlson Canyon) to the mouth occurred in mid-September and in combination with collections for the WDFW hatchery yielded an approximate total of 2,170 Chinook salmon.

The 2021 estimate of 2,630 fish is essentially equal to the second lowest of the 12 year history of the SONAR project and approximately 1,200 fish lower than the average return during that time period. The relatively low return this year is surprising in light of the increased natural production of juveniles recorded over the last three years, the relatively high proportion of jacks in the 2020 return, and the continued large outplants from the WDFW hatchery.

At least 2,300 pink salmon returned to the Elwha River in 2021. Although the project does not explicitly enumerate this species, nor is there other comprehensive data on them from prior years, this likely represents the highest return since dam removal and possibly the highest return since the early 1960's, since pink salmon numbers were at very low levels for decades prior to dam removal.

Our major recommendation moving forward is to perform more species composition sampling in pink (odd years) to aid in the differentiation of Chinook and pink salmon in the SONAR data. Also, 2022 will mark the final year of the Park Service's ten year commitment to monitoring adult Chinook returns in the Elwha. Alternative funding sources must be identified to keep the project going.

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). While all of these technology and techniques have advanced to varying degrees, SONAR 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 relatively low error rates 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 (e.g. 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. 2010-2020 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 during specific windows of time 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 salmon spawning, are seldom an issue at this point post dam removal, SONAR estimates have been shown to be a more precise estimate of Chinook salmon 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 which is much more difficult to survey than the area below the former dams (Pess et al. 2008). Therefore, SONAR is the best technique for producing precise escapement estimates for anadromous salmon populations during and after dam-removal.

One of the species of most concern in the Elwha River is Chinook salmon, which is part of the Puget Sound Chinook Evolutionary Significant Unit (ESU) 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 dynamic environment that includes a consistently changing stream channel morphology due to relatively high stream power (Ritchie et al. 2016). Second, and applicable to many streams in the Pacific Northwest (PNW), is that the DIDSON/ARIS sites require 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 Puget Sound and the Olympic Peninsula, the Elwha River mainstem is an anastomosing or forested island 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 salmon and other species of migrating salmon in the river during the course of the Chinook salmon 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 have traditionally necessitated two separate SONAR installations to accurately detect Chinook salmon passage, one in the east channel, also referred to as the Mainstem and the other in the west channel, also referred to as the Hunt Road Channel (HRC). In each successive year less flow, and therefore fewer Chinook salmon have passed up the Hunt Road Channel (HRC) or west channel (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 decreasing each consecutive year with little flow during the summer months since 2019. In 2021 during June and July approximately 15% of the flow went down the HRC, with the remaining 85% traveling down the Mainstem; by August and September the proportion flowing down the HRC was less than 10%, and the channel was predominantly fed by groundwater (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 Mainstem (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 m across and 1.1 m depth in the thalweg, while the Mainstem site (Fig. 3) was 18-22 m wide and 2 m 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. 4). 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).

The Mainstem (formerly referred to as the Old Mainstem) site was powered by a 24-volt, 400 amp hour battery bank that was continually charged by an array of solar panels. Chinook passage was recorded at the Mainstem site from June 7 through September 20, 2021 with the exception of a six day gap from June 23 through June 28, a three day gap from July 16 through July 18 and a two day gap from August 14 to August 15 (Fig 5a). Chinook passage was recorded continuously at the HRC site from June 7 through July 15, 2021, when low water interrupted operations (Fig. 5b). Due to these low water conditions very little passage was recorded up the HRC (~ 60 fish). Therefore, data from the HRC was not pushed through the following data analysis procedure.

The SONAR was in operation prior to June 7, 2021, throughout the winter and spring of 2021 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., 2022a). Additionally, the SONAR was in operation after September 20 to record coho salmon passage. Data, analysis, and an estimate of coho passage for this time period is available in the project's coho report (Denton et al., in prep).

Species Composition

We conducted tangle net surveys on 14 different days between June 7 and September 20 to capture live adult salmonids at 6 different sites in the lower two kilometers of the river. Two netting sites were ~100 m above the Mainstem SONAR site and the other four were below the SONAR sites and below the channel split at ~Rkm 1. 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 1a) although all captured fish are also presented (Table 1b). The tangle-net was approximately 20 m long and 4 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, jack Chinook, and non-Chinook salmonids, which included mainly pink salmon, but also winter steelhead, chum salmon, and several coho salmon towards the end of the Chinook run.

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 650 mm as the cutoff for inclusion in the final escapement estimate this year to limit the inclusion of smaller bodied salmonids (mainly pink salmon and some jack Chinook salmon) in our final escapement estimate. We captured 60 pink salmon in our net sampling this year with all but one measuring less than 600 mm. We captured relatively few jack Chinook (<550 mm) in 2021 (4/81). An additional two Chinook measured 620 and 630 mm. All other Chinook measured in the field were equal to or greater than 650 mm (Fig. 6). Therefore, we raised the length cutoff from the 600 mm threshold of the previous few years up to 650 mm in 2021. We only used passage events of observer confidence level 1 in the final escapement analysis. One percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (16/1,017). Twenty-five percent of all downstream passage events that met the length criteria were recorded as observer confidence level 2 (34/132).

Data from the HRC was filtered for the previous length and quality requirements and then that raw number of upstream targets was simply multiplied by three (to expand 20 minutes count to full hour counts) to arrive at the total passage up that channel (~60 fish). These fish were then added on to the final, model derived, escapement estimate from the Mainstem which is described below.

Raw targets meeting the above criteria were then aggregated into channel-specific six-hour chunks, four per day. Each channel specific six hour chunk ($n = 432$) was then pushed through a four step adjustment simulation and summed 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 the Mainstem. 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 estimates of escapement at varying temporal scales (6-hour estimates, daily estimates, and annual estimates). Each step of this process was done for the Mainstem and then that data was summed to provide a total estimate 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.

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 12 six hour chunks for the Mainstem (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 on June 7, so all targets after that date were included in further analysis. In-river netting on September 20 revealed that 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, 2 fresh coho salmon (*Oncorhynchus kisutch*) greater than 650 mm in length were captured on the September 7 sampling event, with an additional 10 captured on the September 14 sampling event and 9 captured on September 20 (Table 1a). Therefore

calculation of the 2021 Chinook salmon escapement only included SONAR targets recorded through September 20.

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 1a). 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 – 452) 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:

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

This adjustment down weights 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 15 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 7 and September 20, 2021, there were a total 936 hours (39 days) recorded on the HRC, and 2,280 hours (95 days) recorded on the Mainstem. At least one of the channels was monitored for 2,424 hours out of a total of 2,544 hours, or 95% of the total possible hours. During this time period 2,723 fish passage events were recorded and analyzed. The best estimate for the Chinook salmon escapement to the Elwha River in 2021 was 2,630 fish with a coefficient of variation (CV) of 5.6% (95% CI 2,330 – 2,890) (Table 2, Fig. 9 and Fig 10). A total of 60 (2% of total) Chinook went up the HRC, while the remaining 2,570 (98% of total) Chinook (CV 5.6%, 95% CI 2,770 – 2,830) went up the Mainstem (Figure 10). In order of decreasing variance, the largest sources of error were (1) accounting for observer error (10.5%), (2) the uncertainty associated with expanding the 20 minute counts (3.8%), (3) error in the gap filling procedure (3.6%) and (4) adjusting for species composition (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 June 7 and 25%, 50%, and 75% of the run had passed the OM SONAR site by July 15, July 30 and August 12, respectively (Fig. 10). We caught the last non-spawning Chinook salmon on September 20 (Table 1a). Daily Chinook passage was also plotted against flow (Fig. 11). The run appears to begin in early July when the hydrograph began to decline after the peak of snowmelt. The two highest passage days were consecutive (August 11 and 12) but not associated with an increase in flow.

Discussion

Our estimate of 2,630 Chinook salmon provides a robust measure of Chinook escapement to the Elwha River in 2021 for several reasons. Most importantly we recorded data from approximately 95% of the run (2,448 of 2,640 hours). Furthermore, we feel confident that we accurately recorded the

beginning of the run, June 7, and collected data until near the end of the run, September 20. Minimal passage occurred during almost the entire month of June (only 4% 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 5% (4/81) 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) correcting for observer error (10.5%), (2) expanding the 20 minute counts to 60 minutes (3.8%), (3) filling data gaps (3.6%), and (4) adjusting for species composition (0.8%). 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 slightly higher than previous years but still quite low. Most of this increase can simply be attributed to the lower total escapement estimate which inversely affects the CV. An exception is the CV associated with observer error which was roughly triple what it has been in previous years and is discussed in more detail below.

As mentioned previously, only data from the Mainstem site was used for the model derived escapement estimate and calculated uncertainty estimates for the various corrections. Fish passage was measured in the HRC for the roughly the first quarter of the run when flows allowed, June 7 through July 14. This included from the initial Chinook salmon encounter during species composition sampling on June 7 through July 14, a time period when only 20% of the run had passed up the Mainstem site. Snowpack in the headwaters of the Elwha was relatively robust in 2021 and therefore total river flow during June was higher than the past several years with flows between 2,000 and 3,000 cfs for much of June. So, while the proportion of the total flow moving down that channel appears to be reducing in each successive year, flow down the HRC during the early portion of the Chinook run in 2021 potentially provided the opportunity for Chinook salmon to migrate up the HRC during the early part of the run. Although we did not process the HRC data using the model, we did count 20 fish moving up that channel during that time period. We multiplied these 20 fish times three to account for subsampling and added the subsequent 60 fish onto our total estimate from the Mainstem site.

The highest source of uncertainty this year was due to the observer error correction with a CV of 10.5%. While this is the highest CV associated with this correction over ten year period it is important to focus on the regression coefficient (.99) and the r^2 value (.86) of the regression relationship. The coefficient is basically equal to 1 meaning that, when considering all of the data that both the expert and technician reviewed, there was almost no difference in their total counts. This also means that the correction did not influence the final escapement estimate. The r^2 value indicates a reasonably good fit to the regression line but it is clear from the scatter of points around the regression line that the technician and expert counts for individual six-hour chunks varied and in fact never completely agreed. As previously described, this variation was used to estimate the CV associated with this portion of the

model and is a main driver of this year's higher CV. A likely cause of the disagreement between individual 6 hour chunks this year was the relatively high number of pink salmon concurrently migrating with Chinook salmon that made counting more difficult (see below for a discussion on pink salmon).

The second highest source of uncertainty this year was due to expanding the 20 minute counts, with a CV of 3.8%. The variation between actual and predicted 60 minute counts is characterized by the r^2 value of 0.83 which indicates a strong fit of the data. 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 (.95). 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 third highest source of uncertainty in 2021 was associated with the gap filling procedure, with a C.V. of 3.6%. As in every other year, we recorded data from a high proportion of the run this year, with a total of only 11 days of data gaps on the Mainstem. Six of these days were in late June when very few fish were migrating past the SONAR. Estimated passage during these gaps was ~255 fish or 10% of the total passage estimate. Over several years of operation, the project has worked out most of the potential technical difficulties that contribute to data gaps. The relatively high spring runoff this year complicated operations throughout June but we were able to record data throughout most of that month.

The final source of uncertainty was adjusting for species composition, with a CV of 0.8%. Raising the length cutoff to 650 mm this year effectively removed all other species from inclusion into the species correction with the exception of a few coho at the very end of the run. Therefore, throughout almost the entire run, there were no other species to apportion raw targets to and therefore the CV remained low.

An unmeasured source of error in our Chinook salmon estimate is related to the large number of pink salmon that returned to the Elwha in 2021. Although pink salmon lengths do not overlap with the vast majority of the large bodied Chinook salmon, simply having large numbers of salmon of multiple species migrating passed the SONAR's concurrently has the potential to add error to both the observer error correction and the species composition correction. By simply changing the model inputs to reflect pink salmon lengths and species composition we estimated that approximately 2,300 pink salmon migrated passed the Mainstem SONAR site this year. It is important to note that this is an extremely rough estimate and surely at the lower bound of the true pink salmon escapement primarily because data reviewers were not tasked with focusing on the smaller pink salmon. Many of the smaller bodied pink salmon that moved passed the SONAR were simply not counted in an effort to accurately and efficient count the target Chinook salmon. Nevertheless, they were numerous enough to greatly slow down the review process and potentially add error to accurately counting the larger bodied Chinook salmon. As previously mentioned, our observer error analysis indicated that this was the case, as repeated counts of the same file by an expert and technician showed the highest variability in ten years of the project (but were consistent when taken as a whole). Pink salmon at their current population level (roughly equal to the number of Chinook salmon) present more of a nuisance than a true problem

to accurately counting Chinook salmon although their numbers could increase dramatically in the near future.

Pink salmon existed at very low levels prior to dam removal presumably due to a lack of spawning area due to the large cobble substrate that dominated the sediment starved lower river. In the years immediately following dam removal, a small source population from which to rebuild along with a highly mobile sediment regime has combined to hamper pink salmon population increases in the Elwha. While our species composition net sampling is a poor proxy for abundance, we do sample in the same locations with similar effort every year. We have captured at least a few pink salmon in our species composition net sampling every year (including even years) going back to 2013, with the two biggest encounters before this year being 22 fish in 2013 and 52 fish 2015. Not coincidentally, in both 2013 and 2015 roughly a million pink salmon returned to the nearby Dungeness River. It is likely that the fish that were sampled in the Elwha in 2013 and 2015 were simply strays from the Dungeness's historic runs. In 2021 approximately 160,000 pink salmon returned to the Dungeness River, some of which certainly could have strayed to the Elwha River. However, considering the 2021 pink salmon run to the Dungeness was much smaller than 2013 or 2015 yet we still encountered more in our net operations along with a SONAR based estimate of at least 2,300 fish, it appears as though the pink salmon population in the Elwha is at least showing the beginnings of recovery. While pink salmon recovery is promising from an ecosystem recovery point of view, from a Chinook salmon enumeration point of view, pink salmon numbers in the range seen on the Dungeness will greatly complicate using SONAR to enumerate Chinook salmon (see recommendations below).

We compared our escapement estimate of 2,630 Chinook with other data collected in the watershed. A peak redd survey was conducted in mid September Rkm 56 to the entrance 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 494 redds, which represents roughly 1,240 fish (redds*2.5) (McHenry et al. 2022). Additionally, 933 adult Chinook salmon were removed from the river for WDFW broodstock needs. The combination of these two data sources yields a total of 2,170 adult Chinook in the Elwha in 2021. This represents roughly 83% of our SONAR based estimate. McHenry et al. (2020) reported that 18% (89/494) of the redds were recorded upstream of the former Glines Canyon dam indicating that, for the fifth year in a row, Chinook salmon utilized at least a portion of the additional ~48 KM of mainstem and ~28 KM of tributary habitat that were previously inaccessible (Brenkman et. al. 2008). Our SONAR based estimate being greater than the redd count plus broodstock removal total is consistent with previous years and not unexpected for a variety of reasons, mainly undetected spawning and redd superimposition. 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 possible that additional redds went undetected particularly because the section upstream of the Grand Canyon was surveyed one to two weeks before the historical peak of spawning. Canyon reaches are also not surveyed but spawning is usually observed at the upper and lower ends of some canyon sections, particularly Rica Canyon. Juvenile Chinook salmon have been recorded in these upper river reaches in both electrofishing and snorkel surveys from 2018 to 2020, with the highest RKM observation at the Hayes River confluence (RKM 51.3) in 2019, indicating that Chinook salmon have spawned at least at low densities in these

upstream reaches (ONP, personal communication, 2021). While it is possible that Chinook salmon once again spawned undetected in the upper watershed it is unlikely that they did so in significant numbers, particularly because no redds were seen in the relatively accessible Geyser Valley in 2021 (McHenry et al. 2022). Redd superimposition certainly occurred again in 2021 although not to the extent that it did in 2018 and 2019 when there were much higher Chinook densities. Redd superimposition would result in an undercount of redds. Finally, additional spawning likely occurs in some portions of the watershed after the one pass redd survey is conducted because active entry of Chinook into the lower river occurred until September 20 as evidenced by our species composition netting. These fish would have spawned after the peak redd survey date of September 22. For these reasons, the redd count total should simply be considered a peak count that is indicative of spatial distribution and not a total count.

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 2021 Chinook escapement estimate of 2,630 is smaller than the average of the project (~4,000) going back to 2009 (Table 3, Figure 12). This year's return is roughly equal to the average Chinook run going back to 1986. 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 salmon are age three or four when they return as adults (Weinheimer et al. 2018). Therefore, a majority of the 2021 returning adults were spawned incubated, and subsequently outmigrated during the fall, winter, and spring of 2017-2018 and 2018-2019. 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 salmon egg incubation and survival in the mainstem at this point. These impacts resulted in low numbers of naturally produced juvenile outmigrants between 2014 and 2018 (McHenry et al. 2020). However, in 2019, 2020, and 2021 approximately 571,000; 950,000 and 292,000 natural 0+ outmigrants were estimated to have been produced in the river, respectively, indicating that significant natural production is occurring (McHenry et al. 2022). In 2020, the project sampled the highest proportion of jack Chinook salmon in our species composition sampling to date. This high jack return was possibly a result of the large natural outmigration of 2019. A high jack return would typically predict a large three year old return the following year. This phenomenon, coupled with the large natural 0+ outmigration in 2020 along with other age data led managers to predict a return of ~4,800 Chinook to the river in 2021, or 2,200 fish more than our escapement estimate. So, while incubation and rearing conditions for naturally spawning fish in the river appear to be improving, adult returns, at least in the short term, do not appear to be showing the same improvement. It is important to note that hatchery:natural proportions for the 2021 Chinook return are not available as yet, but the vast majority of adult returns have been hatchery origin through 2020 (Weinheimer et al., 2018, Joe Anderson, WDFW, pers. comm.). Therefore, even with the potential for some naturally produced outmigrants to have returned as 3 year olds this year, 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, for the 2014 through 2018 time period, as measured by a smolt trap in the mainstem, was only about 3% of hatchery outputs (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 at longer time scales.

In comparison to prior years, this year's date at which 50% of the run had passed the SONAR site, July 30, was similar to last year and 2015-2018 and roughly one week later than 2013, 2014 and 2019 (Table 3) (Denton et. al. 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020). The first Chinook salmon was captured during the in-stream netting operations on June 7, which is roughly the average date of first capture since 2013. So, the date of first Chinook salmon capture has varied by a month between late May and late June since netting operations started in 2013. However, the Chinook salmon run does not begin in earnest until July 4 and the date at which 50% of the run has past the SONAR sites remains within roughly of week of each other each year (Table 3). It is interesting to note that the Elwha River saw the highest spring runoff in several years with flows staying between 2,000 and 3,000 cfs for much of June and not dropping below 2,000 cfs until July 4, and yet the overall run timing of Chinook remained basically unchanged. Unlike many previous years of the project, the two biggest days of passage (August 11 and 12) were not linked to a rain induced increase in flow in August or early September. It is unclear why so many fish moved upstream in such a short period of time. The phenomenon of several hundred if not a thousand Chinook holding in the lower ~2 Km of river from early August until the onset of spawning was also apparent this year.

Recommendations

Our recommendations relate to the difficulty surrounding and dealing with non-target species. Previous year's concern has been focused on coho salmon in September and summer steelhead during the course of the Chinook salmon run. As the pink salmon population rebuilds in the Elwha it will be important to get as many field measurements from them as well as Chinook salmon in order to accurately differentiate them in the SONAR data. Concurrently, more resources will be required to deal with increased processing time due to simply more fish in a given file and also to more accurately measuring targets in the SONAR imagery to reduce species apportionment error. There has been encouraging developments in using machine learning and artificial intelligence to count and measure SONAR targets. These efforts should be supported and Elwha data should be used for testing and developing these new technologies. Finally, 2022 will be the last year of Olympic National Park funding for the Chinook SONAR project. New funding sources will need to be identified in the near future.

Acknowledgments

The species composition sampling was aided by the help of numerous helpers in the field, namely Roger Peters from the U.S Fish and Wildlife Service and Mel Elofson and Sonnie Sampson from the Lower Elwha Klallam Tribe. This report greatly benefited from the review of Pat Crain from Olympic National Park. 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 2021 Chinook SONAR project.

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Table 1a. Total number of “new” and “holding” Chinook and other salmonids which measured at least 650 mm captured by date at 8 sites during in-river netting operations on the Elwha River in 2021.

Date	Chinook	Steelhead	Coho	Chum	% Chinook
6/7/2021	1				100%
6/8/2021	2	1			67%
6/17/2021	1				100%
7/7/2021	1				100%
7/14/2021	8				100%
7/19/2021	5				100%
7/26/2021	4				100%
7/29/2021	3				100%
8/2/2021	8				100%
8/16/2021	7				100%
8/23/2021	11				100%
9/7/2021	5		2	1	63%
9/14/2021	7		10		41%
9/20/2021	1		9	1	9%

Table 1b. Total number of all salmonids of all lengths captured during the Chinook run by date at eight sites in the lower 2KM of river during in-river netting operations on the Elwha River in 2021.

Date	Chinook >600 mm	Chinook <600 mm	Pink	Bull trout	Chum	Coho	Steelhead
6/7/2021	1			1			
6/8/2021	2			1			1
6/17/2021	1						2
7/7/2021	1						
7/14/2021	8	2					
7/19/2021	6		3				
7/26/2021	4						
7/29/2021	3						
8/2/2021	11	1	7				
8/16/2021	7		5				
8/23/2021	11		9			1	
9/7/2021	6		16		1	5	
9/14/2021	9	1	17		1	24	
9/20/2021	7		3		1	22	
Total	77	4	60	2	3	52	3

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	Mainstem (Total)
Expansion	3.8%
Species Composition	0.8%
Observer Error	10.5%
Gap Fill	3.6%
Overall	5.6%

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
2020	3,250	3,015 - 3,487	3-Jun	31-Jul
2021	2,630	2,330 - 2,890	7-Jun	30-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 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 almost all fish passage up this channel in 2021.



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. Mainstem SONAR site (formerly referred to as the Old Mainstem). The SONAR is attached to the pole mount which is in turn attached to the ladder.

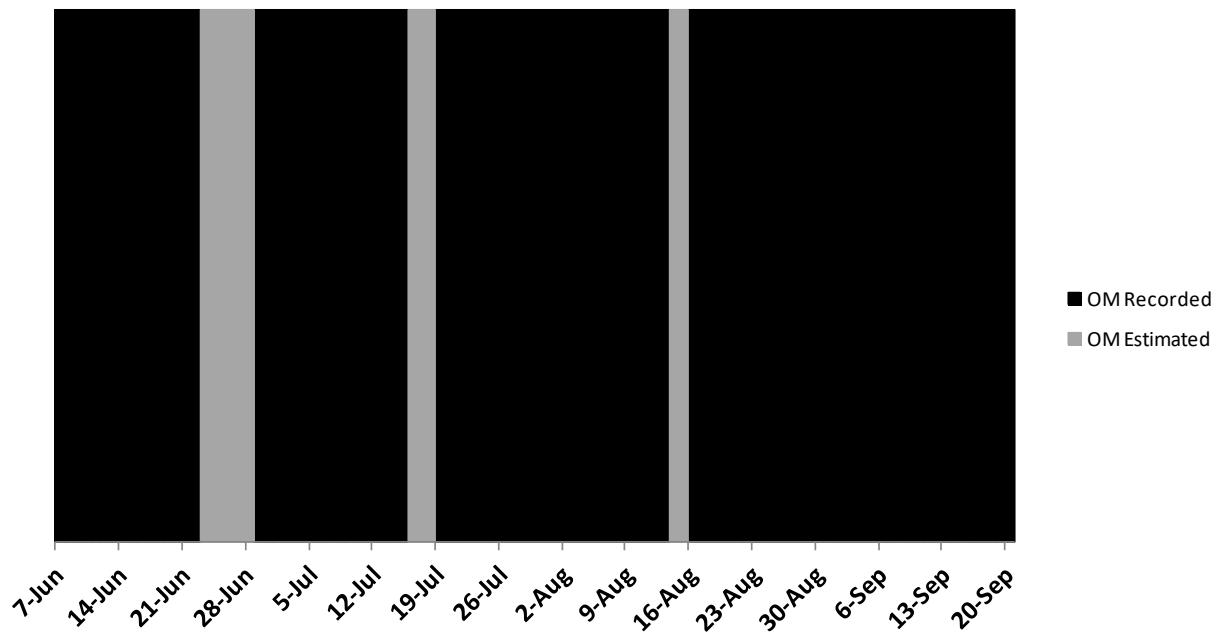


Figure 5a. Dates for which data was recorded or estimated in the Mainstem channel during the Chinook season on the Elwha River in 2021.

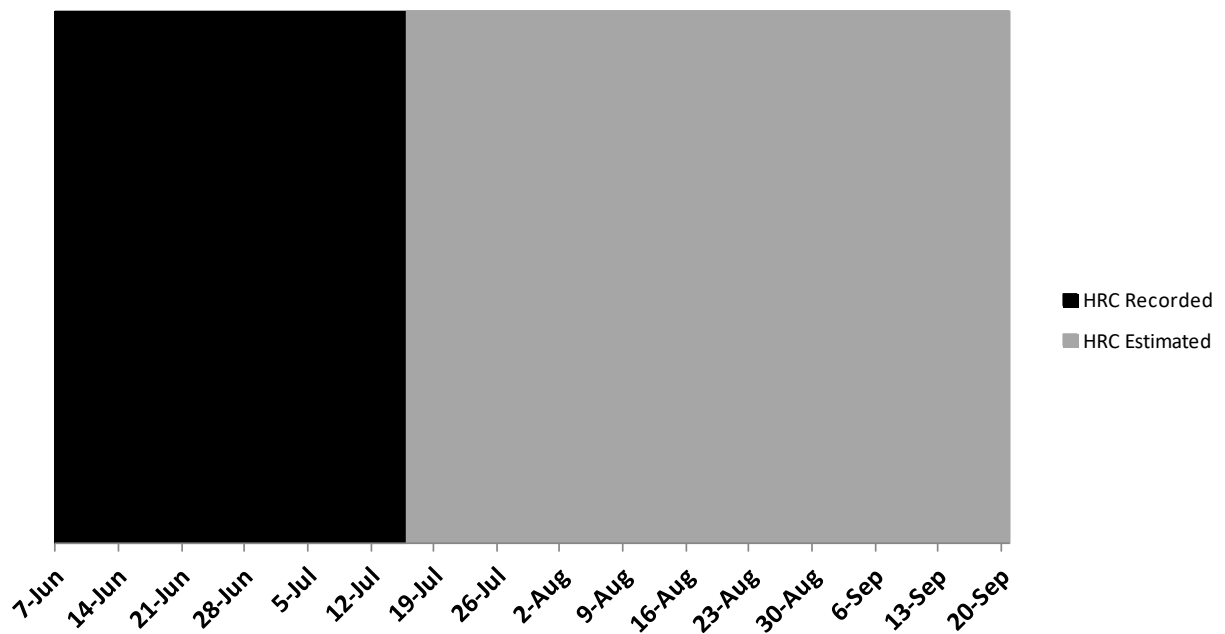


Figure 5b. Dates for which data was recorded or estimated in the Hunt Road channel during the Chinook season on the Elwha River in 2021. All missing dates were due to low water.

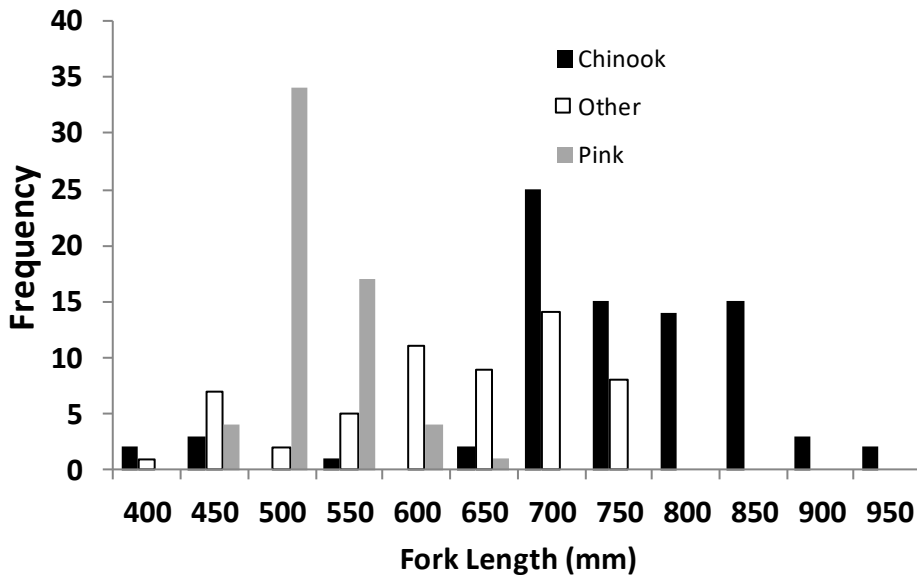


Figure 6. Length frequency histogram for all salmonids caught during 13 different sampling days between June 7, 2021 and September 20, 2021 in the Elwha River.

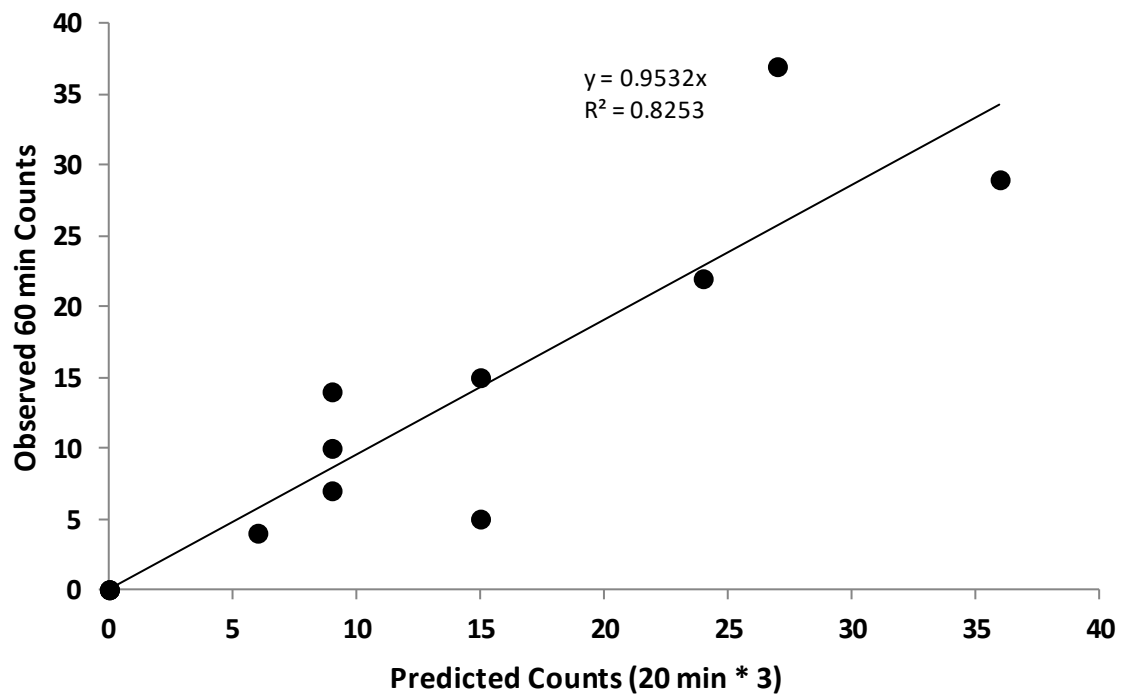


Figure 7. Predicted (20 minutes * 3) vs. observed (actual 60 minute counts) for 12 six-hour chunks of full hour counts for the Mainstem. There are three points at (0,0)

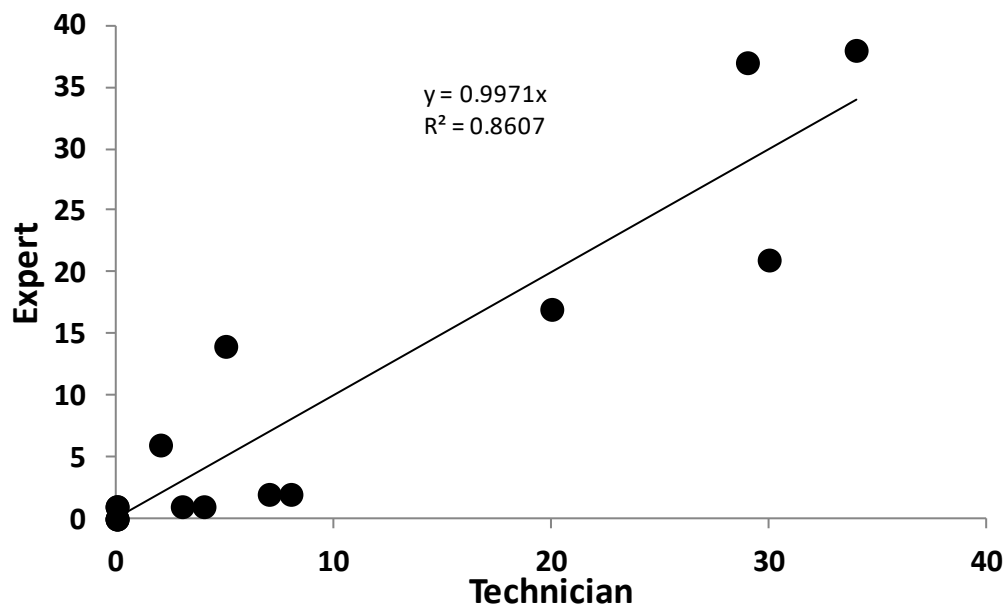


Figure 8. Total upstream passage counted by a technician and expert for 15 six-hour chunks. There are three points at (0,0).

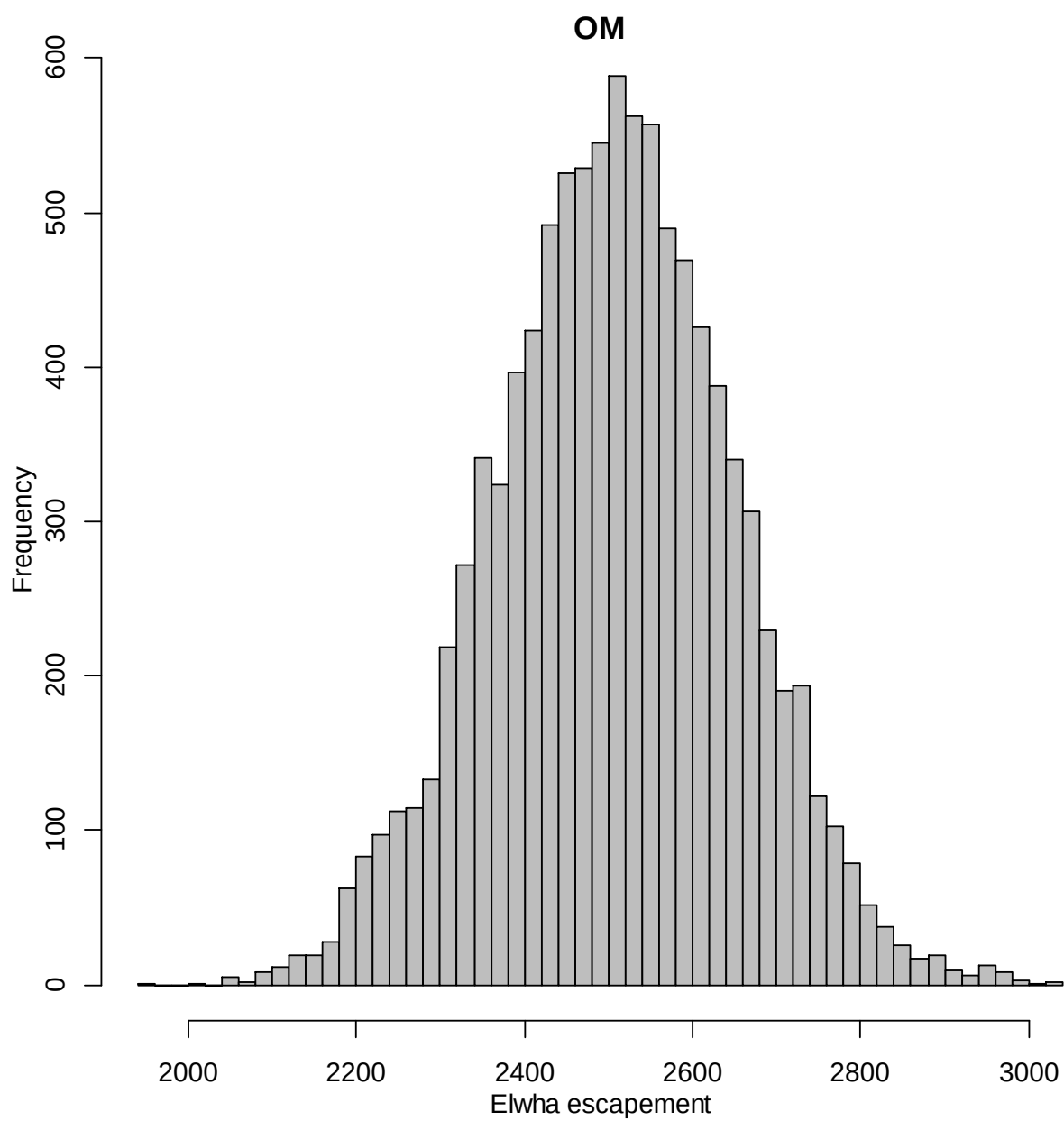


Figure 9. Chinook run size estimates for the Elwha River in 2021 based on 10,000 model runs.

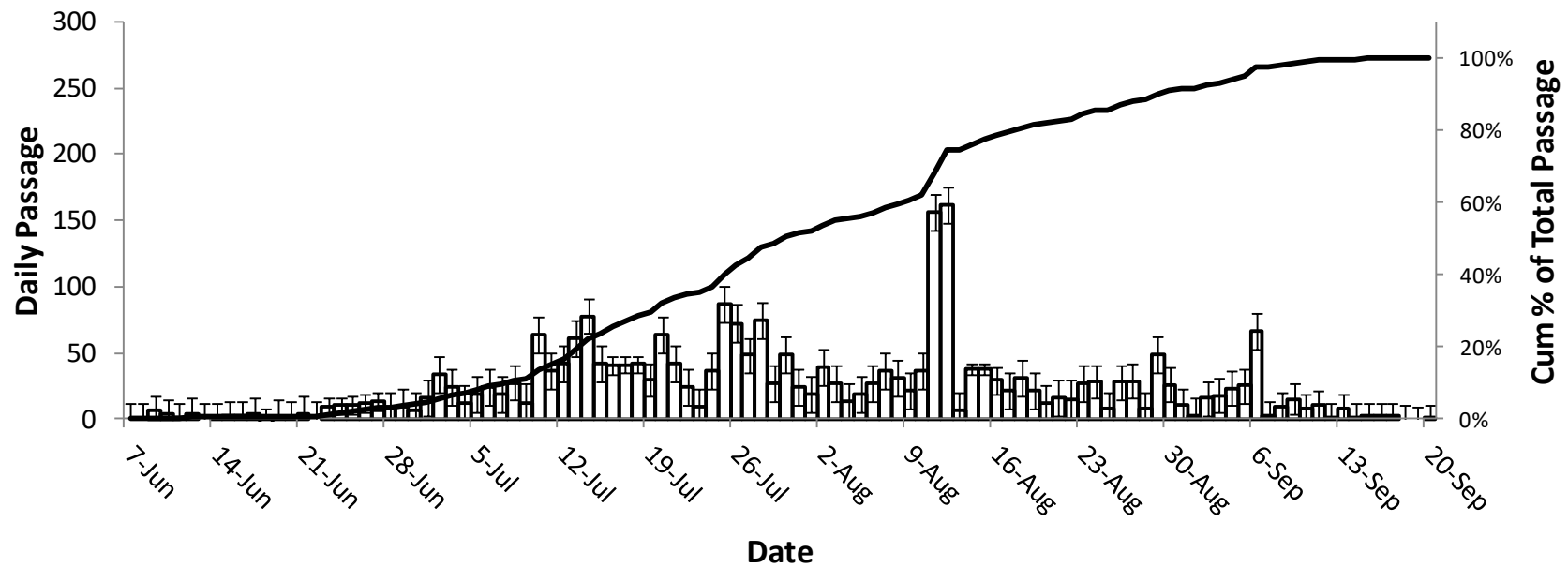


Figure 10. Daily Chinook passage and cumulative percent of total run for the Mainstem, which also represents the entire run, in the Elwha River in 2021. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. Total passage estimate for the Mainstem and the entire run was 2,568 Chinook salmon.

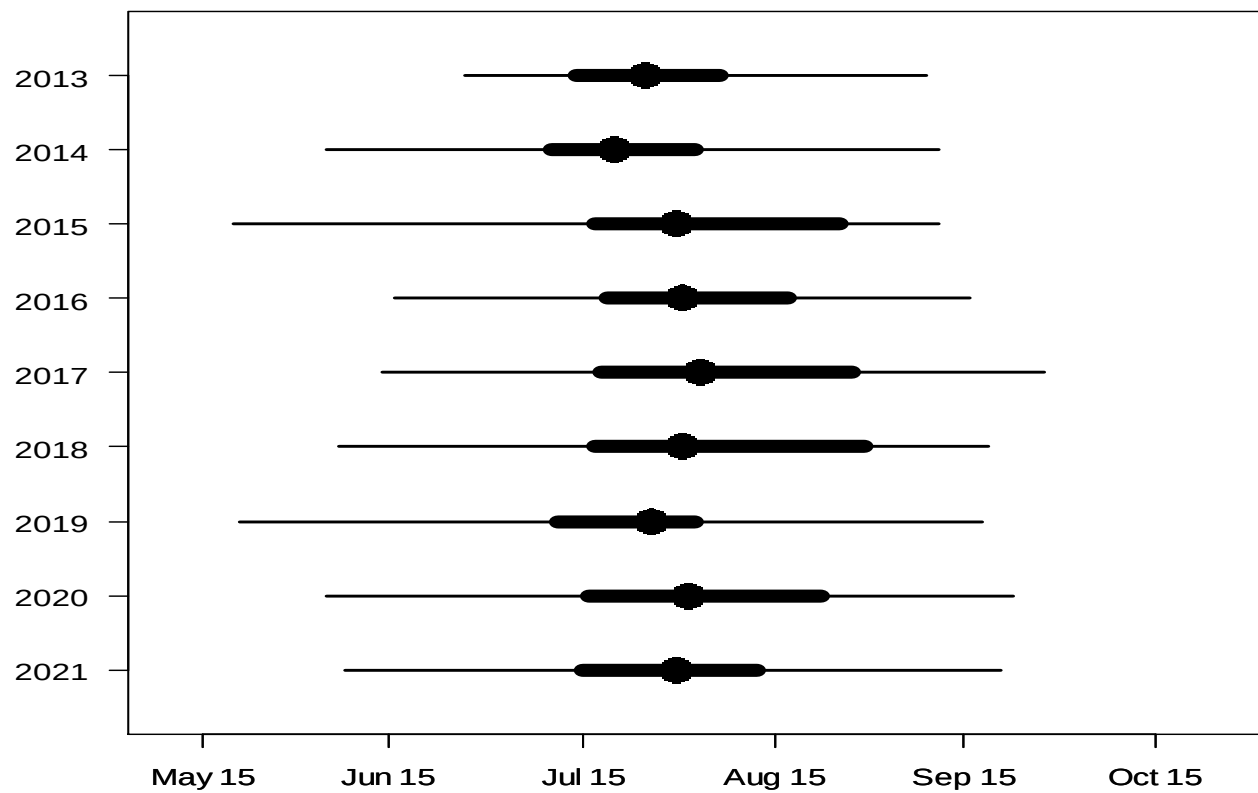


Figure 11. Run timing of Chinook in the Elwha River from 2013 to 2021. For each year the long thin black line encompasses the first Chinook sampled until the end of the run. The thick black line shows the time period during which 25% to 75% of the run passed the SONAR sites. The black dot shows when 50% of the run had passed.

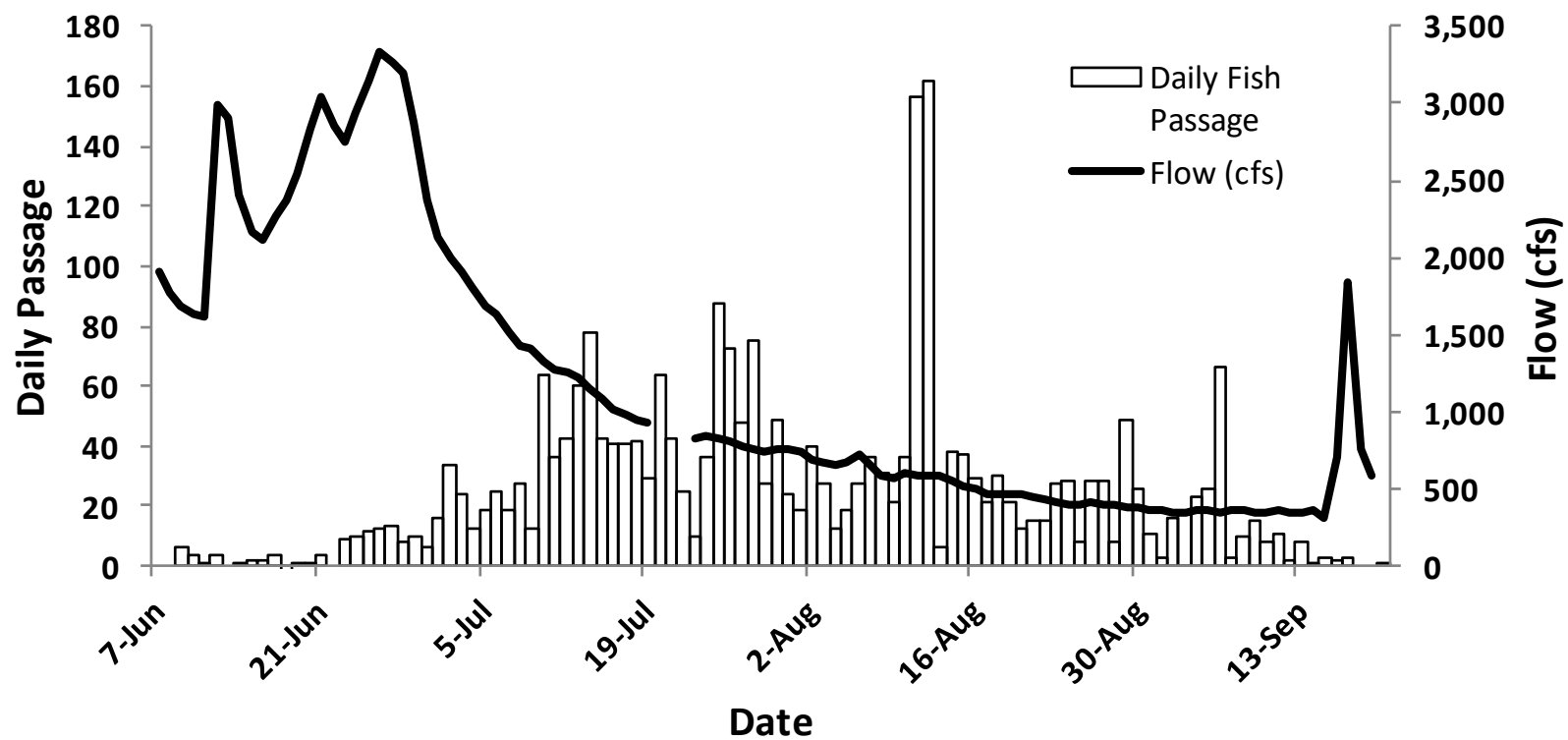


Figure 11. Daily Chinook passage and flow (cfs) for the Elwha River in 2021.

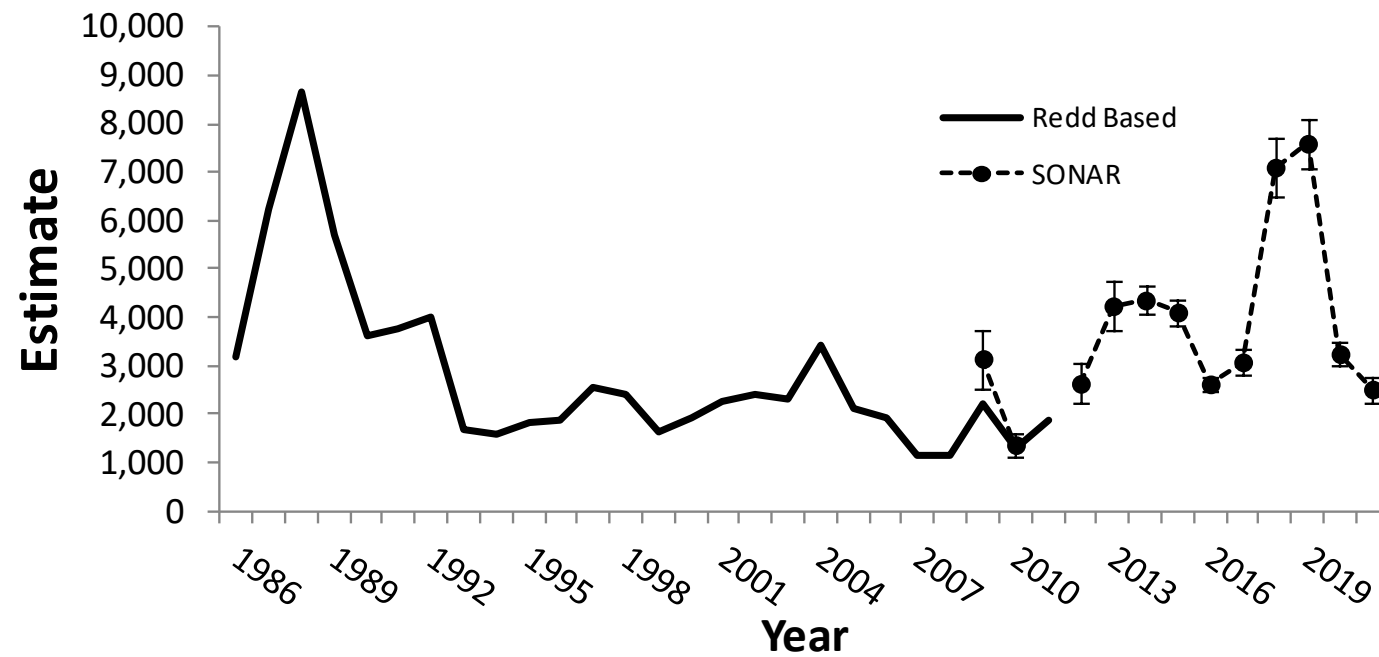


Figure 12. Historical Chinook escapement estimates from the Elwha River based on two different enumeration methods, redd counts and SONAR.