

2022 Elwha River Chinook Escapement Estimate Based on DIDSON/ARIS Multi-Beam SONAR Data



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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 May 23, 2022, through September 16, 2022. 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 model based escapement estimate above the SONAR sites of 4,290 fish, with a coefficient of variation of 2.2% (95% CI 4,080 – 4,450). A snorkel survey during the second week of September between RKM 20 and RKM 50 observed 292 summer steelhead, none of which were accounted for in the species composition correction. Therefore, we subtracted the observed summer steelhead from our original Chinook estimate, yielding a final Chinook escapement estimate to the Elwha River in 2022 of 3,998.

We operated two SONAR sites, one in the Mainstem (formerly called the Old Mainstem) and one in the Hunt Road Channel (HRC) in 2022, as in every other year of the project. However, due to low flow in the HRC this year, approximately only 10 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. The Mainstem site was moved to a new site ~400 m upstream of the former site before the Chinook season began.

Fifty percent of the Chinook salmon run passed the SONAR sites by July 29, which was similar to 2015-2018 and 2020-2021, but a week later than 2019. We captured the first Chinook salmon during species composition netting on May 23, which was about two weeks earlier than the median date of first capture since 2013 (June 5).

Our escapement estimate of 3,998 non-jack Chinook salmon is approximately 900 fish more than the total of other Chinook salmon encounters in the watershed (redd counts and broodstock removal). 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 3,100 Chinook salmon. It should be noted that the observed total of 292 summer steelhead that were subtracted from the original Chinook escapement estimate represents a minimal count and may only represent a half to a third of the total population of summer steelhead in 2022.

The 2022 estimate of 3,998 fish is the sixth highest return in the 13 year history of the SONAR project and about 100 fish higher than the average return since 2009.

Our major recommendation this year is to address the inadequacies of the new Mainstem site, namely the high levels of milling fish that were present during the second half of the Chinook season. Moving the site to a new location (only for Chinook season) to a nearby riffle crest should be considered. Additionally, we recommend that the co-managers (Elwha Tribe and WDFW) discuss solutions to the project's inability to identify summer steelhead in our species composition sampling since it directly affects the escapement estimate that is used for management purposes.

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 numerous 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 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) (Fig 1). In each successive year, less flow, and therefore fewer Chinook salmon, have passed through the Hunt Road Channel (HRC) or west channel. It is important to note that the OM site that has been used since 2012 had to be abandoned on February 16. Access to the former site became difficult and flow dependent due to water over the access road. Additionally, the site itself was no longer acoustically optimal as a result of a high flow event the previous fall. Therefore, a new site was located approximately 400 meters upstream of the old site before the start of Chinook season. 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 2.0. The proportion of flow down each channel varies from year to year and the proportion flowing down the HRC seems to be decreasing each consecutive year with little flow during the summer months since 2019. In 2022 during June and July approximately 10% of the flow went down the HRC, with the remaining 90% 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 10 and 15 m across and 0.9 m depth in the thalweg, while the Mainstem site (Fig. 3) was 12-32 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. The ladder and pole mount setup was the same as the HRC site. Chinook passage was recorded at the Mainstem site from May 23 through September 16, 2022 with the exception of a four day gap from August 19 through August 22 and two day gap from September 4 through September 5 (Fig 5a). Chinook passage was recorded continuously at the HRC site from May 23 through June 21, 2022, when low water interrupted

operations (Fig. 5b). Due to these low water conditions very little passage was recorded up the HRC (<10 fish). Therefore, data from the HRC was not pushed through the following data analysis procedure.

The SONAR was in operation prior to May 23, 2022, throughout the winter and spring of 2022 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., 2023a). Additionally, the SONAR was in operation after September 16 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., 2023b).

Species Composition

We conducted tangle net surveys on 14 different days between May 23 and September 19 to capture live adult salmonids at 7 different sites in the lower four kilometers of the river. Two netting sites were ~500 m above the Mainstem SONAR site, one site was at 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 initiated or finished 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 8# 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 bull trout, pink salmon, winter steelhead, and several coho salmon towards the end of the Chinook run.

Differently than previous years, and due to historically low flows throughout September, we conducted three snorkel surveys of the lower 4 KM of the river, the same area as the tangle net sampling. The snorkeling occurred on August 30, September 6, and September 19 (Table 1a). Snorkel counts were intended to produce the same information as the tangle net surveys but in a more continuous manner. In order to incorporate the larger sample size of the snorkel surveys into the species composition correction procedure and not overwhelm the smaller sample sizes of the net data, the total number of fish sighted for each species was divided by 100 and treated in the same manner as the net data.

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.

An additional counting protocol was introduced this year to accommodate extensive milling in the vicinity of the SONAR site during crepuscular periods. Instead of recording each individual fish passage event along with the associated meta data described above, total net passage for each 20 minute was simply tallied and recorded. This procedure was used for an average of four 20 minute periods each day (out of a possible 24) during approximately 75% of the days in August and September.

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 640 mm as the cutoff for inclusion in the final

escapement estimate this year to limit the inclusion of smaller bodied salmonids (jack Chinook salmon and coho towards the end of the Chinook run) in our final escapement estimate. Twenty five percent of the Chinook captured were jacks (<600 mm)(17/65). An additional Chinook measured 610 mm. All other Chinook measured in the field were equal to or greater than 640 mm (Fig. 6). We only used passage events of observer confidence level 1 in the final escapement analysis. Three percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (79/2,395). Three percent of all downstream passage events that met the length criteria were recorded as observer confidence level 2 (28/793).

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 (~10 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 = 476) 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 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 (476 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 23 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 May 23, so all targets after that date were included in further analysis. In-river netting on September 19 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 complete for the season. One fresh coho salmon (*Oncorhynchus kisutch*) greater than 630 mm in length was captured on the August 23 sampling event, one was captured on the August 30 sampling event and 5 were captured on September 19 (Table 1a). Additionally, the snorkel survey on September 19 revealed several hundred fresh coho between the SONAR site and the mouth of the river and almost all of the few remaining Chinook salmon in the reach actively spawning. Therefore, calculation of the 2022 Chinook salmon escapement only included SONAR targets recorded through September 16.

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. The snorkel data was used in the same manner as the net data except sample sizes were divided by 100 so they would be on the same order of magnitude as the net samples. 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 – 476) 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 daily, 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.

This correction assumes that different species are sampled unbiasedly throughout the season. In 2022, this assumption was known to be violated. A snorkel survey from RKM 20 to RKM 50 (excluding the Grand Canyon) during the second week of September observed 292 summer steelhead (ONP, pers. comm. 1/11/23). These fish almost certainly migrated upstream passed the SONAR sites between May 23 and September 16, yet none of them were sampled during our weekly net sampling in the lower river. Because we did not sample any summer steelhead, our model did not assign any raw SONAR targets as summer steelhead. In fact, the model assigned almost all of them as Chinook. Therefore, to more accurately reflect the true Chinook escapement to the Elwha River in 2022, we subtracted the 292 observed summer steelhead from our model derived Chinook escapement estimate.

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 17 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

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

Results

Between May 23 and September 16, 2022, there were a total of 720 hours (30 days) recorded on the HRC, and 2,664 hours (111 days) recorded on the Mainstem. At least one of the channels was monitored for 2,664 hours out of a total of 2,808 hours, or 95% of the total possible hours. During this time period 4,206 fish passage events were recorded and analyzed. Based on the model inputs, the best estimate for the Chinook salmon escapement to the Elwha River in 2022 was 4,290 fish with a coefficient of variation (CV) of 2.2% (95% CI 4,080 – 4,450) (Table 2, Fig. 9 and Fig 10). However, when the observed, but unaccounted, summer steelhead are subtracted from this total (but the same CI width is used), the final Chinook escapement was 3,998¹ (95% CI 3,813 – 4,183). A total of 10 (0% of total) Chinook went up the HRC, while the remaining 3,988 (100% of total) Chinook (CV 2.2%, 95% CI 4,080 – 4,450) went up the Mainstem (Figure 10). In order of decreasing variance, the largest sources of error were (1) accounting for observer error (3.6%), (2) error in the gap filling procedure (3.2%), (3) the uncertainty associated with expanding the 20-minute counts (1.2%), and (4) 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 May 23 and 25%, 50%, and 75% of the run had passed the OM SONAR site by July 13, July 29, and August 14, respectively (Fig. 10). We caught the last non-spawning Chinook salmon on August 30, although the next net sampling date was September 19. Three separate snorkel surveys from late August to mid September indicated that Chinook had stopped entering the system by September 16 (Table 1a). Daily Chinook passage was also plotted against flow (Fig. 11). As in previous years, the run appears to begin in early July when the hydrograph begins to decline after the peak of snowmelt. The two highest passage days were in early August but not associated with an increase in flow.

Discussion

Our estimate of 3,998¹ Chinook salmon provides a robust measure of Chinook escapement to the Elwha River in 2022 for several reasons. Most importantly we recorded data from approximately 95% of the run (2,664 of 2,808 hours). Furthermore, we feel confident that we accurately recorded the beginning of the run, May 23, and collected data until the end of the run, September 16. Minimal passage occurred during late May and the first half of June (only 1% of the run had passed the SONAR sites by June 15) and the weekly in-river netting operations indicated few Chinook were present in the river during that time period, as only 10% (6/63) of Chinook caught during the course of the run were caught before June 15. Species composition monitoring and snorkel surveys indicated that recently entering Chinook salmon 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

¹ McHenry et al., (2023) in the Chinook redd spatial distribution report cites a Chinook escapement of 4,290 which was based on an earlier draft of this report. That number was revised down to 3,988 to account for unaccounted summer run steelhead.

upon which to base management decisions. This uncertainty comes from four main sources, (1) accounting for observer error (3.6%), (2) error in the gap filling procedure (3.2%), (3) the uncertainty associated with expanding the 20-minute counts (1.2%), and (4) adjusting for species composition (1.1%). 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.

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 roughly the first quarter of the run when flows allowed. This included from the initial Chinook salmon encounter during species composition sampling, May 23, until June 21 a time period when only 3% of the run had passed up the Mainstem site. Snowpack in the headwaters of the Elwha was relatively robust in 2022 and therefore total river flow during June was higher than the past several years (other than 2021) 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 2022 potentially provided the opportunity for Chinook salmon to migrate up the HRC during the early part of the run. As we saw in 2021, even with relatively high flows throughout June, the changing proportion of flow to predominately the Mainstem channel has precluded any significant Chinook passage up the HRC.

The highest source of measured uncertainty this year was due to the observer error correction with a CV of 3.6%. The coefficient of the regression is close equal to 1 (.96) meaning that, there was very little difference in total counts by the expert and technician. This also means that the correction reduced the final escapement by less than 5%. The r^2 value (0.96) indicates a 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 seldom completely agreed. A potentially underrepresented source of error in the data review process may have been caused by the high levels of milling fish in this year's data. Although the observer error analysis included time periods with high levels of milling and both observers recorded similar counts, anytime there are multiple fish holding in the ensonified area or schools of fish are moving back and forth through the ensonified region the potential for error increases. In fact, there were several 20-minute periods (usually associated with dusk) where large schools of fish (20-30 individuals) moved downstream en mass and then slowly moved back upstream throughout the night. This phenomenon introduces a situation where some proportion of the fish need to be counted three times to arrive at net upstream passage, with each fish passage event introducing the possibility of error. It is possible that milling and schools of fish moving in both directions through the ensonified area introduced an unknown bias in both the technician and expert counts that went uncalculated. The fish behavior underlying this issue is almost entirely rooted in the morphology of the new site. The SONAR unit was continually moved downstream and out into the channel as flows receded (standard procedure during Chinook season) to get further away from a large log jam where the fish hold and ensonify a shallower and faster moving portion of the reach where fish are less likely to hold. Nevertheless, the site has no true riffle crest where fish would be likely to move through quickly. Instead, there is a long

shallow glide that apparently was not fast enough or shallow enough to deter fish from moving through it multiple times. See recommendations below on how to deal with this issue in subsequent years.

The second highest source of uncertainty in 2022 was associated with the gap filling procedure, with a C.V. of 3.2%. As in every other year, we recorded data from a high proportion of the run this year, with a total of only 6 days of data gaps on the Mainstem. These six days did occur during periods of relatively high passage and passage estimate during those gaps was ~250 fish. 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 that month.

The third highest source of uncertainty this year was due to expanding the 20-minute counts, with a CV of 1.2%. The variation between actual and predicted 60-minute counts is characterized by the r^2 value of 0.57 which indicates a moderate relation between the predicted and observed counts. Nevertheless, when taken in aggregate, the predicted counts for all 23 six-hour chunks equaled 81 fish while the total predicted counts for the 23 six-hour chunks of the observed 60-minute counts equaled 82 fish. Therefore, while there is variation between the predicted and observed 60-minute counts at the individual six-hour chunk scale, the total counts match almost exactly.

The final source of uncertainty was adjusting for species composition, with a CV of 1.1%. This CV is low because during the majority of the Chinook run, Chinook salmon are the only large bodied fish present in the river. The beginning of the run overlaps with the end of the winter steelhead run, but raw passage is relatively low from late May through mid-June when adults of the two species are both present in the river. Towards the end of the run, Chinook and coho are both in the river at the same time but netting and snorkeling revealed that Chinook had mostly moved upstream passed the SONAR's before hundreds of coho had entered the river. Setting the SONAR length cutoff, and thereby length cutoff for inclusion into the species correction, at 640 mm also eliminated many of the coho that overlapped with the end of the Chinook run.

Another source of error in our species apportionment correction is the presence of summer run steelhead in the Elwha. Since 2018, upriver snorkel surveys in September have counted between approximately 150 and 340 adult summer run steelhead, indicating that a self sustaining population of this distinct run timing of steelhead now migrates upriver each year. In 2022, crews from Olympic National Park sighted 292 summer steelhead between RKM 20 and RKM 50 during the second week of September, excluding the Grand Canyon (ONP, pers comm. 1/11/23). These fish likely migrate passed our SONAR sites from late May up until the snorkel surveys in mid-September, yet we did not sample a single summer steelhead in our species composition netting during that time period, indicating that these fish move quickly through the lower river and we have a limited ability to sample them. The consequence of the project not sampling summer run steelhead as they move passed the SONAR is that none of the raw SONAR targets get assigned as summer steelhead. In fact, they likely all get assigned as Chinook salmon since that is the species we predominately capture during the season. Therefore, we know that at least ~300 summer steelhead passed our SONAR site and were likely counted as Chinook. We accounted for this by subtracting the 292 observed summer steelhead from our model derived

escapement estimate for Chinook. It is important to note that the 292 observed summer steelhead that we accounted for is an absolute minimum estimate for the actual population size of summer steelhead in the Elwha River in 2022. Similar snorkel surveys conducted in 2019 observed 341 summer steelhead. A portion of these fish were previously marked and a mark-resight population estimate of approximately 900 fish was made. Therefore, the actual number of summer steelhead that migrated passed our SONAR sites undetected could have been two or three times higher than the 300 we accounted for. This would represent a significant unaccounted source of error in our Chinook estimate.

We compared our escapement estimate of 3,998 Chinook with other data collected in the watershed. A peak redd survey was conducted in mid-September from ~RKm 56 to the entrance of the Grand Canyon to the mouth in late-September. These surveys recorded 963 redds, which represents roughly 2,400 fish (redds*2.5) (McHenry et al. 2023). Additionally, 718 adult Chinook salmon were removed from the river above the SONAR sites for WDFW broodstock needs. The combination of these two data sources yields a total of 3,118 adult Chinook in the Elwha in 2022. This represents roughly 78% of our SONAR based estimate. McHenry et al. (2023) reported that 8% of the redds were recorded upstream of the former Glines Canyon dam indicating that, for the sixth 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 in 2022, it is unlikely that any Chinook redds went uncouned above Rica canyon as ONP staff reported a landslide and likely blockage (at least during the Chinook run) in Rica canyon (ONP, pers. comm. 1/20/23). Redd superimposition certainly occurred again in 2022 although probably 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 16 as evidenced by our species composition netting. These fish likely would have spawned after the peak redd survey date of the third week of September. 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 2022 Chinook escapement estimate of 3,998 is similar to the average of the project (~3,800) going back to 2009 (Table 3, Figure 12). 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 2022 returning adults were spawned incubated, and subsequently outmigrated during the fall, winter, and spring of 2018-2019 and 2019-2020. 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). It is important to note that hatchery:natural proportions for the 2022 Chinook return are not available as yet, but the vast majority of adult returns have been hatchery origin through 2021 (Weinheimer et al., 2018, Joe Anderson, WDFW, pers. comm.). Therefore, even with the potential for some naturally produced outmigrants to have returned as 4 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. From 2011 through 2013 average Chinook 0+ releases were ~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. With the potential for both 3 and 4 year old naturally produced returns to contribute to the escapement this year it would be concerning to not see any reduction in hatchery:natural proportions in 2022.

In comparison to prior years, this year's date at which 50% of the run had passed the SONAR site, July 29, was similar to last year and 2015-2018 and roughly one week later than 2013, 2014 and 2019 (Table 3) (Denton et. al. 2013-2021). The first Chinook salmon was captured during the in-stream netting operations on May 23, which is two weeks earlier than 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, for the second year in a row, 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. However, the netting operations during the months of May and June encountered the most Chinook in the history of the project (11). Genetics samples of these fish are currently being processed by WDFW to investigate the potential existence of a genetic legacy to the historical spring run timing of Elwha Chinook. Unlike many previous years of the project, the two biggest days of passage (August 5 and 9) were not linked to a rain induced increase in flow in August or early September. 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 especially pronounced this year as the fall rains did not materialize until late October.

Recommendations

Our first recommendation relates to dealing with inadequacies of the new SONAR site during Chinook season. Chinook have a tendency to hold in the deep logjam holes of the lower river throughout the summer. High quality SONAR data has historically been captured during these time periods by simply moving the SONAR to the downstream end of the reach at the head of a riffle crest where fast shallow water forces fish to move through quickly. The new SONAR site has several positive qualities including a good bottom profile, it is extremely safe from a rising hydrograph and it gets good solar exposure. Unfortunately, the downstream end of the reach does not have a riffle crest and even with several infrastructure movements throughout the Chinook season, some level of milling was present. This situation is likely to exacerbate on years of higher Chinook returns and in pink years. A possible solution is to move the site downstream to a nearby riffle crest that would accommodate the solar infrastructure. This move would have to occur during the month of June when few fish are likely to be in the system between the two sites and could go uncounted without greatly affecting the final escapement estimate. There is always the possibility that a new site would have additionally unpredictable limitations. We recommend a detailed plan is discussed and developed among project partners before next June.

Our second recommendation concerns accounting for summer steelhead in our escapement estimate. In years previous to 2021 we have encountered at least some summer steelhead in our species composition sampling (between two and six). This allows us to apportion at least some raw SONAR targets to summer steelhead. However we did not sample any during the 2021 or 2022 Chinook season when most of the summer steelhead are presumed to migrate upstream. It appears as though a combination of their rapid upstream migration, our reduced sampling effort during the month of June, and high water due to snow melt severely impacts our ability to sample these fish in our traditional sampling sites. Co-managers must decide how they want to deal with this known, unaccounted for, error in our Chinook escapement estimate since it directly impacts the number that is used for management decisions. One possible solution is to simply continue to use the method employed this year, subtract the observed number of summer steelhead from upstream snorkel surveys. This approach could also be modified based on the findings of the 2019 mark resight project to more accurately portray the true number of summer steelhead. A second solution is to perform more netting in the lower river during the presumed run timing of summer steelhead, June.

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Literature Cited

- Beechie, T. J., M. Liermann, M. M. Pollock, S. Baker, J. R. Davies. 2006. Channel pattern and river-floodplain dynamics in forested mountain river systems. *Geomorphology*, 78(1-2):124-141. ➡
- Belcher, E. O., B. Matsuyama, and G. M. Trimble. 2001. Object identification with acoustic lenses. Pages 6–11 in *Conference proceedings MTS/IEEE oceans*, volume 1, session 1. Honolulu, Hawaii.
- Belcher, E. O., W. Hanot, and J. Burch. 2002. Dual-frequency identification sonar. Pages 187–192 in *Proceedings of the 2002 International Symposium on underwater technology*. Tokyo, Japan.
- Brazil, C. E. 2007. Sonar enumeration of Pacific salmon into the Nushagak River, 2003. Alaska Department of Fish and Game, Divisions of Sport Fish and Commercial Fisheries, Fishery Data Series 07-37, Anchorage.
- Brenkman, S.J. , Pess, G., Torgersen, C., Loehn, K., Duda, J., and Corbett, S. 2008. Predicting recolonization patterns and interactions between potamodromous and anadromous salmonids in response to dam removal in the Elwha River, Washington State, USA. *Northwest Science*, 82(sp1):91-106.
- Cousens, N.B., Thomas, G. A., Swann, C. G., and Healy, M. C. 1982. A review of salmon estimation techniques. *Can. Tech. Rep. Fish. Aquat. Sci.* No. 1108.
- Cronkite, G. W., Enzenhofer, Ridley, T. Holmes, J., Lilja, J. and Benner, K. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River, British Columbia. *Can. Tech. Rep. Fish. Aquat. Sci.* 2647: vi + 47p.
- Cronkite, G.M.W., Enzenhofer, H.J., and Holmes, J.A. 2008. Evaluation of the BlueView ProViewer 900 Imaging Sonar as a tool for counting adult sockeye salmon in the Adams River, British Columbia. *Can. Tech. Rep. Fish. Aquat. Sci.* 2798: iv + 21 p.
- Denton, K.P. and Liermann, M.M. 2009. Enumeration of Summer Chinook Escapement in the Elwha River, 2009, Using BlueView Multi-beam Sonar Technology. Prepared for the Lower Elwha Tribe.
- Denton, K.P. and Liermann, M.M. 2010. Estimation of the 2010 Summer Chinook Escapement in the Elwha River Using BlueView Multi-beam Sonar Technology. Prepared for the Lower Elwha Tribe.
- Denton, K.P. and Liermann, M.M. 2012. Estimation of the 2012 Chinook Escapement in the Elwha River Using DIDSON Multi-beam Sonar Technology. Prepared for the Lower Elwha Tribe.
- Denton, K.P., Moses, R., McHenry, M., McMillan, J., Liermann, M., Pess, G. 2013. Final Report: 2013 Elwha River Chinook escapement estimation based on DIDSON multi-beam SONAR data. Prepared for the Lower Elwha Tribe.

- Denton, K., Moses, R., McHenry, M., McMillan, J., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2014. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., McMillan, J., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2015. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., McMillan, J., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2016. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2017. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2018. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2019. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2020. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2021. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2023a. Elwha River Winter Steelhead escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2023b. Elwha River coho escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Dunbar, R. 2001. Copper River Hydroacoustic Salmon Enumeration Studies, 2000 and 2001. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A01-3, Anchorage.

- Dunbar, R. 2003. Anvik River sonar chum salmon escapement study, 2003. Regional Information Report No. 3A03-14. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.
- Dunbar, R. and C.T. Pfisterer. 2004. Sonar estimation of fall chum salmon abundance in the Sheenjek River, 2002. Regional Information Report No. 3A04-10. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.
- Elwha River Fisheries and Ecosystem Restoration Act, 1992. Public Law 102-495. Signed October 24, 1992 (106 Stat. 3173).
- Enzenhofer, H. J., Olsen N., Mulligan, T. J. 1998. Fixed-location riverine hydroacoustics as a method of enumerating migrating adult Pacific salmon: comparison of split-beam acoustics vs. visual counting. *Aquat. Living Resour.* 11:61-74.
- Enzenhofer, H.J., and Cronkite, G. 2005. A simple adjustable pole mount for deploying DIDSON and split-beam transducers. *Can. Tech. Rep. Fish. Aquat. Sci.* 2570: iv + 14 p.
- Enzenhofer, H. J., Cronkite, G. M. W., Holmes, J. A. 2010 Application of DIDSON Imaging SONAR at Qualark Creek on the Fraser River for Enumeration of Adult Pacific Salmon: An Operation Manual. *Can. Tech. Rep. Fish. Aquat. Sci.* 2869.
- Holmes, J. A., Cronkite, G. W., Enzenhofer, H. J., Mulligan, T. J. 2006. Accuracy and precision of fish-count data from a “dual-frequency identification sonar” (DIDSON) imaging system. *Journal of Marine Science.* 63:543-555.
- Levy, D. A., Nealson, P. A., and Cheng, P. 1991. Fixed-aspect hydroacoustic estimation of Fraser River sockeye salmon abundance and distribution at Mission, B. C. *in* 1986. *Pac. Salmon Comm. Tech. Rep. No. 4.*
- Lilja, J., Ridley, T., Cronkite, G. M., Enzenhofer, H. J., and Holmes, J. A. 2008. Optimizing sampling effort within a systematic design for estimating abundant escapement of sockeye salmon (*Oncorhynchus nerka*) in their natal river. *Fisheries Research* 90:118-127
- Maxwell, S. L. 2008. Hydroacoustics: Rivers. Pgs 133-152 *in* *Salmonid Field Protocols Handbook Techniques for Assessing Status and Trends in Salmon and Trout Populations.* Amer. Fish. Soc., Bethesda, MD.
- McElhany, P., M.H. Ruckelshaus, M.J. Ford, T.C. Wainwright, and E.P. Bjorkstedt. 2000. Viable salmonid populations and the recovery of evolutionarily significant units. U.S. Dept. Commer., NOAA Tech. Memo. NMFS-NWFSC-42,156 p.
- McHenry, M.G., Elofson, M., Liermann, M., Bennett, T., Corbett, S., Pess, G. 2021. 2020 Elwha River Smolt Enumeration Project. Report submitted to Olympic National Park.

- McHenry, M., G. Pess, J. Anderson. 2021. Spatial distribution of Chinook Salmon (*Oncorhynchus tshawytscha*) spawning in the Elwha River, Washington State during dam removal and early stages of recolonization (2012-2020). 32 pp.
- McHenry, M., J. Anderson, H. Conner, G. Pess. 2023. Spatial distribution of Chinook Salmon (*Oncorhynchus tshawytscha*) spawning in the Elwha River, Washington State during and after dam removal (2012-2022). Report to Olympic National Park.
- McKinley, W.L. 2002. Sonar enumeration of Pacific salmon into the Nushagak River, 2001. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A02-25, Anchorage.
- Miller, J. D., D. L. Burwen, and S. J. Fleischman. 2007. Estimates of Chinook salmon abundance in the Kenai River using split-beam sonar, 2005. Alaska Department of Fish and Game, Fishery Data Series 07-92, Anchorage.
- Montgomery, D. R. 2003. King of Fish: The Thousand Year Run of Salmon. Westview Press, Cambridge, MA.
- Reynolds, J. H., Woody, C. A., Gove, N. E. and Fair, L. F. 2007. Efficiently Estimating Salmon Escapement Uncertainty Using Systematically Sampled Data. American Fisheries Society Symposium 54:121–129.
- Peters, R.J., Denton, K., Liermann, M. 2020. Proportion of Hatchery Origin Steelhead and Broodstock Collection in the Elwha River: 2019. Report to the Lower Elwha Klallam Tribe.
- Westerman, D. L., and T. M. Willette. 2003. Upper Cook Inlet salmon escapement studies, 2002. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 2A03-24, Anchorage.
- Weinheimer, J., Anderson, J., Cooper, R., Williams, S., McHenry, M., Crain, P., Brenkman, S., and Hugunin, H. 2018. Age structure and Hatchery Fraction of Elwha River Chinook Salmon: 2017 Carcass Survey Report.
- Xie, Y., A. P. Gray, F. J. Martens, J. L. Boffey and J. D. Cave. 2005. Use of Dual-Frequency Identification Sonar to Verify Salmon Flux and to Examine Fish Behaviour in the Fraser River. Pacific Salmon Comm. Tech. Rep. No. 16: 58 p.

Table 1a. Total number of “new” and “holding” Chinook and other salmonids which measured at least 640 mm captured by date at seven sites during in-river netting operations on the Elwha River in 2022. Three snorkel surveys occurred from the SONAR site to the mouth of the river on August 30, September 6, and September 19 and are highlighted in grey.

Date	Chinook	Steelhead	Coho	Bulltrout	% Chinook
5/23/2022	1	1		1	33%
5/31/2022	3	1			75%
6/13/2022	2				100%
6/21/2022	5				100%
7/6/2022	7				100%
7/18/2022	3				100%
7/25/2022	11				100%
8/8/2022	4				100%
8/15/2022	5				100%
8/23/2022	4		1		80%
8/30/2022	1		1		50%
8/30/2022	800		6		99%
9/6/2022	700		12		98%
9/19/2022	8		300		3%
9/19/2022			5		0%

Table 1b. Total number of all salmonids of all lengths captured during the Chinook run by date at seven sites in the lower 4KM of river during in-river netting operations on the Elwha River in 2022.

Date	Chinook >600 mm	Chinook <600 mm	Pink	Bull trout	Sockeye	Coho	Steelhead
5/23/2022	1			1			2
5/26/2022				1			2
5/31/2022	3			1			6
6/13/2022	2			1			1
6/16/2022				1			
6/21/2022	5						1
7/6/2022	7						
7/18/2022	3						
7/25/2022	11	4					
8/8/2022	4	3					
8/15/2022	5	7	3		1		
8/23/2022	4	3	2			1	
8/30/2022	1					4	
9/19/2022			4			13	
Total	46	17	9	5	1	18	12

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	1.2%
Species Composition	1.1%
Observer Error	3.6%
Gap Fill	3.2%
Overall	2.2%

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
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
2022	3,998	3,813 - 4,183	23-May	29-Jul

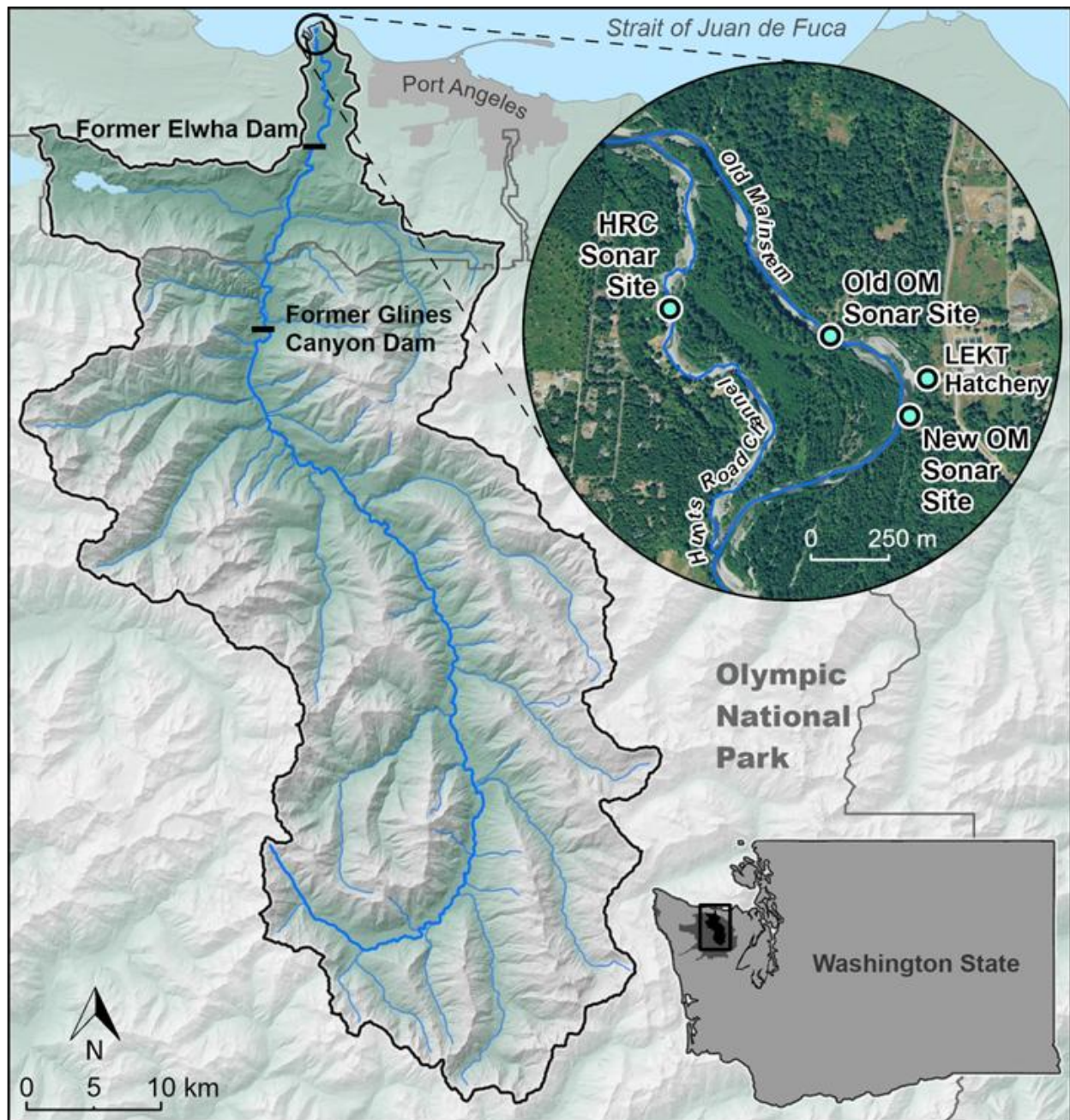


Figure 1. Map of the Elwha River, depicting the former dam sites, SONAR sites, Elwha Tribal Hatchery, and the two distinct migratory pathways near the mouth of the river.



Figure 2. Photo of the HRC DIDSON site. Note low water that precluded almost all fish passage up this channel in 2022.



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.

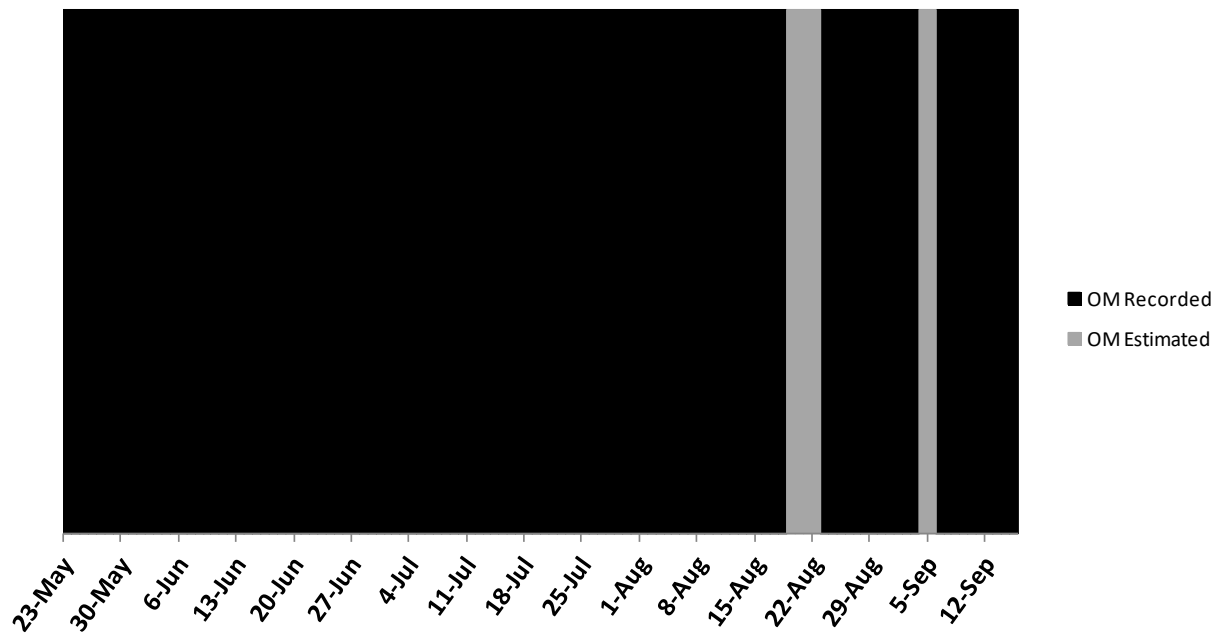


Figure 5a. Dates for which data was recorded or estimated in the Mainstem channel during the Chinook season on the Elwha River in 2022.

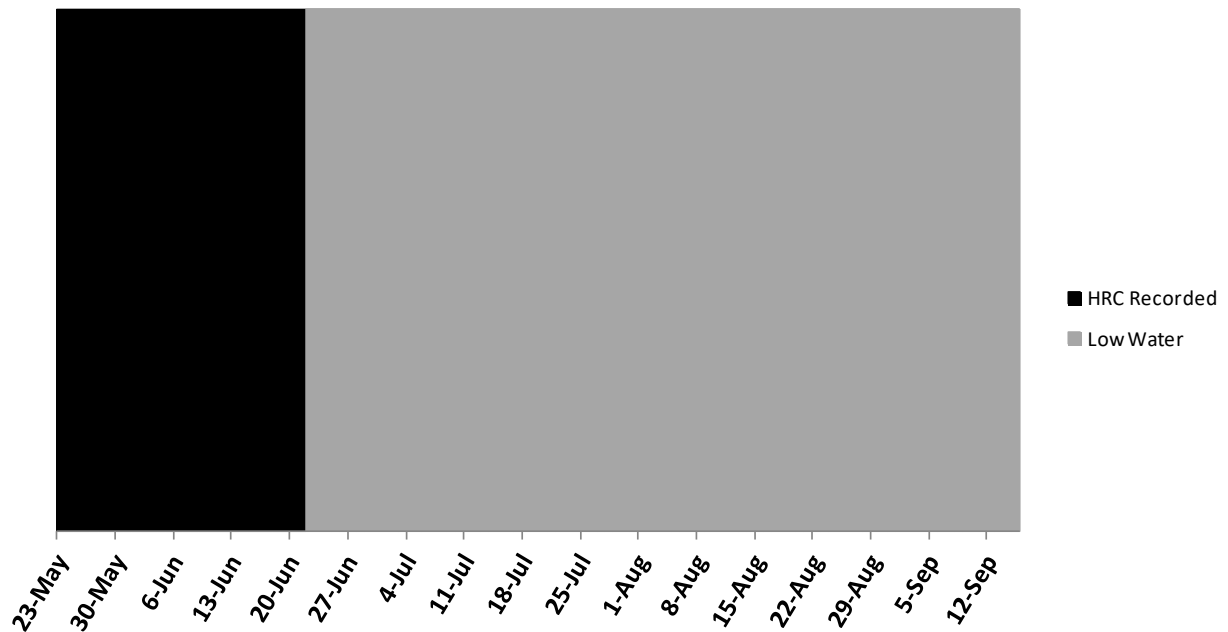


Figure 5b. Dates for which data was recorded or estimated in the Hunt Road channel during the Chinook season on the Elwha River in 2022. All missing dates were due to low water.

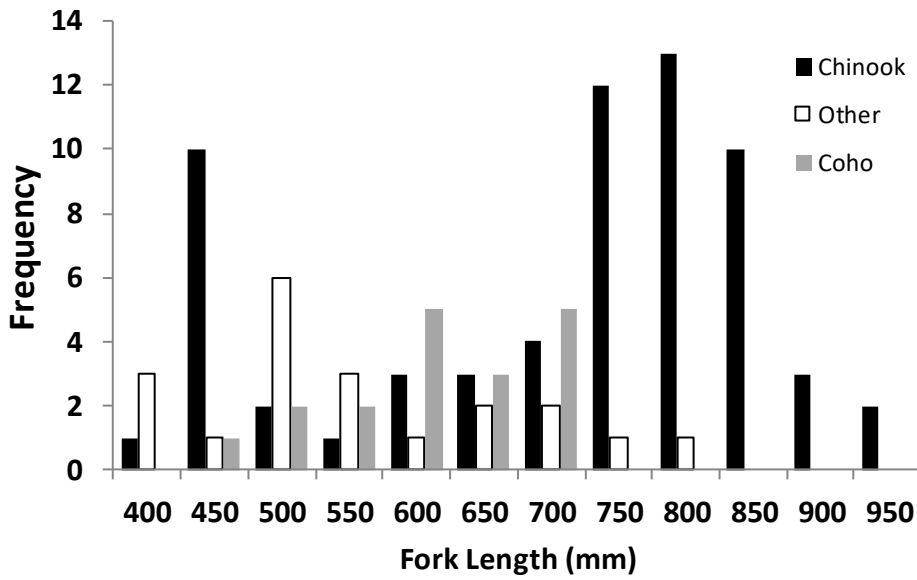


Figure 6. Length frequency histogram for all salmonids caught during 14 different sampling days between May 23, 2022 and September 19, 2022 in the Elwha River.

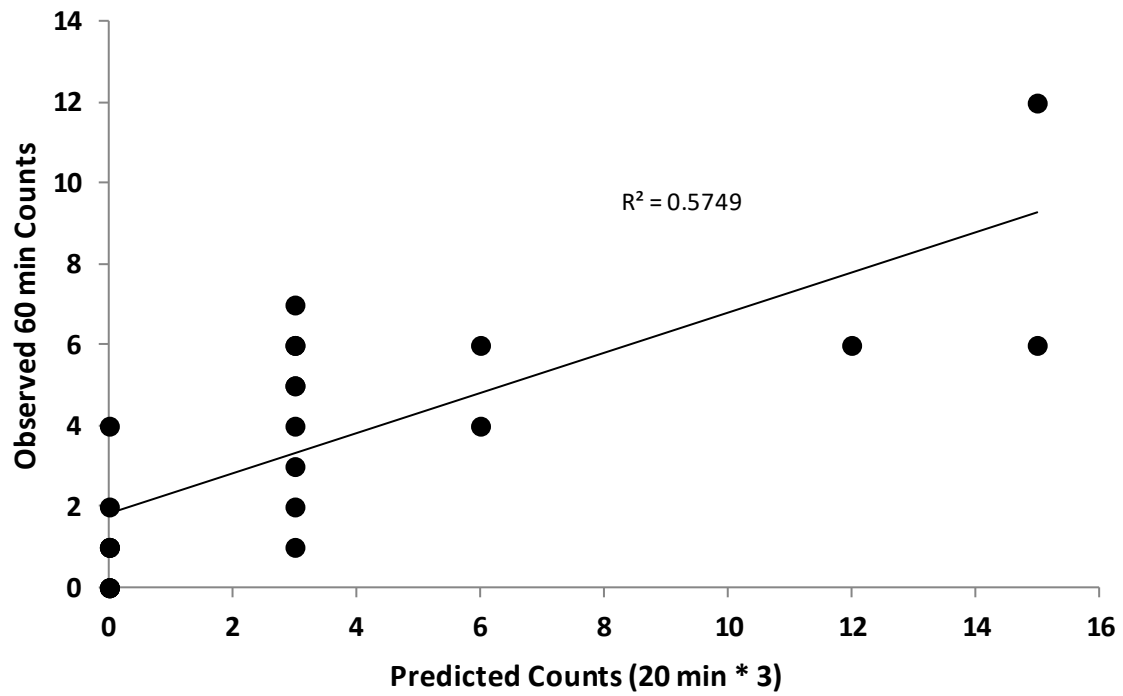


Figure 7. Predicted (20 minutes * 3) vs. observed (actual 60 minute counts) for 23 six-hour chunks of full hour counts for the Mainstem. There are four points at (0,0), three points at (1,0), two points at (5,3) and two points at (6,3).

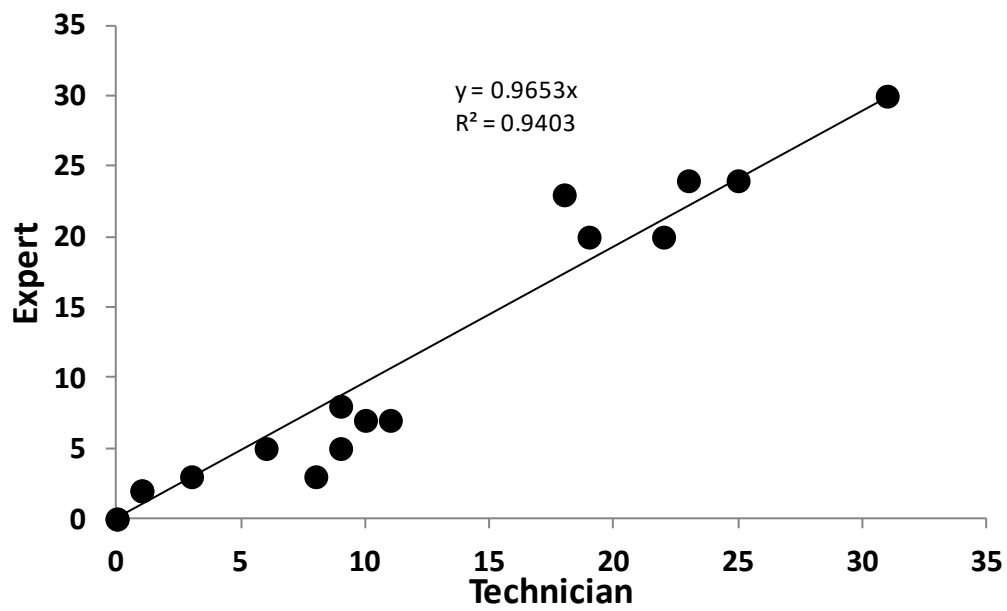


Figure 8. Total upstream passage counted by a technician and expert for 15 six-hour chunks. There are two points at (0,0).

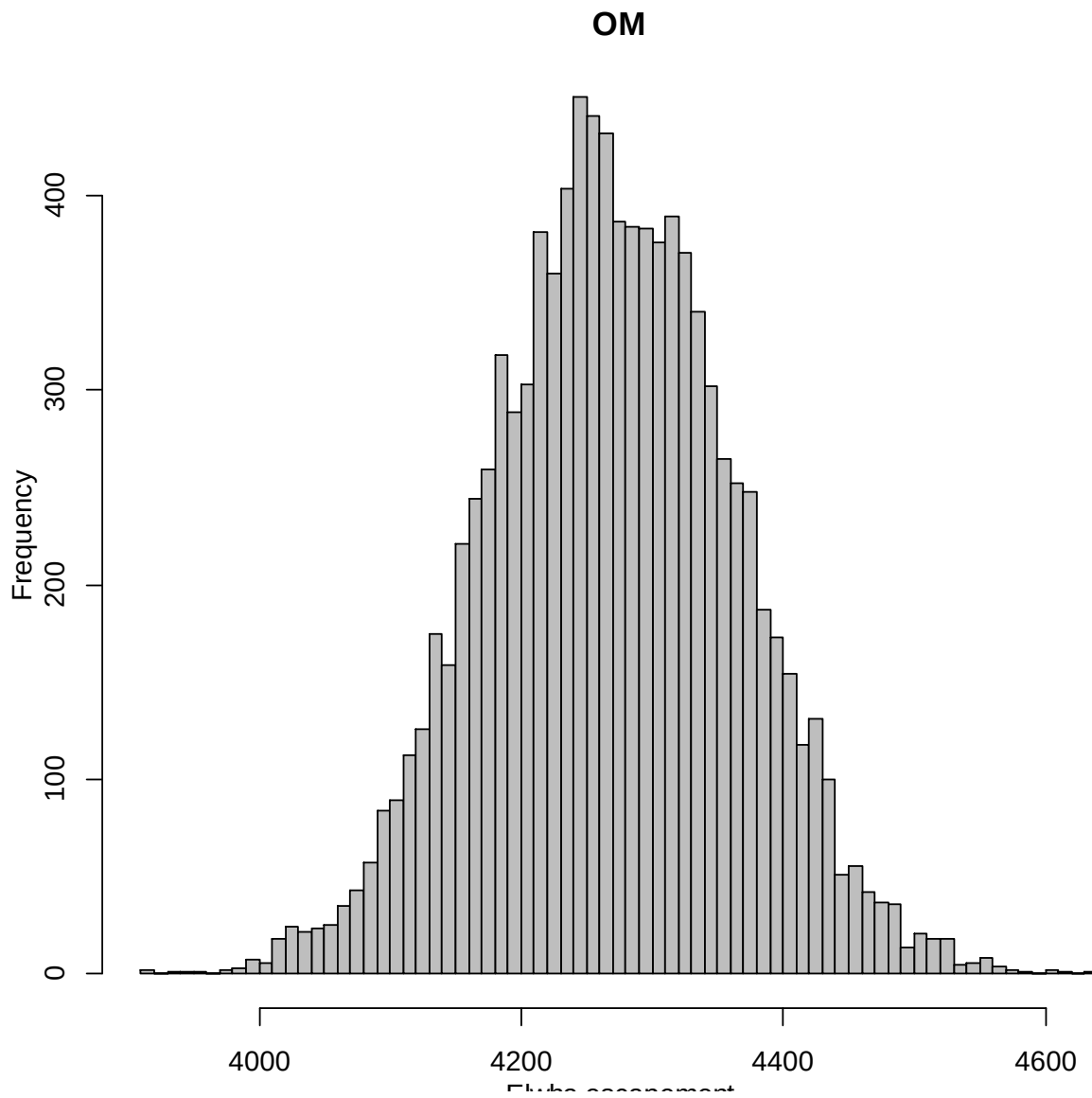


Figure 9. Chinook run size estimates for the Elwha River in 2022 based on 10,000 model runs. This output does not account for the 292 summer steelhead that were subtracted from the mean estimate.

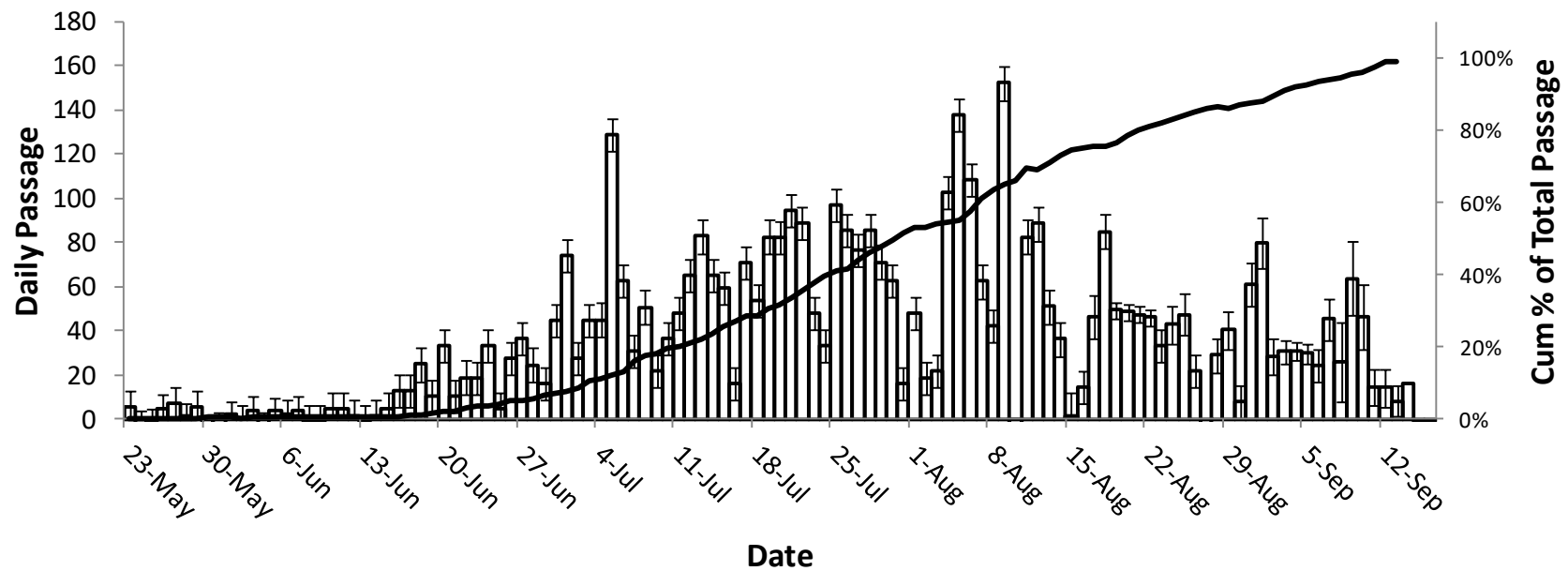


Figure 10. Daily Chinook passage and cumulative percent of total run for the Mainstem, which also represents the entire run, in the Elwha River in 2022. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. Total passage estimate for the Mainstem and the entire run that is depicted here is 4,290 Chinook salmon. The 292 observed summer steelhead that were subtracted from that total are not reflected in this graph.

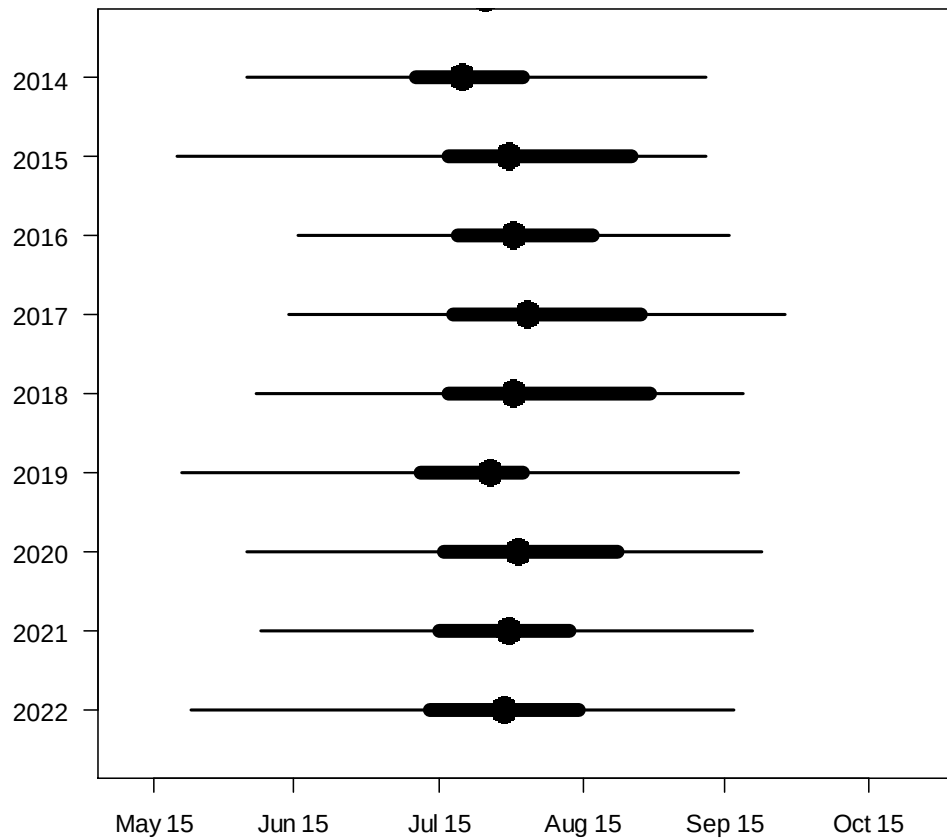


Figure 11. Run timing of Chinook in the Elwha River from 2013 to 2022. For each year, the long thin black line encompasses the first Chinook sampled until the end of the run. The thick black line shows the time period during which 25% to 75% of the run passed the SONAR sites. The black dot shows when 50% of the run had passed.

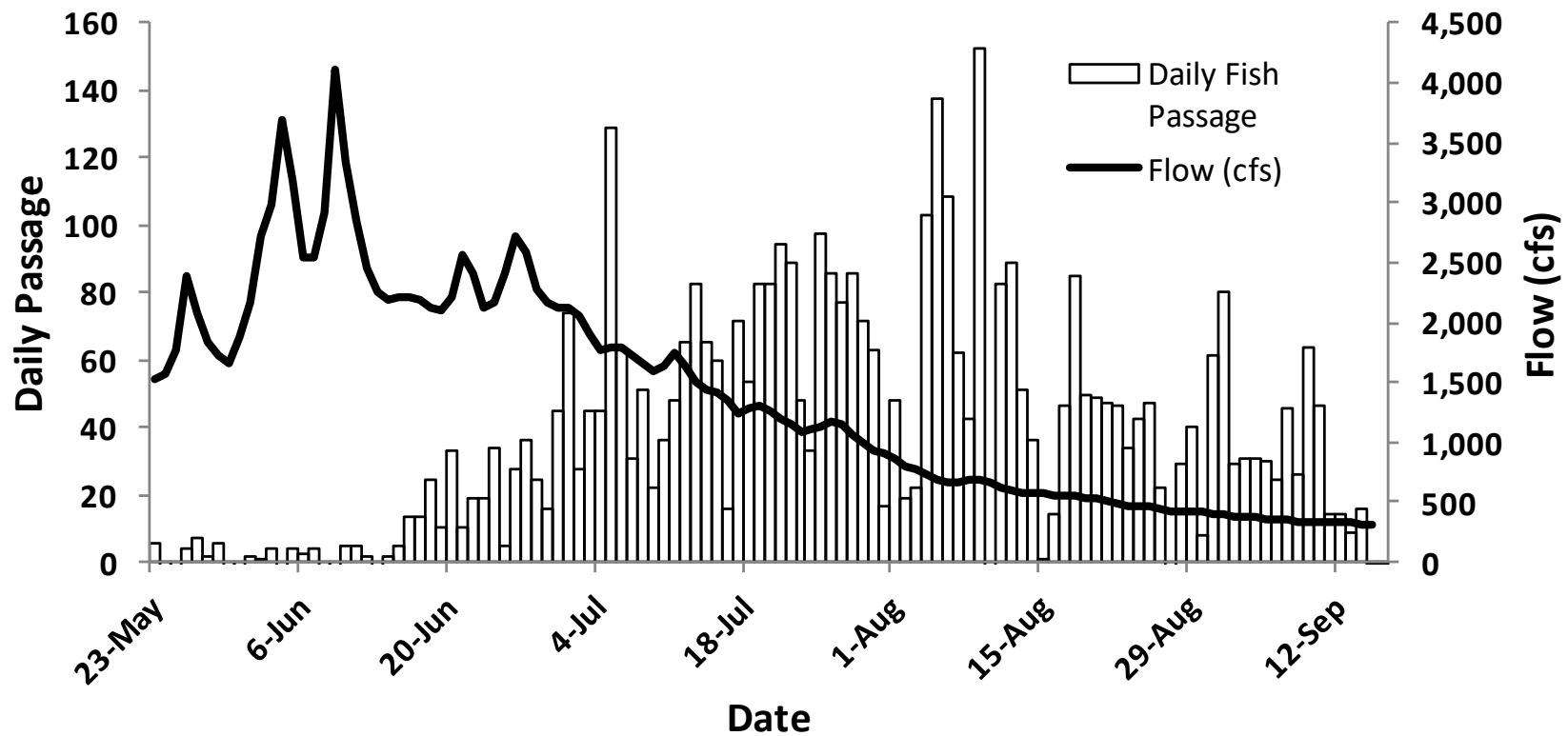


Figure 11. Daily Chinook passage and flow (cfs) for the Elwha River in 2021.

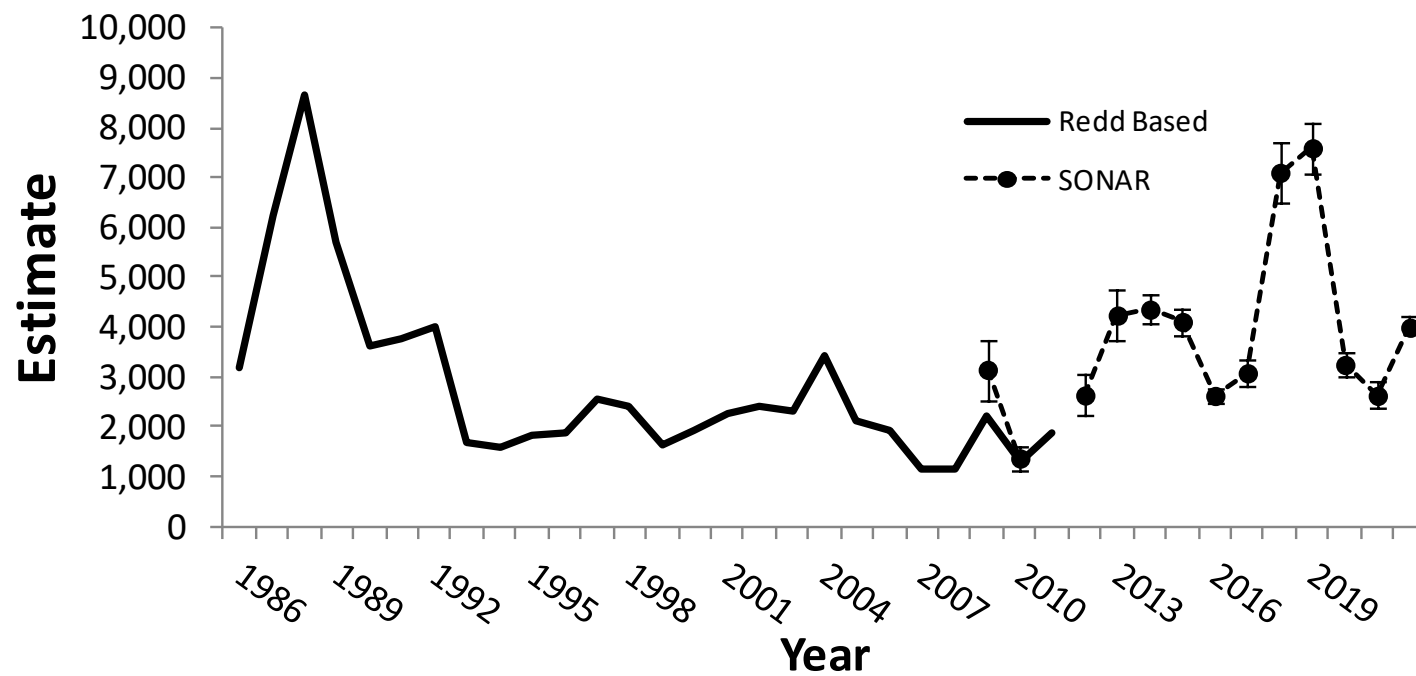


Figure 12. Historical Chinook escapement estimates from the Elwha River based on two different enumeration methods, redd counts and SONAR.