

2023 Elwha River Chinook Escapement Estimate Based on ARIS Multi-Beam SONAR Data



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Executive Summary

We used an ARIS 1800 multi-beam SONAR unit to monitor Chinook salmon escapement in the Elwha River daily from June 7, 2023, through September 18, 2023. 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 site of 3,950 fish, with a coefficient of variation of 2.0% (95% CI 3,800 – 4,100). A snorkel survey during the second week of September between RKM 20 and RKM 50, excluding canyon reaches, observed 317 summer steelhead, approximately 211 of which were accounted for in the species composition correction. Therefore, we subtracted the additional ~100 observed summer steelhead from our original Chinook estimate, yielding a final Chinook escapement estimate to the Elwha River in 2023 of 3,850 (95% CI 3,700 – 4,000).

In all previous years of the project, two migratory pathways, and two SONARs were operated to enumerate Chinook salmon. Due to channel morphology changes and the lack of water and therefore fish passage up the Hunt Road Channel, only one SONAR site was necessary, the Mainstem site, in 2023. Due to fish milling issues encountered in 2022, the Mainstem site was moved approximately 400 meters downstream in 2023 to improve image quality. This site was also located below the LEKT hatchery outfall which some Chinook enter.

Fifty percent of the Chinook salmon run passed the SONAR sites by July 30, which was similar to 2015-2018 and 2020-2022, but a week later than 2019. We captured the first Chinook salmon during species composition netting on June 7, which was very similar to the median date of first capture since 2013 (June 5).

Our escapement estimate of 3,850 non-jack Chinook salmon is approximately 550 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 and LEKT hatcheries yielded an approximate total of 3,300 Chinook salmon.

The 2023 estimate of 3,850 fish is the seventh highest return in the 14-year history of the SONAR project and equal to the average return since 2009.

We also estimated a return of approximately 6,400 pink salmon to the Elwha River in 2023, which far eclipses the previous high return of 2,300 in 2021.

Our major recommendation this year is to address the likelihood that the pink salmon population in the Elwha will continue to grow and thereby present issues enumerating Chinook that include increased time and reduced accuracy for data review and complications with species apportionment.

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 technologies 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. 2010-2022 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, due to variable stream flows related to snowmelt during the Chinook migration, the SONAR site requires constant attention, including removal and re-installation to avoid loss or damage to the equipment. Lastly, like other Puget Sound rivers, the Elwha River mainstem has an anastomosing or forested island morphology resulting in multiple channels for fish to migrate through (Beechie et al. 2006). However, in 2023, due to multiple factors including stream channel changes and the effects of multiple engineered logjams (ELJ's), only one channel on the east side of the valley was hydrologically active during the Chinook migration season. 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. In 2023, not enough water was conveyed down the HRC to permit Chinook passage and only the Mainstem site was installed. 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.

Following the recommendations of the 2022 report, the Mainstem site was moved approximately 400 meters downstream to the location it had occupied previously to 2022, labeled as “Old OM Site” (Fig 1). It has become apparent that the “new” OM site is ideal for higher flow operations during steelhead and coho season while the “old” site is better for the lower flow Chinook season. An ARIS 1800 was used to monitor the Mainstem site (1.1/1.8 Mhz, provided by Olympic National Park).

The Mainstem site (Fig. 2) was 25-30 m wide and 1.5 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°. 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 18, 2023 with the exception of a one-day gap on September 4 and a two-day gap on September 10 and 11 (Fig 3).

The SONAR was in operation prior to June 7, 2023, throughout the winter and spring of 2023 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., 2023). Additionally, the SONAR was in operation after September 18 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 19 different days between June 7 and September 18 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 site 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, many pink salmon, winter steelhead, and several coho salmon towards the end of the Chinook run.

Data Analysis

All ARIS data was processed using ARIS proprietary software (V2.8). 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.

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, and length (mm). Length was measured in millimeters using software specific procedures.

An additional counting protocol was used this year to accommodate the large number of pink salmon that returned to the Elwha River in 2023 and exhibited milling behavior in the vicinity of the SONAR during crepuscular periods. This milling was assumed to be mostly pink salmon based on the large schools of pink sized fish (45-55 cm) that were involved. 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. Approximately 10% of the fish counted in this way were measured for length. This procedure was only intended to account for the large schools of pink salmon milling in the vicinity of the SONAR sites, all large bodied (presumably Chinook salmon) were individually counted and all metadata including length was 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 630 mm as the cutoff for inclusion in the final escapement estimate this year to limit the inclusion of smaller bodied salmonids (mostly the thousands of pink salmon present during the Chinook run, but also jack Chinook salmon and coho towards the end of the Chinook run) in our final escapement estimate. Twenty percent of the Chinook captured were (<630 mm) (35/178) (Fig. 4). In contrast to previous years, there was no clear break in the length frequency histogram between adult and jack Chinook (Fig. 4) Therefore we chose 630 mm as the cutoff in an attempt to include almost all of the adult Chinook salmon while eliminating most of the pink salmon. Nine percent (16/178) of all sampled Chinook measured between 600 and 620 mm, inclusive. Only 1 of 117 sampled pink salmon measured over 620 mm.

Raw targets meeting the above length criteria were then aggregated into channel-specific six-hour chunks, four per day. Each channel specific six-hour chunk (n = 420) 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 (420 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 5). 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 June 7, so all targets after that date were included in further analysis. In-river netting on September 18 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 620 mm in length was captured on the August 21 sampling event and four were sampled on September 18 (Table 1a). An additional 11 coho measuring 620 mm or smaller were captured between August 14 and September 18 (Table 1b). Finally, a snorkel survey from the SONAR site to the mouth of the river on September 14 counted only 100 Chinook salmon in spawning condition and several dozen fresh coho salmon. Therefore, calculation of the 2023 Chinook salmon escapement only included SONAR targets recorded through September 18.

In river netting also provided the necessary data to adjust the expanded counts to account for the number of Chinook moving passed the SONAR sites (Table 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:

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

where i represents the iteration (1 – 10,000) and j indexes the 6-hour chunk (1 – 420). The total number of fish, $N_{i,j}^{total}$, and total number of Chinook $N_{i,j}^{chinook}$ 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:

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

This adjustment down weights the raw SONAR passage to just Chinook passage. This 2-step sampling accounts 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 2023, this assumption was known to be violated with summer steelhead although much less so than in previous years. A snorkel survey from RKM 20 to RKM 50 (excluding the Grand Canyon) during the second week of September observed 317 summer steelhead (ONP, pers. comm. 12/13/23). These fish almost certainly migrated upstream passed the SONAR sites between June 7 and September 18, yet only four of them were sampled in our species composition netting, three of which measured over 620 mm (Table 1a). When pushed through the described simulation model, these three summer steelhead represent a SONAR count of approximately 211 summer steelhead. Or about 100 less than the known minimal population number based on visual observations during the snorkel survey. Therefore, to more accurately reflect the true Chinook escapement to the Elwha River in 2023, we subtracted the 100 unaccounted for 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 16 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. 6). 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.

Estimating Pink Salmon Escapement

Pink salmon escapement was calculated in a similar way to the described Chinook escapement method except it was done in an Excel spreadsheet and did not include the simulation procedure. Only SONAR targets that measured between 450 mm (the smallest recorded targets) and 620 mm (the lower bound of the Chinook cutoff), were included. Unmeasured targets that were recorded during the net passage counting procedure described above were also included. Some of these raw targets were then apportioned as pink salmon on a daily basis by simply multiplying the raw passage number by the percentage of field measured targets between 450 mm and 620 mm that were pink salmon. This daily pink salmon passage number was then multiplied by three to account for sub-sampling 20 minutes of each hour.

Results

Between June 7 and September 18, 2023, there were a total of 2,420 hours (101 days) recorded on the Mainstem. During this time period 6,854 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 2023 was 3,950 fish with a coefficient of variation (CV) of 2.0% (95% CI 3,800 – 4,000) (Fig. 7 and Fig 8). 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 3,850 (95% CI 3,700 – 4,000) (Table 3). In order of decreasing variance, the largest sources of error were (1) error in the gap filling procedure (3.3%), (2) adjusting for species composition (1.1%), (3) the uncertainty associated with expanding the 20-minute counts (0.5%), and (4) accounting for observer error (0.4%) (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 22, respectively (Fig. 9). Similar to previous years, the run appears to begin in earnest in early July on the descending limb of the snowmelt peak, although approximately 200 fish were counted migrating upstream in June in 2023. The highest passage day of the season was on July 25 and was associated with a short term rise in stream flow.

We also provide a rough estimate of 6,400 pinks returned to the Elwha River in 2023, which is far greater than the previous high of 2,300 in 2021. Years previous to 2021 had pink populations too low to warrant calculating an escapement estimate.

Discussion

Our estimate of 3,850 Chinook salmon provides a robust measure of Chinook escapement to the Elwha River in 2023 for several reasons. Most importantly we recorded data from approximately 97% of the run (2,424 of 2,496 hours). Furthermore, we feel confident that we accurately recorded the beginning of the run, June 7, and collected data until the end of the run, September 18. Minimal passage occurred the first half of June (only 1% of the run had passed the SONAR sites by June 23) and the weekly in-river netting operations indicated few Chinook salmon were present in the river during that time period, as only 5% (10/179) of Chinook salmon caught during the course of the run were caught before June 23. Species composition sampling and snorkel surveys indicated that Chinook salmon stopped entering the river by mid-September. The ability to confidently denote the beginning and end of the run is crucial to providing assessing uncertainty around our Chinook salmon 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) error in the gap filling procedure (3.3%), (2) adjusting for species composition (1.1%), (3) the uncertainty associated with expanding the 20-minute counts (0.5%), and (4) accounting for observer error (0.4%) (Table 2). 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.

The greatest source of measured uncertainty this year was due to the gap filling procedure, with a C.V. of 3.3%. As in every other year, we recorded data from a high proportion of the run this year, with a total of only 3 days of data gaps on the Mainstem. These three days did occur during periods of relatively high passage and also high daily variability of passage. Over several years of operation, the project has worked out most of the potential technical difficulties that contribute to data gaps. While the gap filling procedure was the highest source of uncertainty this year it was still an acceptable level.

The second greatest 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 salmon are both in the river at the same time but netting and snorkeling revealed that Chinook salmon 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 630 mm also eliminated many of the coho and almost all of the pink salmon that overlapped with the Chinook run.

It is important to note that the species correction CV only applies to the simulations that adjust the SONAR measured targets that were at or above the length cutoff of 630 mm. In all previous years of the project there was a clear break in the length frequency histogram of field measured Chinook, whereby the length difference between "adult" and "jack" Chinook was ~50-100 mm. Furthermore, during odd year pink returns, the size difference between the smallest adult Chinook and the biggest pink salmon was also ~50-100 mm. Before 2021, there were very few pink salmon in the river to misappropriate (~2,300 in 2021 and less than a few hundred before 2021). Therefore, we had high confidence that the species apportionment was working as intended. Unfortunately, none of these three phenomena occurred in 2023. There was no obvious break in the length frequency histogram of adult and jack Chinook (Fig. 4), the biggest field measured pink salmon (630 mm) was similar in length to several field measured Chinook (11%, 20/178 of sampled Chinook salmon measured 610 mm to 630 mm), and approximately 6,400 pink salmon returned to the river in 2023. An additional complication is that both the SONAR measured lengths and the field measured lengths have an associated error. Helminen et al. (2020) reported SONAR measurement errors ranging from -99 mm to +78 mm for Atlantic salmon. During our net sampling, salmon are not anesthetized and are quickly measured with a flexible tape leading to unknown error. Therefore, unique to Chinook in 2023, there were several sources of added uncertainty surrounding the species apportionment of SONAR targets in approximately the 600 – 650 mm range. It is possible that the model did not account for some Chinook that passed the SONAR and measured less than 630 mm because they were not included due to the length cutoff. It is also possible that some SONAR targets that measured over the length cutoff were in fact pink salmon that were simply over measured in the SONAR software. The effect of changing the length cutoff is somewhat muted by the fact that a change in the length cutoff would necessitate changing the cutoff for the field measured fish for inclusion in the species apportionment part of the model. For example, if the length cutoff was lowered to 600 mm it would include approximately 350 more targets but a higher proportion of all the SONAR targets would get apportioned as pink salmon in the simulation because lowering the field measured cutoff to 600 mm would include 5 more pink salmon in the binomial draw that apportions raw targets to species. We feel that the length cutoff is robust based on the field measurements and strikes a balance between the possibility of both overestimating or underestimating the Chinook escapement, but the reader should be aware of the complications in 2023.

The third greatest source of uncertainty this year was due to expanding the 20-minute counts, with a CV of 0.5%. The variation between actual and predicted 60-minute counts is characterized by the r^2 value of 0.95, which indicates a very tight relation between the predicted and observed counts. There is no reason to predict that, over the course of the three-month Chinook salmon run, there would be any difference in passage rates between different 20-minute periods of an hour. In fact, during the steelhead

portion of the project (Denton et al. 2023), where we count the whole 60 minutes of each hour, multiplying passage during the first 20 minutes of each hour by three over the course of the entire season equals almost the same total passage as the actual counts over the five-month period.

The final source of uncertainty in 2023 was associated with the observer error correction with a CV of 0.4%. The coefficient of the regression is close to 1.0 (0.93) meaning that there was very little difference in total counts by the expert and technician. The r^2 value (0.95) 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 milling fish (presumably pink salmon) 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 masse 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. However, these milling fish were almost all smaller bodied pink salmon that would not have made the length cutoff for inclusion in the final estimate thereby lowering the potential uncertainty associated with them.

An additional potential 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 2023, crews from Olympic National Park sighted 317 summer steelhead between RKM 20 and RKM 50 during the second week of September, excluding the Grand Canyon (ONP, pers comm. 12/13/23). These fish likely migrate passed our SONAR sites from late May up until the snorkel surveys in mid-September. Fortunately, our net sampling encountered four summer steelhead in 2023 (three of which were above the length cutoff). Because these fish were sampled during high passage time periods of late July and early August, they expanded to an estimate of ~200 summer steelhead passed the SONAR's during the Chinook season. Nevertheless, we know that at least ~100 summer steelhead passed our SONAR site and were likely counted as Chinook. We accounted for this by subtracting the difference between the observed and predicted summer steelhead (100) fish) from our model derived escapement estimate for Chinook. It is important to note that the 317 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 2023. 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 317 we accounted for in our estimate. This represents a potential significant unaccounted source of error in our Chinook estimate.

We compared our escapement estimate of 3,850 Chinook with other data collected in the watershed. A peak redd survey was conducted in mid-September in non-canyon areas between ~Rkm 56 to the mouth in late-September. These surveys recorded 789 redds, which represents roughly 2,000 fish (redds*2.5) (McHenry et al. 2023). Additionally, 1,275 adult Chinook salmon were removed from the river above the SONAR sites for WDFW broodstock needs or returned to the LEKT hatchery facility. The combination of these two data sources yields a total of 3,275 adult Chinook in the Elwha in 2023. This represents roughly 85% of our SONAR based estimate. McHenry et al. (2023) reported that 18% of the redds were recorded upstream of the former Glines Canyon dam indicating that, for the seventh 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 2023, it is unlikely that any Chinook redds went uncaptured above Rica canyon as ONP staff reported a landslide and likely partial blockage (at least during the Chinook run) in Rica canyon (ONP, pers. comm. 1/20/23). One redd was documented at Rkm 36.4, above the partial blockage. Redd superimposition certainly occurred again in 2023 although probably not to the extent that it did in 2018 and 2019 when there were much greater Chinook densities. Redd superimposition would result in an undercount of redds. Also, 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 18 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. Perhaps the most likely reason for the greater SONAR counts as compared to other data sources is the very high male to female ratio seen in 2023. Both the WDFW and LEKT hatcheries saw male to female ratios of approximately 3:1, although carcass surveys recorded male to female ratios of only 1.2:1 in 2023 (WDFW and LEKT, unpublished data). During spawning ground surveys, several females were seen accompanied by multiple males (M. McHenry, pers. comm. 1/10/24). So, while male to female ratios varied depending on their source, they all indicated more males than females in 2023. This phenomenon would lead to the redd count underrepresenting the total number of fish since it assumes an equal sex ratio. For these reasons, the redd count total should simply be considered a peak count that is indicative of spatial distribution and not an independent escapement estimate. When sex ratios are so skewed, redd counts could also provide valuable information on egg deposition that is not well characterized with the total escapement estimate provided by the SONAR.

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 2023 Chinook escapement estimate of 3,850 is similar to the average of the project (~3,800) since 2009 (Table 3, Figure 11). Most Elwha Chinook salmon out-migrate as age 0+ fingerlings and spend three to five years at sea before returning to spawn. Most Elwha Chinook salmon are age three or four when they return as adults (Weinheimer et. al, 2018). Therefore, a majority of the 2023 returning adults were spawned, incubated, and subsequently out-migrated during the fall, winter, and spring of 2019-2020 and 2020-2021. While most of the sediment in the reservoirs has stabilized (Ritchie et al. 2018), egg survival is still related to flow and sediment dynamics (Pess et al. *in review*). These impacts resulted in low numbers of naturally produced juvenile outmigrants

between 2014 and 2018 (McHenry et. al. 2020). However, in 2019, 2020, 2021, and 2022 approximately 571,000; 950,000, 292,000, and 111,000 natural 0+ outmigrants were estimated to have been produced in the river, respectively, indicating that significant natural production is occurring (McHenry et al. 2022). Additionally, while most adult returns have been hatchery origin through 2021 (~95%), the upper reaches of the middle river and the former Mills reservoir saw mark rates drop to ~75% in 2022 (Weinheimer et al., 2018, Joe Anderson, WDFW, pers. comm.). Therefore, while variability in hatchery releases is likely still the major driver in adult returns three to five years later at this point in Chinook recovery post dam removal, smolt trapping of naturally produced juveniles and dropping mark rates of adults in the upper river from 2022 indicate that NOR adults are beginning to reestablish themselves.

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. 2013-2022). The first Chinook salmon was captured during the in-stream netting operations on June 7, which was about the average date of first capture since 2013. 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 usually 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). Although in 2023, 150 Chinook passed the SONAR during the last 5 days of June and the net sampling encountered more Chinook in June (23) than any previous year (previous high, 2022 with 11). It is interesting to note that the average size of these fish (812 mm) is much larger than the average of the rest of the Chinook sampled in 2023 (700 mm). Genetic 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.

Similar to many previous years of the project, the biggest day of passage (July 25) was linked to a rise in flow. 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 also occurred this year, whereby these fish moved upstream immediately before spawning.

Our estimate of 6,400 pink salmon returning to the Elwha River in 2023 is by far the biggest return to the Elwha since dam removal and perhaps since the 1960's. We estimated approximately 2,300 returned in 2021 and in the years previous to 2021 there were too few to warrant making an estimate. Further evidence of the high return in 2023 was the 3,165 live/dead count of pink salmon recorded during the one pass Chinook redd survey during the third week of September (McHenry et al. 2023). 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 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. We sampled 117 pink salmon in 2023, far more than the 58 in 2021, or 22 and 52 in 2013 and 2015, respectively. 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. Pink salmon returns to the Dungeness in 2021 and 2023 were both approximately 150,000, far lower than 2013 or 2015, yet the Elwha saw an increase over that same time period, indicating the beginnings of a self-sustaining population. 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).

Recommendations

We are pleased to report that our primary recommendation from 2022, to move the SONAR to a riffle crest to minimize milling was mostly effective. The new site (which had been used from 2013 until 2021) had a wide, shallow, and fast-moving riffle crest which seemed to prevent Chinook salmon milling. However, even in this location pink salmon still moved in and out of the ensnared area during crepuscular periods, probably because they were chased there by the Chinook that occupied the deep water immediately upstream.

Our primary recommendation for 2023 is related to this increase in pink salmon numbers. As detailed in the discussion, not only do pink salmon complicate accurate data review, but they also add an unknown but increased level of uncertainty to the species apportionment part of the simulation model. At their current levels, the added resources required to process the data is acceptable but at population levels seen in the nearby Dungeness River (10's of thousands to 100's of thousands) increased subsampling may be necessary. At some point, counting thousands of Chinook salmon in the midst of several hundred thousand pink salmon will probably become impossible and the project may have to rely on redd surveys for escapement estimates during odd years. We recommend developing more nuanced species apportionment models to deal with the overlap in length and timing of pink and Chinook salmon. For example, using different adjustment procedures for fish of different size categories could lower uncertainty by assigning almost all SONAR targets over 700 mm as Chinook and then using a different apportionment in the area of overlap between approximately 550 and 700 mm.

Our second recommendation is a repeat of last year's concerning summer steelhead. While the net sampling encountered four summer steelhead this year, which allowed us to estimate two thirds of the observed summer steelhead, our net sampling in the lower river does not appear to accurately reflect summer steelhead proportions. Considering the potential complications from an increasing pink population this issue is relatively minor, but at a minimum, we recommend continuing the upriver fall snorkel surveys to provide an estimate of how many summer steelhead were likely missed in our species apportionment.

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Table 1a. Total number of “new” and “holding” Chinook and other salmonids which measured at least 630 mm captured by date at seven sites during in-river netting operations on the Elwha River in 2023.

Date	Chinook	Coho	Pink	Steelhead	% Chinook
6/7/2022	1				100%
6/12/2022	1				100%
6/15/2022	1				100%
6/21/2022	3				100%
6/22/2022	3			1	75%
6/26/2022	7				100%
6/27/2022	5				100%
7/6/2022	5				100%
7/10/2022	6				100%
7/18/2022	14			2	88%
7/26/2022	9				100%
7/31/2022	7				100%
8/7/2022	7				100%
8/14/2022	14				100%
8/21/2022	11	2			85%
8/29/2022	17				100%
9/5/2022	11		1		92%
9/12/2022	6				100%
9/18/2022		4			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 2023.

Date	Chinook >620 mm	Chinook <620 mm	Pink	Coho	Steelhead	Bulltrout
6/7/2022	1				1	
6/12/2022	1				2	
6/15/2022	1				1	
6/21/2022	3				2	
6/22/2022	3	1			1	1
6/26/2022	7				1	1
6/27/2022	5					2
7/6/2022	5				1	
7/10/2022	6					
7/18/2022	14	1	1		3	
7/26/2022	9	1	3			
7/31/2022	7		11			
8/7/2022	7	5	7		1	
8/14/2022	14	5	7	1		
8/21/2022	11	5	11	2		
8/29/2022	17	7	22	1		
9/5/2022	15	3	32	2		
9/12/2022	10	3	17	3		
9/18/2022	4	1	3	8		

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	CV
Expansion	0.5%
Species Composition	1.3%
Observer Error	0.4%
Gap Fill	3.3%
Overall	2.0%

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
2023	3,850	3,700 - 4,000	7-Jun	30-Jul

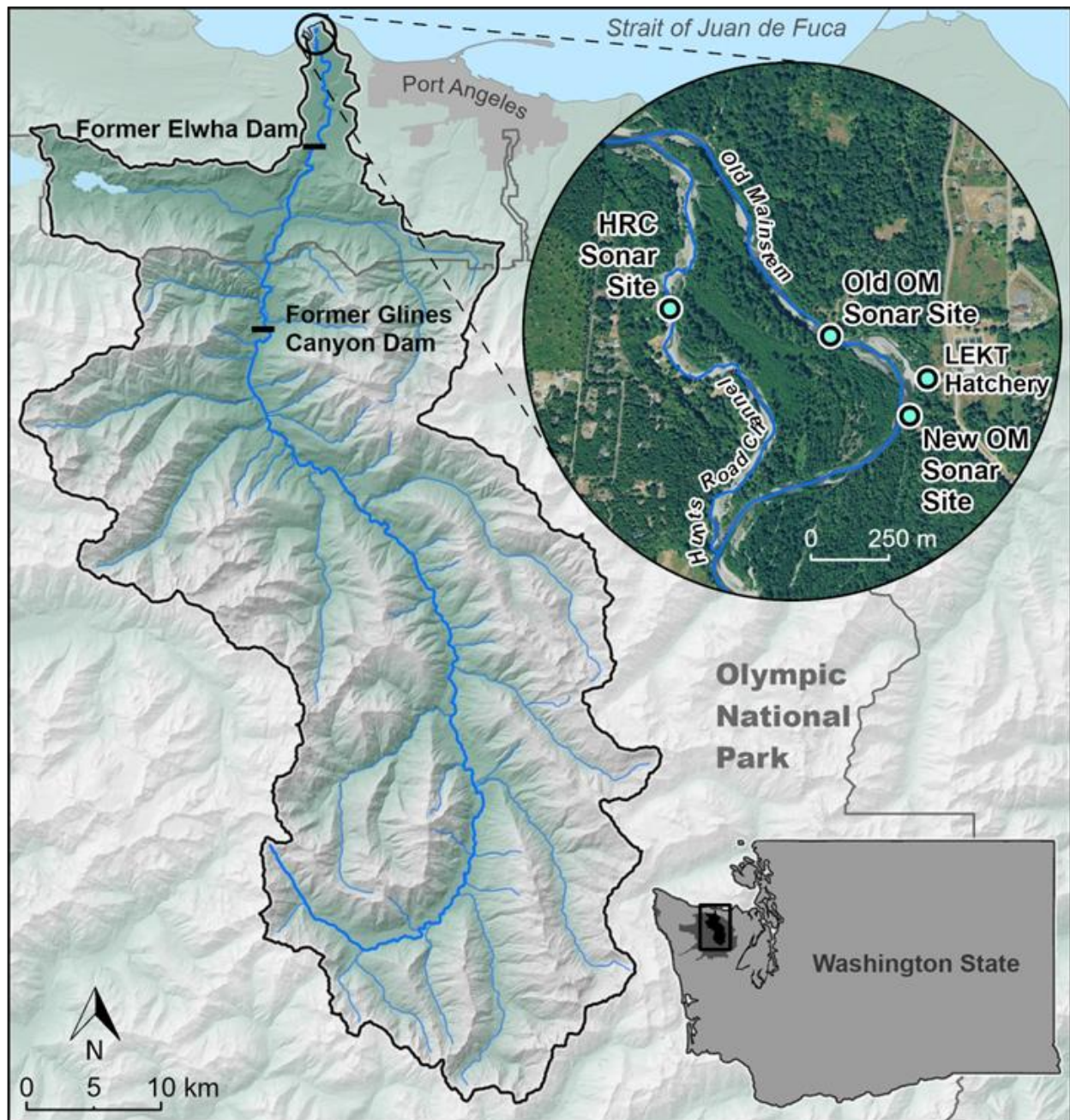


Figure 1. Map of the Elwha River, depicting the former dam sites, SONAR sites, Elwha Tribal Hatchery, and the two distinct migratory pathways near the mouth of the river. Although the Hunt Road Channel did not convey enough water in 2023 to allow Chinook passage and therefore no SONAR data was collected on that channel.



Figure 2. 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.

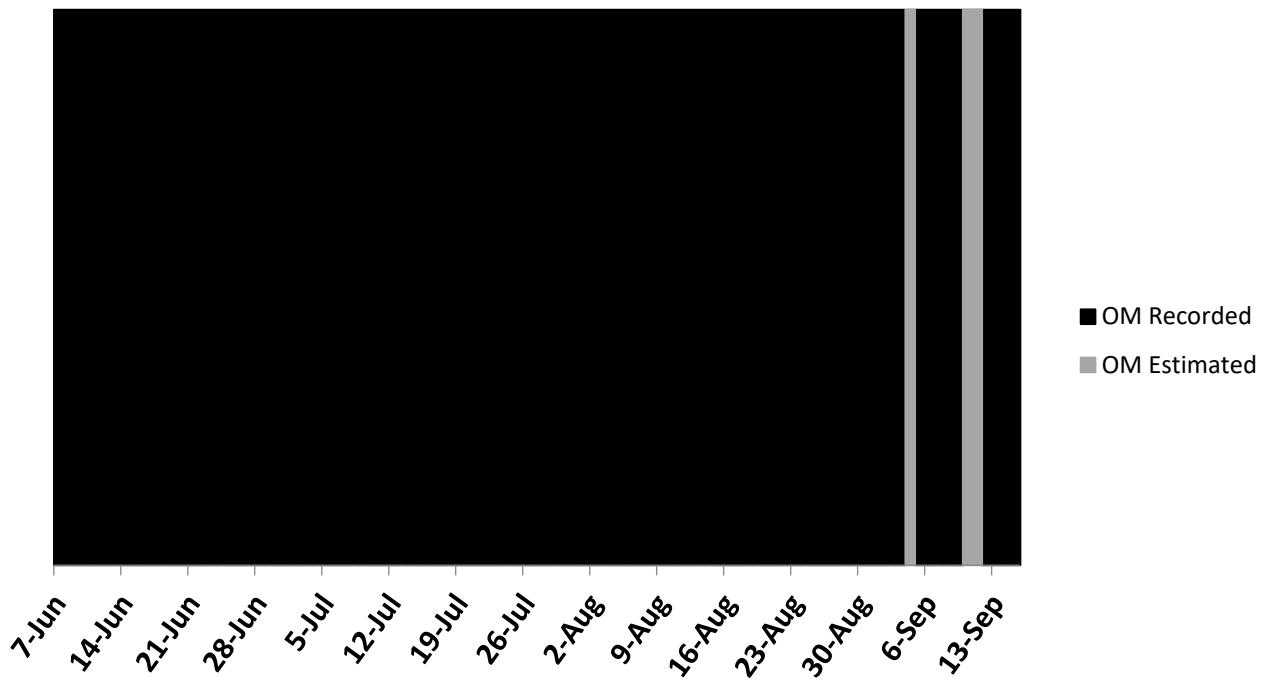


Figure 3. Dates for which data was recorded or estimated in the Mainstem channel during the Chinook season on the Elwha River in 2023.

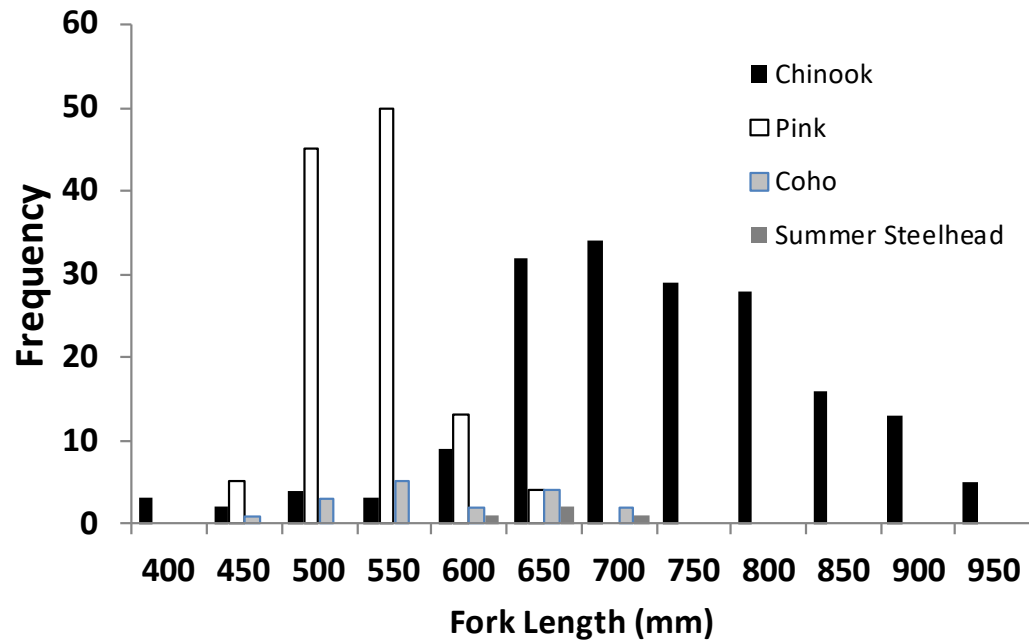


Figure 4. Length frequency histogram for all salmonids caught during 19 different sampling days between June 7, 2023 and September 18, 2023 in the Elwha River.

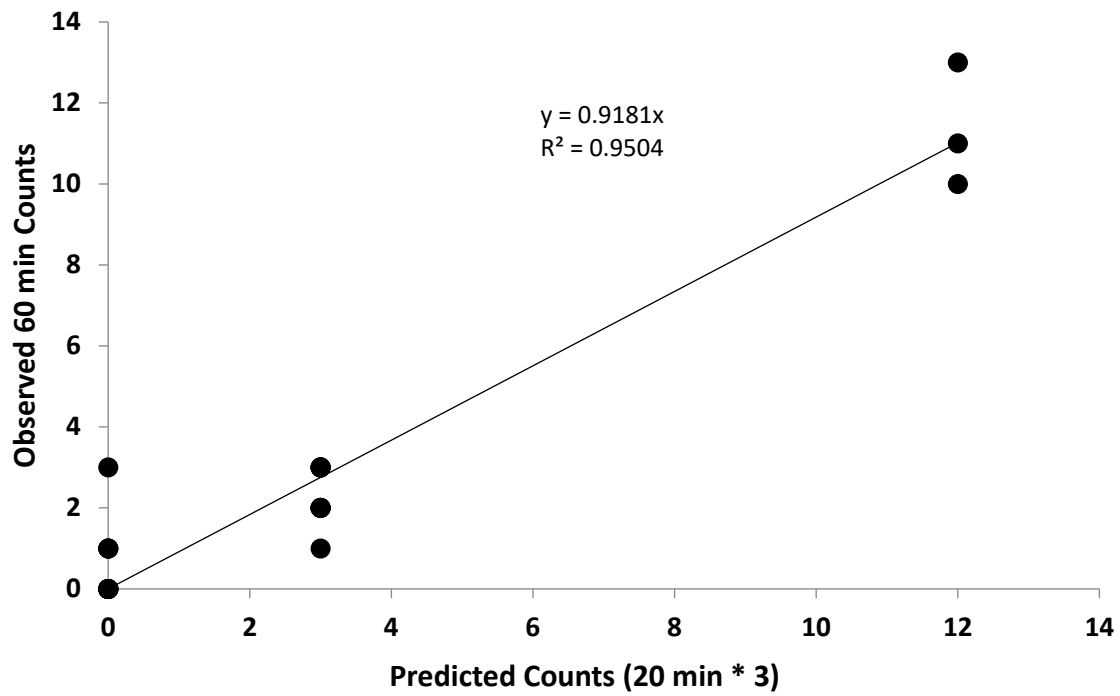


Figure 5. Predicted (20 minutes * 3) vs. observed (actual 60-minute counts) for 23 six-hour chunks of full hour counts for the Mainstem. There are six points at (0,0), three points at (1,0), four points at (2,3) and three points at (3,3).

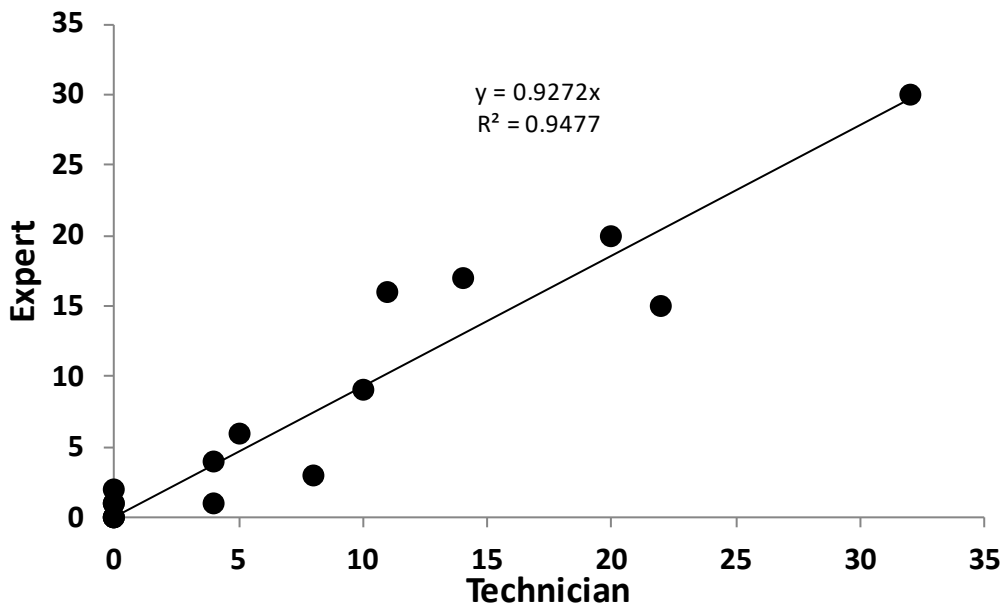


Figure 6. Total upstream passage counted by a technician and expert for 16 six-hour chunks. There are three points at (0,0) and two points at (0,1).

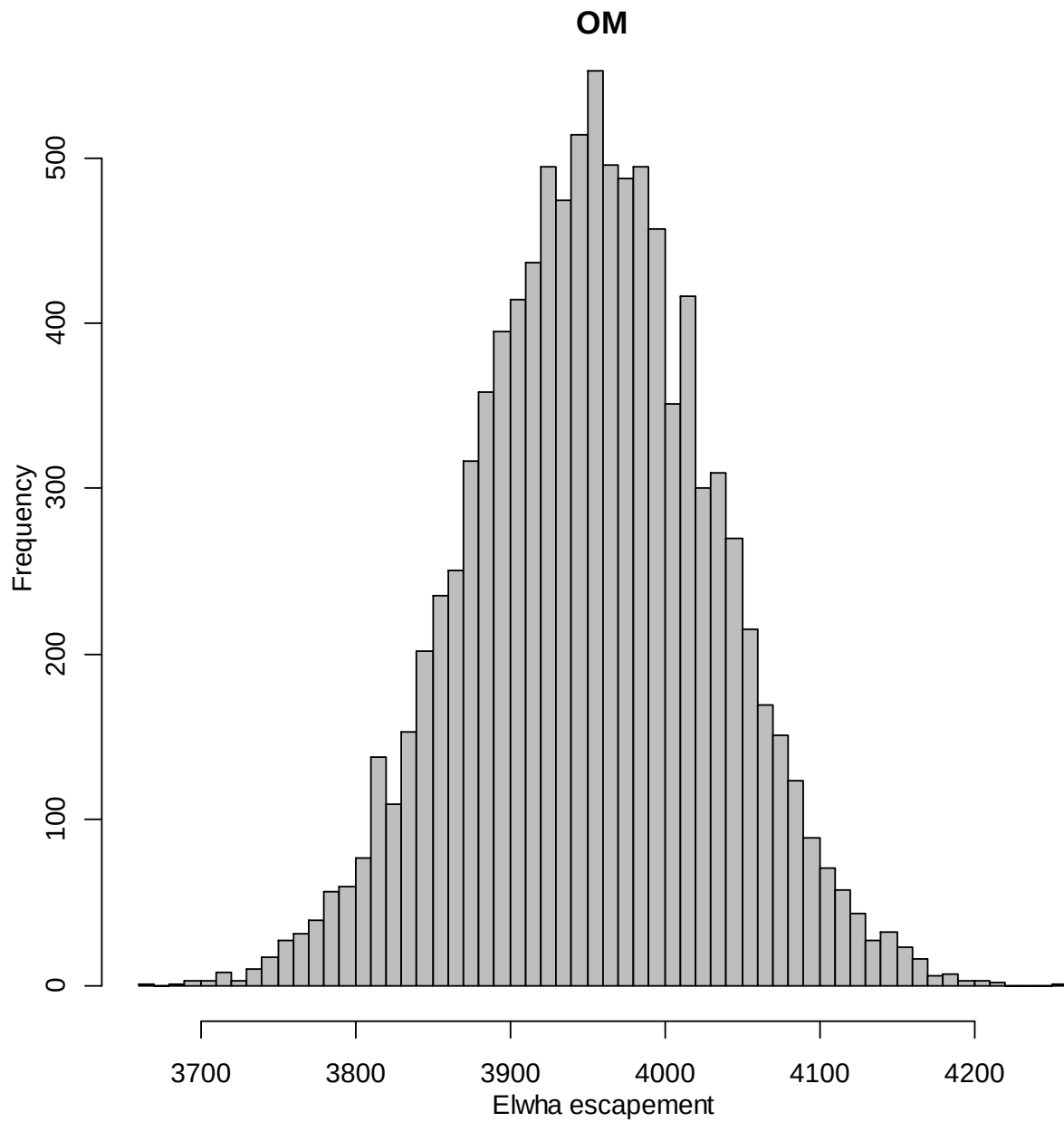


Figure 7. Chinook run size estimates for the Elwha River in 2023 based on 10,000 model runs. This output does not account for the 100 summer steelhead that were subtracted from the mean estimate.

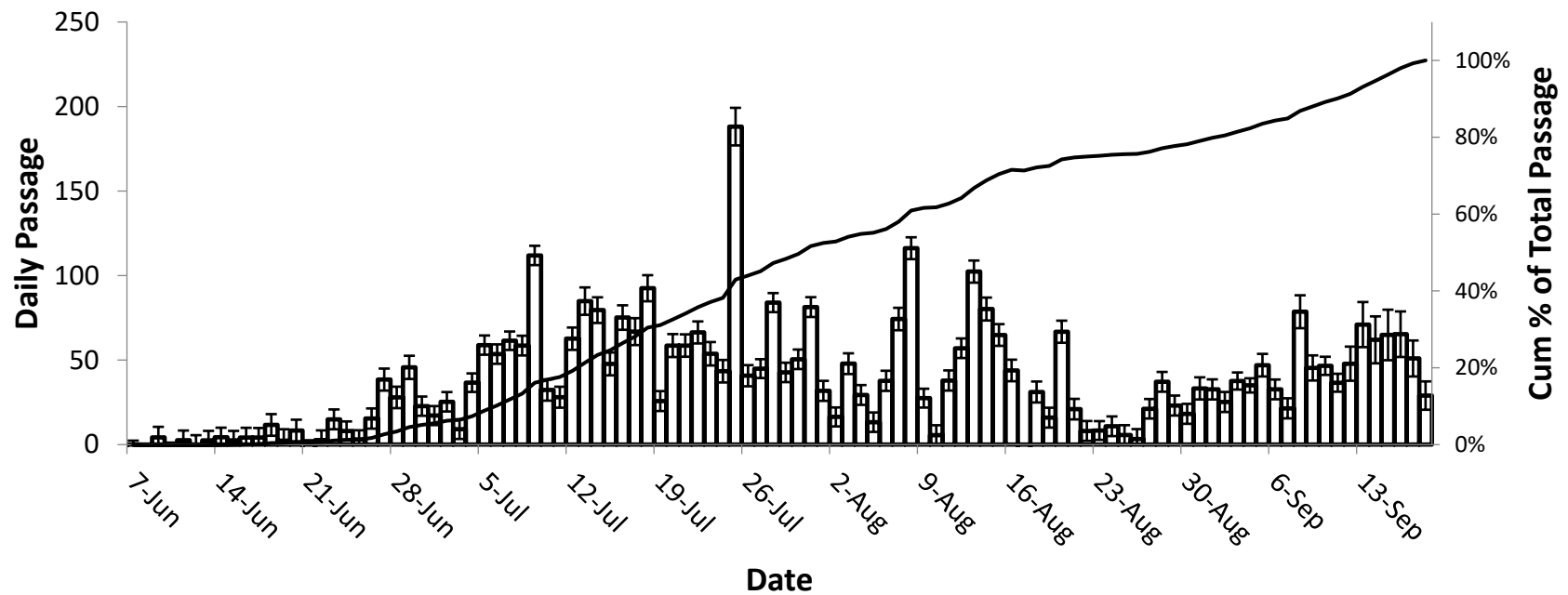


Figure 8. Daily Chinook passage and cumulative percent of total run in the Elwha River in 2023. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. The total passage estimate for the entire run that is depicted here is 3,950 Chinook salmon. 100 summer steelhead that were subtracted from that total are not reflected in this graph.

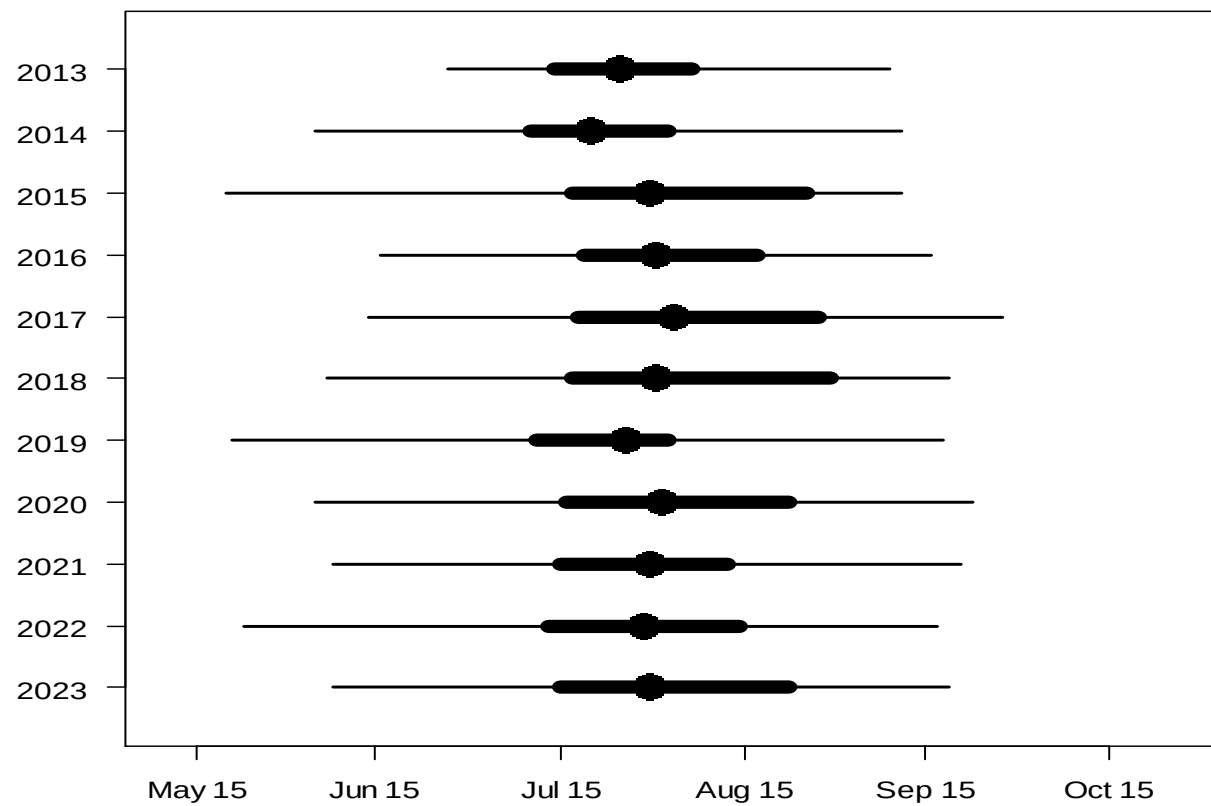


Figure 9. Run timing of Chinook in the Elwha River from 2013 to 2023. For each year, the long thin black line encompasses the first Chinook sampled until the end of the run. The thick black line shows the time period during which 25% to 75% of the run passed the SONAR sites. The black dot shows when 50% of the run had passed.

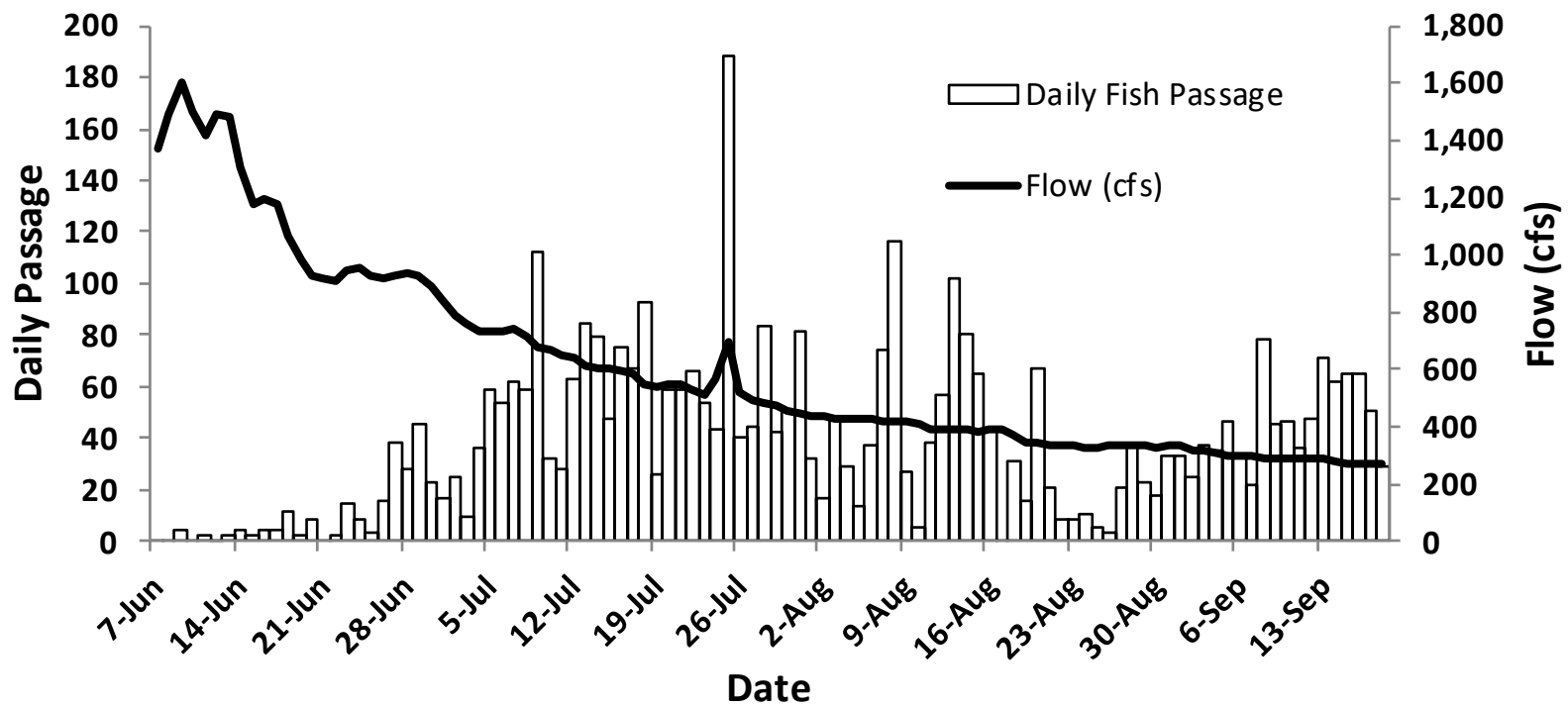


Figure 10. Daily Chinook passage and flow (cfs) for the Elwha River in 2023.

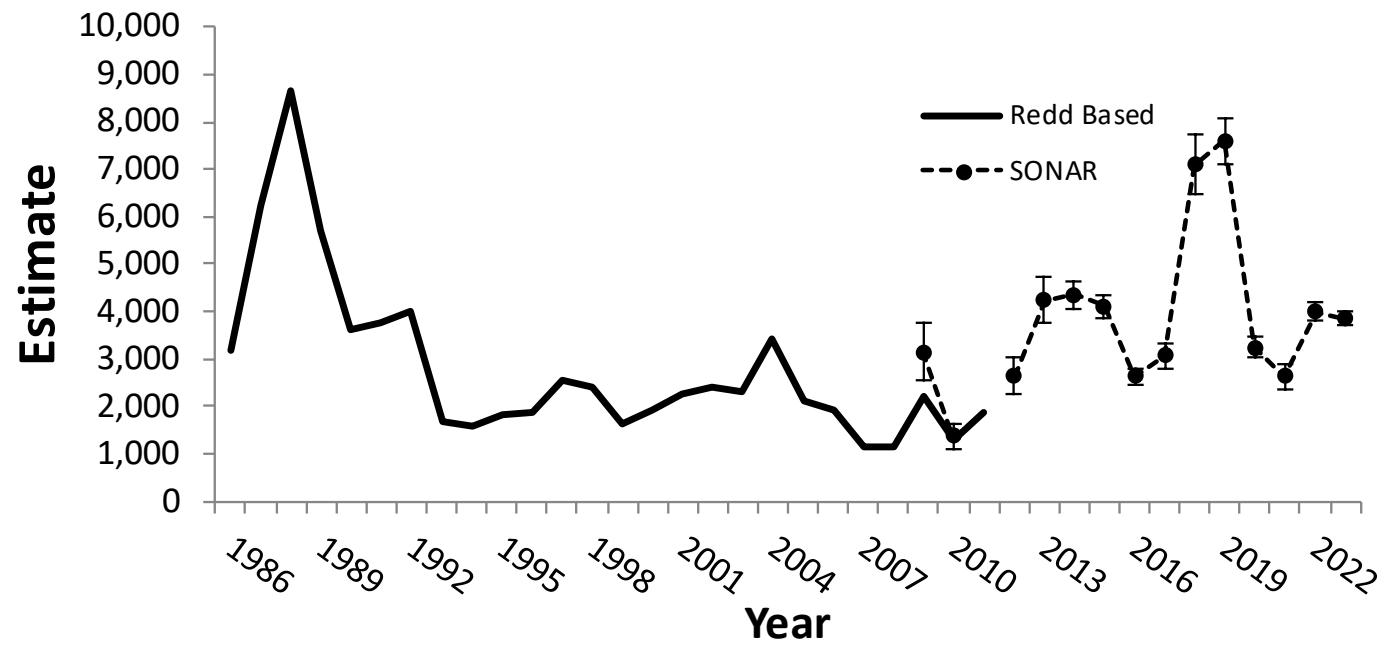


Figure 11. Historical Chinook escapement estimates from the Elwha River based on two different enumeration methods, redd counts and SONAR.