

Estimating Coho salmon escapement and mark rates in the Elwha River in 2022 using multi-beam SONAR technology.



Prepared For: Lower Elwha Klallam Tribe, Department of Natural Resources

Prepared By: Keith Denton, Oleksandr Stefankiv, and C.J. Urnes

K. Denton and Associates, LLC

Executive Summary

We used an ARIS 1800 multi-beam SONAR unit to monitor coho salmon escapement in the Mainstem, or East Channel (EC) of the Elwha River on a daily basis from August 23, 2022 through November 28, 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 an adult coho salmon (>500 mm) escapement estimate above the EC SONAR site of 5,600 fish, with a coefficient of variation of 2.2% (95% CI 5,380 – 5,870). We also operated a DIDSON (LR) SONAR in the Hunt Road Channel (HRC) for one three-day period in November and provide a low, medium, and high estimate of passage up that channel for the entire run of 30, 85 and 170 fish, respectively. Taking the EC estimate and the medium estimate for the HRC yields a total estimate of 5,685 coho passed the SONAR sites in 2022. Adding the 1,136 coho (>500 mm) that returned to the Lower Elwha Tribe hatchery facility downstream of the SONAR site yields a total escapement estimate of 6,821 coho to the Elwha River in 2022. Adding the hatchery return and the low and high estimates from the HRC to the low and high ends of the 95% CI, respectively, yielded upper and lower bounds of the total escapement of coho greater than 500 mm to the Elwha in 2022 of 6,546 and 7,176 fish. We also provide an estimate of approximately 1,400 coho salmon jacks (<500 mm) that returned to the river in 2022.

Fifty percent of the coho salmon run passed the SONAR sites by October 30, which was three to four weeks later than the 2019-2021. The first coho was captured in the species composition sampling on August 23, 2022 and the last was captured on December 5, 2022. Species composition sampling produced 258 coho greater than 500 mm for mark rate tabulation. Adipose clip only, CWT only, and fish exhibiting both marks represented 92%, 4%, and 4% of marked fish, respectively. Additionally, 36% of all captured fish over 500 mm were not marked in any way, and are considered natural origin fish. Mark rates varied significantly longitudinally with 61% (187/306) marked in the lower river while only 7% (2/25) were marked in the middle river. The male: female ratio for adult coho salmon from the net sampling was 1.1:1 (143:130). Using our SONAR based estimate of 5,685 coho and the male:female ratio, approximately 2,707 of the in river spawners would be female.

We are pleased to report that both recommendations from last year were implemented. We moved the SONAR upstream of the hatchery outflow, reducing milling and improving the efficiency and accuracy of data review. We also net sampled former Lake Aldwell on two different dates to provide samples for a longitudinal analysis of coho salmon mark rates. We have no new recommendations moving forward to 2023.

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, and SONAR technology (reviewed by Cousens et al., 1982). Over the years, the technology and techniques involved has remained basically static for most of these methods except SONAR, whose technology and application to escapement estimation has rapidly evolved over the last few decades (Maxwell 2008).

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

Several studies have compared 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). These studies have shown that SONAR counts were more accurate (insignificant error calculations) when compared to more traditional methods. It is important to note; however, that almost all of the fisheries applications of SONAR are focused on large salmon runs that transpire over the course of only a few weeks, which requires large technical staffs and operating budgets (eg. Lilja et al. 2008, Enzenhofer et al. 2010).

SONAR has been used to enumerate winter-timed steelhead (*Oncorhynchus mykiss*) and summer/fall Chinook salmon (*O. tshawytscha*) in the Elwha River, Washington from late January/early February through late September since 2010 (Denton et al. 2010-2023). This is the fourth year the project has continued operations throughout the fall and into the early winter to enumerate coho salmon (*O. kisutch*), as well as document the mark rates of the returning adults.

Although not listed under the Endangered Species Act, coho salmon are a stock of interest to various stakeholders on the Elwha. Attempts at enumerating escapement with redd surveys have been ongoing since at least 2013 but due to high flows and low visibility during their spawn timing, these surveys have not been useful for estimating total basin escapement which has led to this current effort to improve enumeration. Prior to dam removal, Elwha coho were managed for hatchery production and returns were dominated by hatchery origin returns (HOR). Since dam removal, coho have reestablished themselves in the middle river and its tributaries and the lower portion of the upper river to at least Geyser Valley. Additionally, the stock is of regional concern for fisheries managers

interested in assessing mark selective fisheries in salt water and has therefore been the subject of a targeted mark program whereby all hatchery releases are marked by a combination of two different marks, an adipose clip and/or a coded wire tag (CWT). Information on the relative proportions that these mark rates represent in the adult returns is critical to evaluating the effects of mark selective fisheries.

The objectives of this study were 1) to enumerate the number of non-jack (>500 mm) and jack (< 500 mm) coho salmon migrating passed the SONAR sites; 2) provide mark rate information on all captured coho; 3) provide run timing information; 4) incorporate and describe various sources of error in the estimate; 5) determine the proportion of coho salmon and other species in the river during the course of the run; and 6) make recommendations on how to improve the project in future years.

Methods

Data Collection

Continually changing river conditions and two distinct stream channels (migratory pathways) in the lower Elwha River necessitated two separate SONAR installations to accurately detect coho salmon passage in 2022 as the river splits into two channels in the lower 4 KM (Fig. 1). However, the Hunt Road Channel (HRC) on the west side of the valley has conveyed less flow in each successive year and in 2022 almost no flow went down that channel until November. The primary enumeration site was located in the Mainstem, or East Channel (EC) (formally referred to as the Old Mainstem, OM) while a secondary site was located in the Hunt Road Channel (HRC). Both sites were located at approximately RKM 2. While current data does not exist on the proportion of flow down each channel, in 2022, at flows above approximately 1,200 cfs, roughly 10% of the flow is transported down the HRC, with the remaining 90% traveling down the EC. At total river flows less than approximately 1,200 cfs, no surface flow is transported down the HRC (Personal communication, Mike McHenry 2022). Two different SONAR units were used during the course of this study; a DIDSON LR (long range, 0.7/1.1 MHz, provided by NOAA Fisheries) and an ARIS 1800 (1.1/1.8 Mhz, provided by the National Park Service – Olympic National Park).

Site selection was based on four criteria: 1) almost all fish would pass the site; 2) the location was downstream of the majority of coho 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. Depending on stream flow, the HRC site was between 10 and 15 m across and 1 meter deep in the thalweg, while the EC site was 22-32 meters wide and 2 meters deep in the thalweg.

Each SONAR was attached to a pole mount (Enzenhofer and Cronkite 2005) that was mounted on a reinforced aluminum step-ladder. The SONAR and ladder were positioned just under the surface of the water with a downward angle of approximately 4-6° (Fig. 2). The goal of this placement was to ensonify the bottom of the river across the entire width of the channel in addition to clearly

identifying the far bank (see Enzenhofer et al. 2010 for details on aiming the beam).

The HRC site was connected to line power, which ensured a constant power supply. The EC site was powered by a 24-volt, 400 amp hour battery bank that was continually charged by an array of solar panels (Fig 3). In 2022, the EC site was moved ~400 meters upstream from the location used during the 2021 coho season.

Coho salmon passage was recorded at the EC site from August 23 through November 28 with three recording gaps totaling 10 days (October 29-November 1, November 4-5 and November 17-20) (Fig. 4a). These gaps were mostly due to high flows but also to power issues. Data was recorded on the HRC for one three day period (November 7-9) (Fig. 4b). The limited recording on the HRC channel was mostly due to extremely low flows throughout the majority of the coho season.

Because of the limited amount of data available for the HRC, the data analysis procedures presented below were only performed on the EC data. The procedure for estimating passage up the HRC is presented at the end of the data analysis section.

Species Composition

We conducted 15 tangle net surveys between August 23 and December 15, 2022 to capture live adult salmonids at seven different sites in the lower four kilometers of the river. We did this to differentiate the species of salmonids over the course of the run and to determine the total duration of the coho salmon run. Captured fish were measured for fork length and qualitatively categorized as “new” if they appeared to have entered the river within the previous 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 spawning or were already spawned out. The tangle-net was designed to snare fish from the jaw and not the gills in order to reduce encounter effects and limit sampling bias. The net was approximately 18 m long and 3 m deep with loosely hung 10 cm stretch mesh.

We also used the in-stream netting data to determine a minimum threshold for SONAR measured targets to be included in the final escapement estimation by comparing the lengths of coho and all other salmonids (Fig 5). Additionally, fish captured during species composition netting in conjunction with fish captured during additional sampling at supplemental upstream sites were used to determine mark rates of coho salmon.

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

Post Processing

All DIDSON data was processed using DIDSON proprietary software (V5.25.26). There were 24 hour long files for each day of operation. Twenty minutes of each hour of each file was reviewed. Raw data was transformed in a four step process that enabled empty periods of time to be efficiently reviewed, while still 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 96 beams were included rather than only the center beam. This dramatically increases the probability that any fish entering the ensonified area was 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 is blank. If a fish swims through the ensonified area, the echogram has 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. The raw video imagery was then reviewed to ensure identified targets were indeed fish.

The procedure for processing ARIS data was the same (background subtraction, echogram formation, manual review of likely targets), except ARIS data is processed with its own software, ARISFish (v.1.5). After determining that a pattern on the echogram was indeed 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 centimeters using software specific procedures.

Escapement Estimation and Uncertainty Tabulation

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

$$N = U - D$$

Where N is the net upstream movement of fish for a given period of time, 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 twenty minute file, we first had to determine which passage events to include in our analysis, namely the minimum length threshold. A length frequency histogram of the in-stream netting data revealed that coho were between 310 mm and 820 mm, with a break at roughly 500 mm that indicated a size difference between jack and non-jack coho and only one coho (.3% of total) measured over 800 mm (Fig. 5). Based on this data, only SONAR targets recorded between 500 mm and 800 mm were included in the final escapement analysis.

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

We used a simulation based approach and replicated this simulation procedure a large number of times (10,000). We initialized the values in each cell (388 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, and at varying temporal scales (6-hour estimates, daily estimates, and annual estimates). 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 also applied each step of the procedure individually to the raw six-hour chunk counts from each channel.

20 Minute Count Expansion

Although counting 20 minutes of each hour is on the upper end of recommended sub-sampling regimes (Lilja et al. 2008), it requires treating two thirds of the total passage data as unknown. In order to expand our 20 minute counts and encompass the uncertainty inherent in the process we counted the full 60 minutes of 10 six hour chunks for the EC (Fig 6). 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

Calculation of the 2022 coho salmon escapement only included SONAR targets recorded from August 23, the date of first coho capture, through November 28. Two additional sampling events occurred on December 5 (two “new” coho and eight “spawned” coho were captured) and December 15 (no “new” coho and three “spawned” coho were captured).

In-river netting also provided the necessary data to adjust the raw counts to reflect just the number of coho moving past the SONAR sites (Table 1). Because of the low numbers of fish caught during some of the sampling events, we summed fish between adjacent events to arrive at daily totals of “all fish” versus coho 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 the EC, we simulated the proportion of coho for a given iteration and day as:

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

where i represents the iteration (1 – 10,000) and j indexes the 6-hour chunk (1 – 388). The total number of fish, $N_{i,j}^{total}$, and total number of coho, $N_{i,j}^{coho}$, were available on a daily basis, so the four six-hour chunks from each day were assumed to have the same species composition.

We then adjusted each of the raw counts for the proportion that were coho as a random draw from a Binomial distribution:

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

where X is the number of coho and total number of fish for each six-hour chunk.

The CV for escapement for this step was calculated by performing the correction directly on the net passage data. Then the counts of all 6-hour chunks were summed for each iteration, yielding 10,000 estimates. Finally, the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates.

Observer Error

We quantified observation error by comparing counts for 19 six hour chunks between the primary technician and a more experienced, “expert” counter. 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. 7). A trend line was fit to the data with an intercept of 0 and then a vector of observer error residuals was generated. Each cell of the coho 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 species composition adjusted data used by the simulation. Then the counts of each 6-hour chunk 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.

Filling Data Gaps

A number of different approaches could be used to fill in missing counts, including borrowing data from the neighboring channel or assuming return timing to follow some distribution (normal, double half-normal, etc). We used a generalized additive modeling (GAM) approach to fill in missing

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

Estimating Passage up the HRC

Due to the limited amount of recorded data on the HRC, a much more simplistic approach was taken to estimate passage up that channel. We were not able to report confidence intervals around an estimate but instead offer three different methods for calculating an estimate that can be viewed as a low, medium, and high approach. Fish passage was measured up both channels at a range of flows (800 – 1,500 cfs) over a three day period in early November. The proportion of fish moving up the HRC during this three day period was only 7% of the number of fish moving up the EC during the same time period (8 vs 107). Also, no fish were recorded moving up the HRC at flows less than 1,200 cfs. The three passage estimates for the HRC were estimated by varying both the minimum flow threshold for passage to occur up the HRC and the proportion of fish that passed when flows were above that threshold. The low passage estimate predicted that 5% of the fish passed up the HRC at flows above 1,500 cfs. The medium passage estimate predicted that 7.5% of the fish passed up the HRC at flows above 1,200 cfs. The high passage estimate predicted that 15% of the fish passed up the HRC at flows above 1,200 cfs.

Estimating the number of jack coho salmon (<500 mm)

We estimated the total number of jack coho (<500 mm) to the Elwha River in 2022 by simply multiplying the total adult escapement estimate of 6,821 by the proportion of jack (57) to adult (279) coho captured in our species composition sampling or 20%.

Results

Between August 23 and November 28, 2022 there were a total of 2,088 hours (87 days) recorded on the EC (90% of the total possible) and 72 hours (3 days) recorded on HRC. During this time period 4,643 fish passage events were recorded and analyzed. The best estimate for coho salmon (> 500 mm) passage passed the EC SONAR site in the Elwha River in 2022 was 5,600 fish with a coefficient of variation (CV) of 2.2% (95% CI 5,380 – 5,870) (Fig. 9, Table 4). The three estimates of coho salmon (>500 mm) passage up the HRC were 30 fish, 85 fish and 170 fish. Using the middle estimate of passage up the HRC in conjunction with the estimate up the EC, we estimate a total adult coho passage passed the SONAR sites in 2022 of 5,685 fish. Adding the Elwha tribal hatchery returns of 1,136 (which occur

downstream of the EC SONAR site) yielded a total river escapement estimate of 6,821. Adding the hatchery return to both the low and high ends of the 95% CI and then adding the low and high estimates from the HRC to the low and high ends of the 95% CI, respectively, yielded upper and lower bounds of the total escapement of coho salmon greater than 500 mm to the Elwha in 2022 of 6,546 and 7,176, respectively. We calculated four sources of uncertainty for the estimate of passage up the EC, in decreasing order they are: (1) error in the gap filling procedure (3.6%), (2) the uncertainty associated with adjusting for observer error (3.5%), (3) adjusting for species composition (1.3%) and (4) expanding 20 minute counts to full hour counts (0.5%) (Table 2).

The SONAR data in combination with in-stream species composition netting provided detailed information on run timing. We captured the first coho salmon on August 23 and 25%, 50%, and 75% of the run had passed the EC SONAR site by October 7, October 30, and November 10, respectively. Daily coho passage was also plotted against flow (Fig. 10). The run began in earnest during the last week of September even though the hydrograph did not increase from summer low flow until the very end of October.

In stream netting provided 306 total coho from the lower river for mark rate tabulation, of which 258 were > 500 mm. Of the 306 total coho, 171 fish (91% of marked fish) were ad-clipped only, 9 fish (5% of marked fish) were CWT marked only, and 7 fish (4% of all marked fish) were marked with both methods. An additional 119 fish (39% of the total captured) were not marked in any manner (Table 3a). Of the 258 coho > 500 mm assessed for mark rate, 152 (92% of marked fish) were ad-clipped only, 7 fish (4% of marked fish) were CWT marked only, and 7 (4% of marked fish) were marked with both methods. An additional 92 fish (36% of the total adults sampled) were not marked in any manner (Table 3b). Including the additional 27 coho salmon sampled in the middle river provides information on longitudinal variation in mark rates. Fish with any hatchery mark comprised 61% (187/306) of catches in the entire lower river and 57% (83/146) of catches below the channel split at RKM 1. In contrast, marked fish only comprised 7% of catches in the middle river (2/27) (Table 3c). There was little variation in mark rates through time although September had a lower mark rate (54%) than October (59%) or November (58%) (Table 3d).

We estimated a jack coho salmon (< 500 mm) return of approximately 1,400 fish.

Using the non-jack passage estimate passed the SONAR sites of 5,685 fish and applying the netted fish non-jack male to female ratio of 143:130 or 1.1:1 equates to a return of approximately 2,700 females to the river (Table 4).

Discussion

We were successful at estimating coho escapement to the Elwha River for the fourth consecutive year. We believe our escapement estimate of 6,821 coho salmon is robust for several reasons. Most importantly, we recorded data from the main passage channel (EC) for what was likely the majority of the coho run. Net sampling occurred for weeks prior to the first coho being sampled and net sampling towards the end of the run showed declining catches, particularly near the mouth of the river. Although it is important to note that two “new” coho were caught on December 5, one week after the end of the SONAR data. A final net sampling event occurred on December 15 and three “spawned”

coho were sampled. We were also able to produce coefficients of variation for the four measured sources of uncertainty in our estimate. In decreasing order these sources were, (1) error in the gap filling procedure (3.6%), (2) the uncertainty associated with adjusting for observer error (3.5%), (3) adjusting for species composition (1.3%) and (4) expanding 20 minute counts to full hour counts (0.5%) (Table 2).

The highest source of uncertainty came from the gap filling procedure (3.6%). The CV associated with this procedure in 2022 was similar to the last two years and is higher than the Chinook or steelhead project. This is almost entirely due to the highly variable hydrograph during this year's coho salmon run which necessitated removing the equipment during three different high flow events in November. Fortunately, the hydrograph stayed uncharacteristically low until October 28 and the three passage gaps in November were all four days or less. Even with only 10 days of data gaps towards the end of the season, the gap filling procedure still predicted that 1,300 fish (19% of run) moved passed the SONAR sites during the data gaps. This is mostly due to fish moving upstream in significant numbers as soon as the hydrograph increased from summer low flows and again when it recedes from each high water event. This leads to a situation where the SONAR records hundreds of fish moving upstream as the hydrograph begins to increase, then the SONAR is removed to safeguard it from high flows creating a data gap, and when it is reinstalled on the declining hydrograph, it records above average passage until flows and passage rates flatten out again. The data filling procedure is influenced the most by the high passage periods during the increasing and declining limbs of the hydrograph. It is possible that fish movement actually slows during the peak of high flows as fish seek cover in logjams and off channel habitat. In this scenario, the gap filling procedure would overestimate passage. The gap filling procedure makes no attempt to estimate passage after the SONAR was removed for the season, November 28. Two coho salmon classified as "new" were captured December 5 and an additional 8 were classified as "spawned" indicating that coho were still actively entering the river after the end of SONAR data collection. On December 15, no "new" or "holding" coho salmon and three "spawned" coho were captured indicating that new entry had likely stopped. Catches of "new" coho salmon dropped considerably from November 14 (14) to a total of 8 from four sampling events from November 21 to December 15 suggesting that any coho passage after November 28 was probably limited (Table 1).

It is important to note that the measured uncertainty associated with filling data gaps only applies to the data gaps from the EC channel. The three estimates provided for passage up the HRC were simply three different scenarios encompassing the likely range of passage up that channel (30-170) but not enough data was collected from that channel to provide an estimate of the uncertainty surrounding those estimates. An unusually low hydrograph for most of the season that prohibited passage up that channel coupled with minimal passage when data was recorded makes it unlikely that our range of estimates contained any significant error. The range between our high and low passage estimates, 140 fish, only amounts to 2% of our total escapement estimate, so any additional error in passage up that channel would likely have little effect on our total estimate.

The second highest source of measured uncertainty came from the adjustment for observer error. The measured CV (3.5%) of this adjustment was relatively low and similar to most other years and species of this project. The project has been using the same data review technician for the last ten years. By moving the site upstream of the hatchery intake, the project also avoided the issue of milling in the vicinity of the SONAR site that led to review issues in 2021.

The third source of uncertainty was associated with adjusting raw passage totals to reflect just coho salmon passage (1.3%). This CV was low mainly because during the bulk of coho entry, late September through mid-October, coho made up the vast majority of our species composition samples. While there were still Chinook in the vicinity of the SONAR sites throughout September most of them were in spawning condition or were over 800 mm in length. Three snorkel surveys spanning late August to mid-September also greatly informed the species composition sampling. Actually seeing the bulk of the fish present in the lower 4 KM of the river helps mitigate any bias caused by the relatively small sample size of the net sampling or the different capture probabilities of milling, large toothed Chinook salmon (higher) versus streamlined, migrating coho salmon (lower). Most of the cause of the CV associated with assigning species to raw SONAR targets is from the higher number of chum salmon (21) captured this year. This is the highest number of chum salmon encountered during the four years of netting during coho season with the second highest being 14 in 2019.

The smallest source of uncertainty was due to expanding 20 minute counts to full hour counts (0.5%). This is expected to be low as there is no reason why passage during the first 20 minutes of an hour should be any different than passage during the following 40 minutes, especially when averaged out over more than 2,000 hours.

We estimated that 1,400 jack coho salmon (<500 mm) returned to the river in 2022, which is the second highest jack return of the four years of the project (2020: 1,800). We were only able to estimate jack salmon using the proportion of jacks present in our net sampling this year as data reviewers no longer count fish smaller than 450 mm in an effort to streamline the counting of thousands of fish passage events. Seventy-two percent (41/57) of all coho salmon measuring less than 500 mm measured less than 450 mm, meaning the majority of jack sized fish captured in the SONAR imagery would have been ignored. Our net sample proportion method was likely biased high since the size of the mesh was designed to tangle adults but actually captured fish <450 mm by the body or gills. This phenomenon likely leads to a situation where jack salmon are more likely to be captured in the net, thereby artificially inflating the proportion of them in the overall net data.

Redd surveys conducted on some middle and upper river tributaries during the 2022 coho salmon season may be useful to compare to our escapement estimate. Olympic National Park staff counted a total of 171 redds in tributaries in the middle and upper river, very similar to the 179 they counted in 2020 and 2021 and more than the 163 they counted in 2019 (Olympic National Park, pers. comm., 3/14/23). Redd totals on the middle river tributaries of Indian Creek and Little River, were the same as 2021 when taken in total (111 vs 112). When considered individually, Indian Creek saw a decrease from 79 redds in 2021 to 55 redds in 2022 while Little River saw an increase from 33 redds in 2021 to 56 redds in 2022. It should be noted that 156 adult coho salmon were moved from the LEKT hatchery facility into Indian Creek during the season and likely created some of the observed redds. Coho salmon were moved from the LEKT hatchery into Indian Creek in larger numbers in other years of the project.

Thirty-nine percent of our samples from the species composition netting were natural origin returns (NOR)(119/306)(Table 3a). When only considering coho salmon over 500 mm, 36% were NOR (92/258) (Table 3b). This would represent a return of approximately 2,455 NOR adult coho. Previous to 2021, using all fish to calculate PHOS would bias the return towards hatchery fish because the NOR proportion in the net sampling is biased low due to the proximity of several capture sites to the LEKT

hatchery. Mark rates near the hatchery have been shown to be biased towards hatchery origin returns (HOR) for steelhead on the Elwha (Peters et al. 2020-2022). In 2021 and 2022 however, mark rates were very similar regardless of how they were grouped, with samples near the hatchery being 68% HOR (97/142), the sites below the channel split being 57% HOR (83/146) and the entire lower river being 61% HOR (187/306). Although only slight differences in pHOS were detected within the lower river, when compared to the middle river, pHOS dropped dramatically to only 7% (2/27). It is possible that with a hatchery origin run of approximately 4,365 fish confined to at most the lower 8KM of river while the natural origin run of 2,455 fish is spread over at least 25 KM of mainstem and tributary habitat, that using pHOS data from any section of the lower river could be biased towards hatchery fish. There was a slight trend in temporal variability of pHOS with a greater proportion of NOR fish being captured in September (Table 3d). This trend is actually the opposite of what has been observed in previous years although the differences across months are small.

Our timing information can be compared to the entry timing data from 2019 through 2021 (Figure 11). The fifty percent entry date (October 30) was more than three and four weeks later, respectively, than in 2021 and 2020 (October 7 and 2) and more than a month later than 2019 (September 25). There is a trend of the 50% passage data moving later each year of the project but this year there was a pronounced jump. This is likely due to a true protraction of the run but also due to the uncharacteristically low hydrograph in 2022. In the previous three years of the project there was at least one high water event in September and several in October that saw significant upstream movement of fish. In 2022, although several days in October saw over a hundred fish pass upstream during low flows, an increase from summer low flows and the associated sustained upstream movement of fish did not occur until October 28. In the four years of the project, coho salmon passage had either stopped or significantly slowed by late November (although that was difficult to ascertain in 2021), much earlier than other streams in Western Juan de Fuca. Pess et al. (2020) found that the average return date for coho salmon from NOR populations in three Western Juan de Fuca stream was during the middle of the month of November, a week later than our 50% return date this year, but a month later than the three previous years of the project.

Finally, it is important to compare this year's coho salmon escapement estimate to the three previous years of the project (Figure 12). The coho escapement in 2022 was the largest recorded during the four years of the project and approximately 10% higher than last year, 30% higher than 2020 and more than three times larger than 2019. This dramatic increase in the coho population is even more striking when considering the few number of redds counted in most years before the SONAR project began, (Mike McHenry, pers. comm. 3/27/2023). While coho redd counts should be used with caution to interpret actual population sizes, especially during the high turbidity years following dam removal, it is clear that the coho population in the Elwha has been increasing steadily since the SONAR project began in 2019 and that the population was likely even smaller in the years before the SONAR project began. This population increase, coupled with the protracting timing of the run, are significant signs of recovery for the Elwha coho salmon population.

Recommendations

We are pleased to report that both recommendations from the 2021 season were implemented. The EC SONAR site was moved upstream of the hatchery intake, reducing milling behavior and increasing both the efficiency and accuracy of the data review. Our second recommendation of extending net sampling upstream of former Elwha Dam was accomplished by sampling Lake Aldwell on two different dates in November, yielding 27 coho for mark rate analysis.

We have no new major recommendations moving forward.

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Table 1. Total number of “new” and “holding” captured salmonids measuring over 500 mm at 7 sites during in-river netting operations in the lower 4 KM of the Elwha River in 2022. Data for August 30, September 6 and September 19 (grey shaded entries) are visual observations from snorkel surveys of the lower 4 KM of the river.

Date	Coho	Chinook	Chum	Other	% Coho
8/23/2022	1	3	0	0	25%
8/30/2022	4	0	0	0	100%
8/30/2022	20	800	0	0	2%
9/6/2022	50	800	0	0	6%
9/19/2022	11	0	0	1	100%
9/19/2022	250	50	0	0	83%
9/26/2022	29	0	0	1	100%
10/3/2022	38	0	0	0	100%
10/11/2022	37	0	0	1	100%
10/17/2022	18	0	0	0	100%
10/24/2022	30	0	0	0	100%
11/2/2022	14	0	3	0	82%
11/8/2022	12	0	4	0	75%
11/15/2022	14	0	4	0	78%
11/21/2022	4	0	2	0	67%
11/28/2022	2	0	0	0	100%
12/5/2022	2	0	0	1	100%
12/15/2022	0	0	0	3	NA

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

Source of Uncertainty	OM (Total)
Expansion	0.5%
Species Composition	1.3%
Observer Error	3.5%
Gap Fill	3.6%
Overall	2.2%

Table 3a. Mark rates for all coho captured in the lower 4 KM of the Elwha River between August 23 and December 5, 2022.

Mark	Ad Clip Only	CWT Only	Both	Neither	Total
Raw Number	171	9	7	119	306
Percentage of Marked Fish	91%	5%	4%		
Percentage of Total	56%	3%	2%	39%	

Table 3b. Mark rates for coho greater than 500 mm captured in the lower 4 KM of the Elwha River between August 23 and December 5, 2022.

Mark	Ad Clip Only	CWT Only	Both	Neither	Total
Raw Number	152	7	7	92	258
Percentage of Marked Fish	92%	4%	4%		
Percentage of Total	59%	3%	3%	36%	

Table 3c. Hatchery origin (HOR) and natural origin (NOR) coho captured in different sections of the Elwha River in 2022. HOR fish can exhibit any combination of an adipose clip and/or CWT.

River Section	HOR	NOR	pHOS
Below Channel Split	83	63	57%
All Lower River	187	119	61%
Middle River	2	25	7%

Table 3d. Mark rates for coho of all lengths recorded as “new” or “holding” captured in different months in the lower section of the Elwha River in 2022. September data includes two NOR fish and one HOR fish captured in August. November data includes 2 NOR fish captured in December.

Month	HOR	NOR	pHOS
September	25	21	54%
October	84	58	59%
November	37	27	58%

Table 4. Three different estimates of coho returns to the Elwha River in 2022, all of which include passage up both channels. The first estimate is for coho greater than 500 mm. The second number adds the subtracts the number of fish that entered the LEKT hatchery facility which is downstream of the SONAR site. The final estimate applies the male:female ratio from the net sampling to the second estimate.

Estimate

Total Non-Jack return	6,821
Total Non-Jack Return to River	5,685
Total Non-Jack Female Return to River	2,707

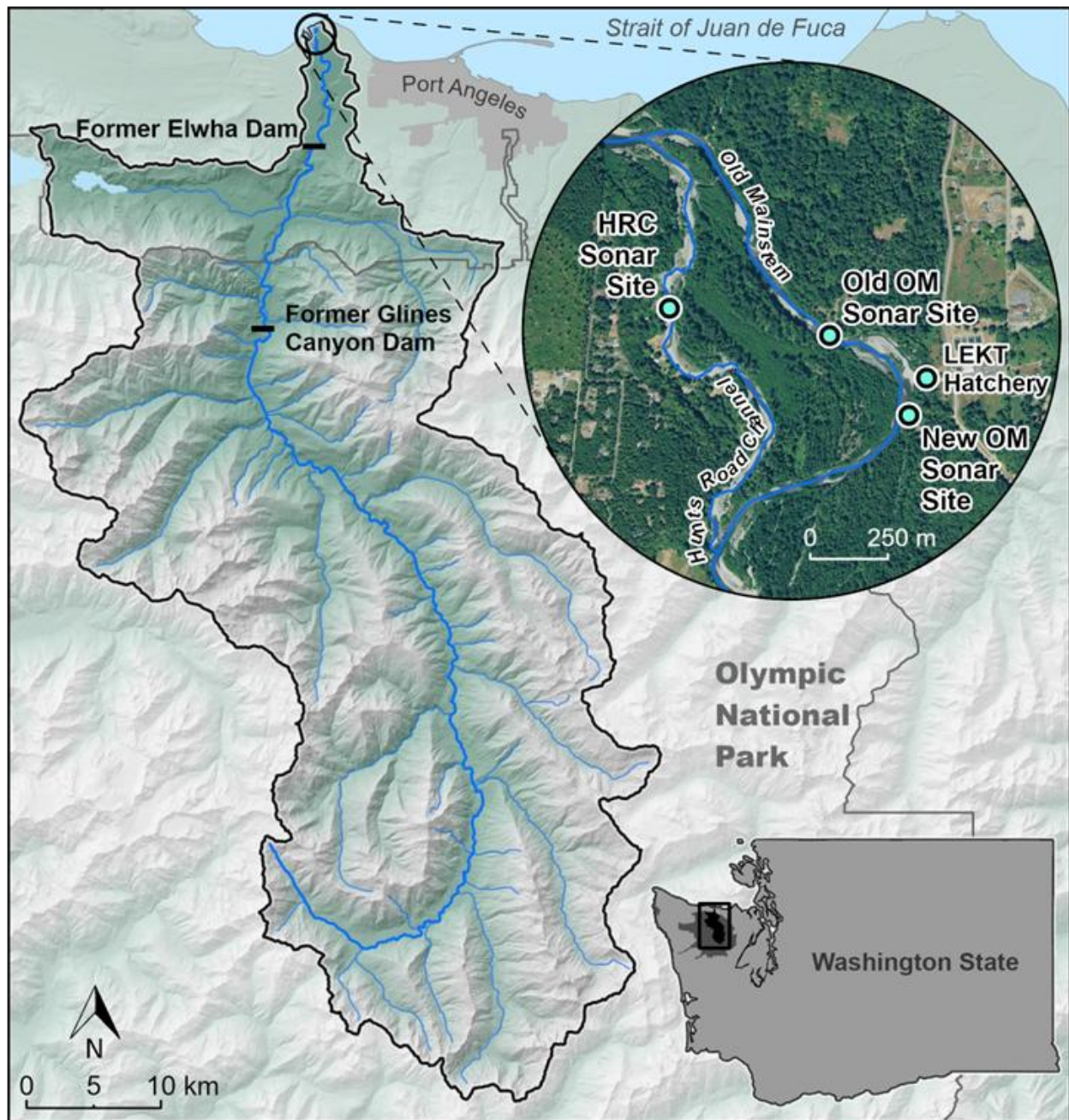


Figure 1. Map of the Elwha River, depicting the former dam sites, SONAR sites, Elwha Tribal Hatchery, and the two distinct migratory pathways near the mouth of the river.



Figure 2. Photo of the HRC DIDSON site. Note low water that precluded fish passage up this channel during the majority of the coho salmon run.



Figure 3. East Channel or Mainstem SONAR site looking upstream. The SONAR is attached to the pole mount which is in turn attached to the ladder.

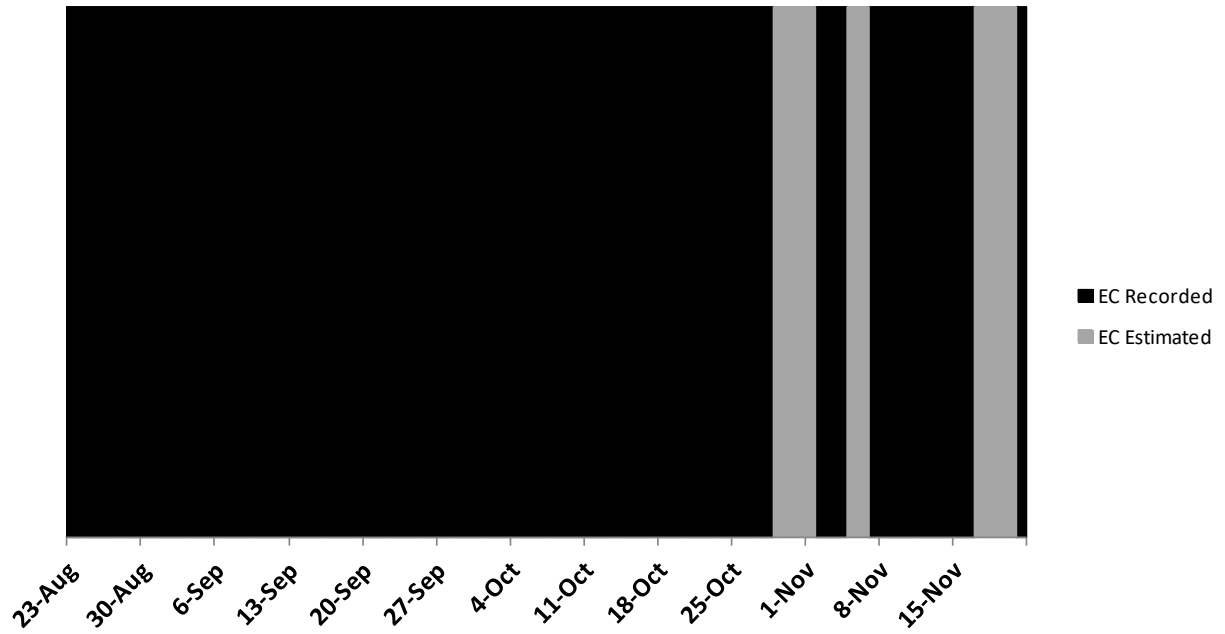


Figure 4a. Dates for which data was recorded or estimated in the East Channel during the coho salmon season on the Elwha River in 2022.

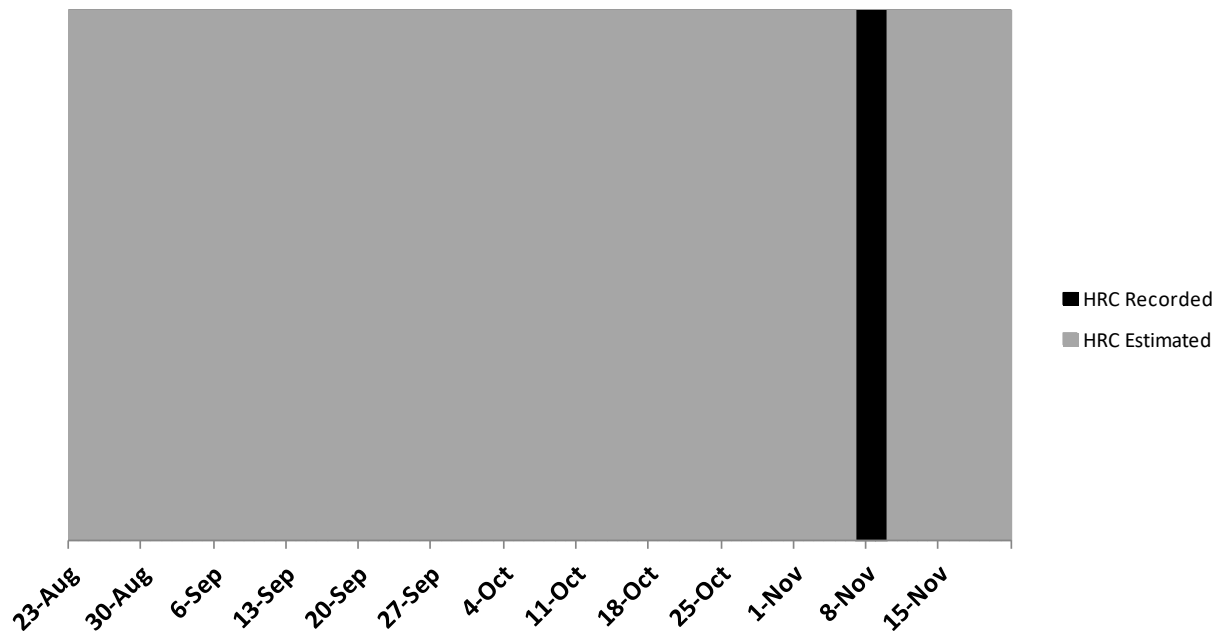


Figure 4b. Dates for which data was recorded or estimated in the Hunt Road channel during the coho salmon season on the Elwha River in 2022. The HRC was dry for most of the run in 2022.

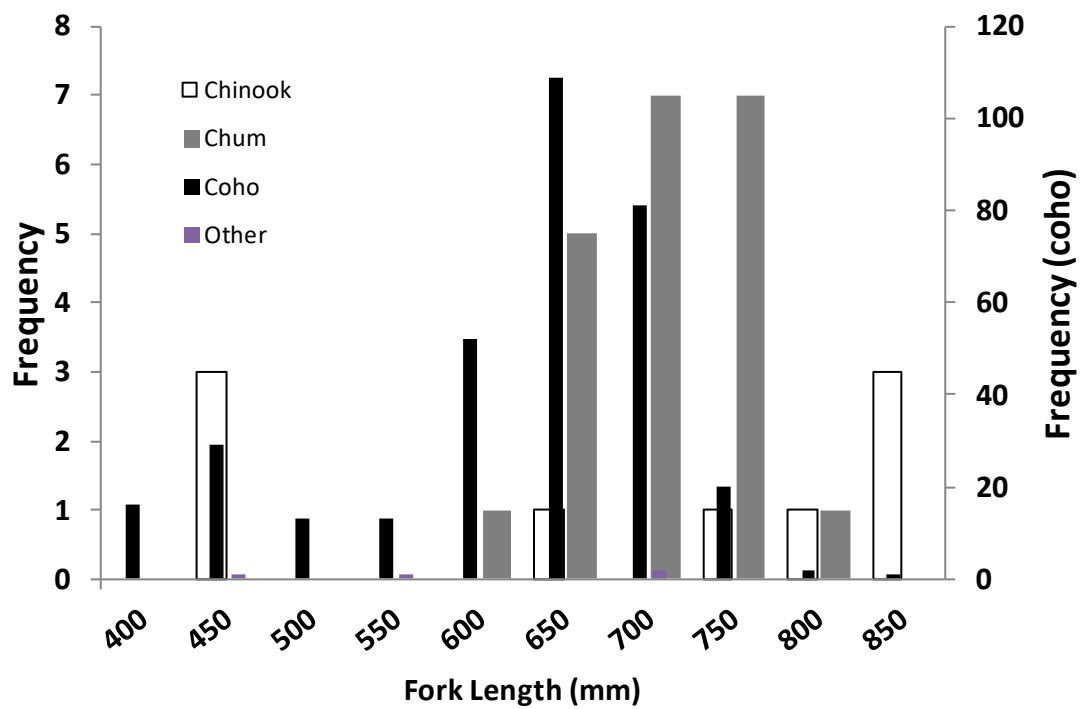


Figure 5. Length frequency histogram for all salmonids caught during 15 different sampling days between August 23, 2022 and December 15, 2022 in the Elwha River. Coho catches are shown on the right hand y-axis, all others on the left hand y-axis.

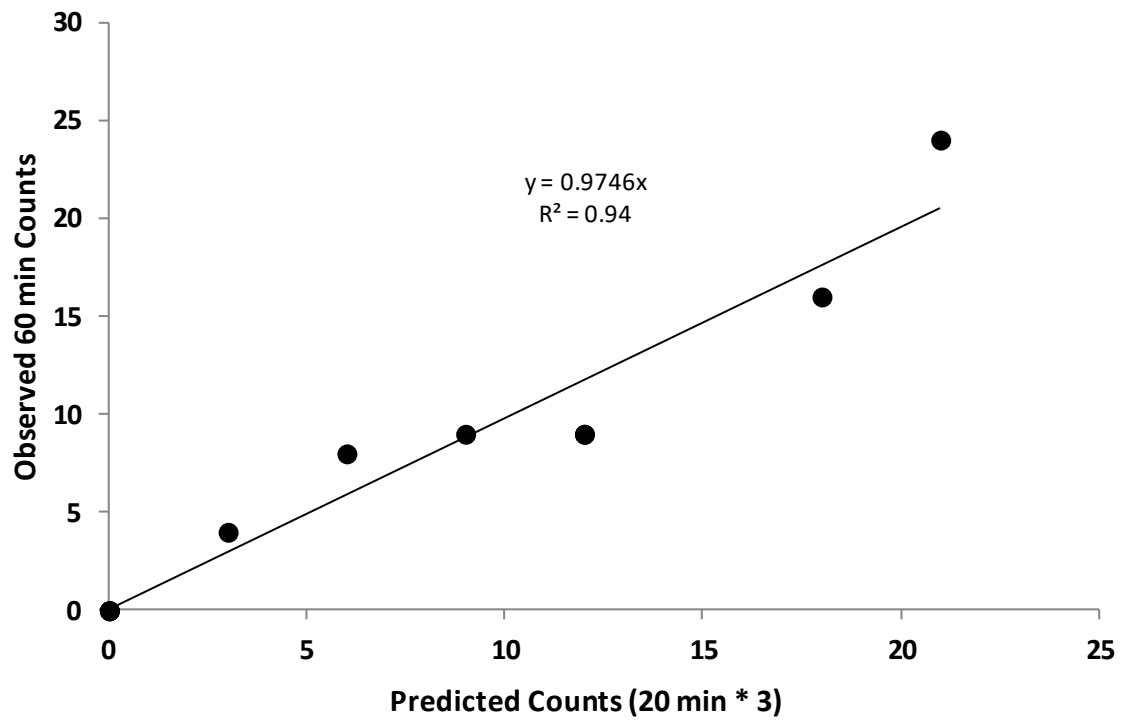


Figure 6. Predicted (20 minutes * 3) vs. observed (actual 60 minute counts) for 10 six-hour chunks of full hour counts for the East Channel (EC). Point (0,0) has three data points.

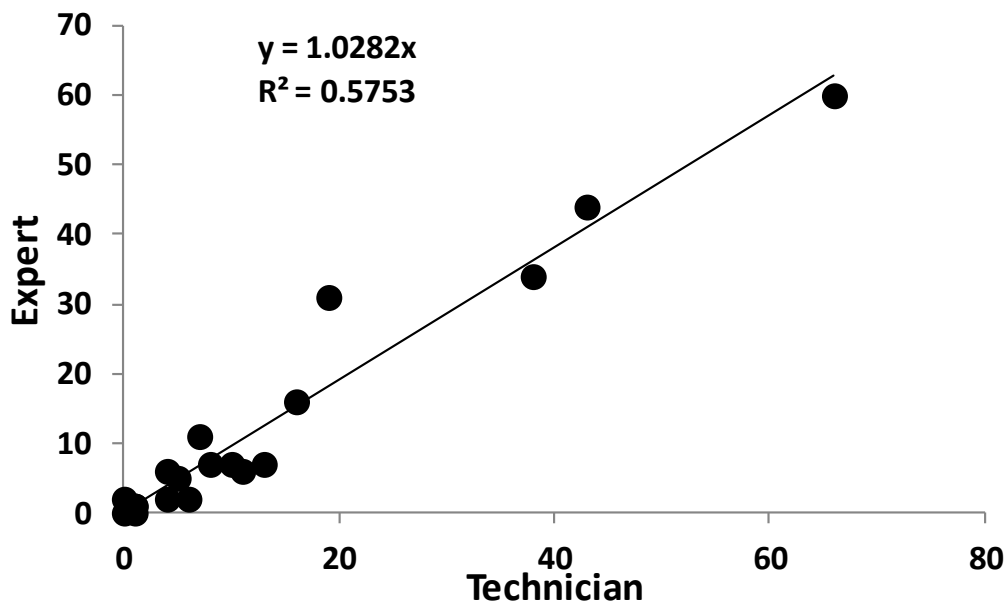


Figure 7. Total upstream passage counted by a technician and expert for 19 six-hour chunks. Point (1,1) has two data points.

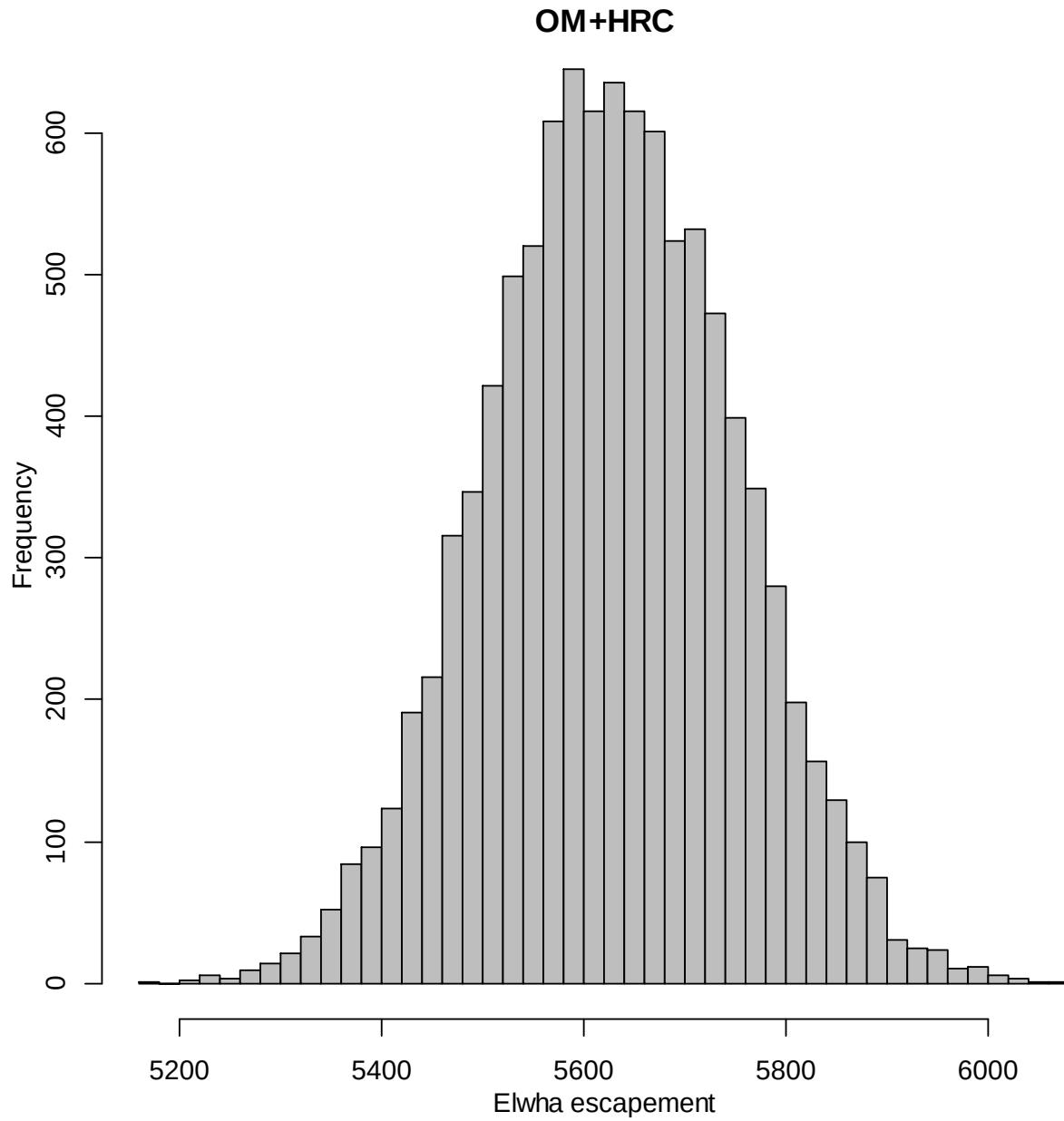


Figure 8. East Channel (EC) coho salmon run size estimates passed the SONAR site for the Elwha River in 2022 based on 10,000 model runs. This shows only non-jack (>500 mm) coho salmon numbers and does not include the rack return to the Lower Elwha Tribe Hatchery.

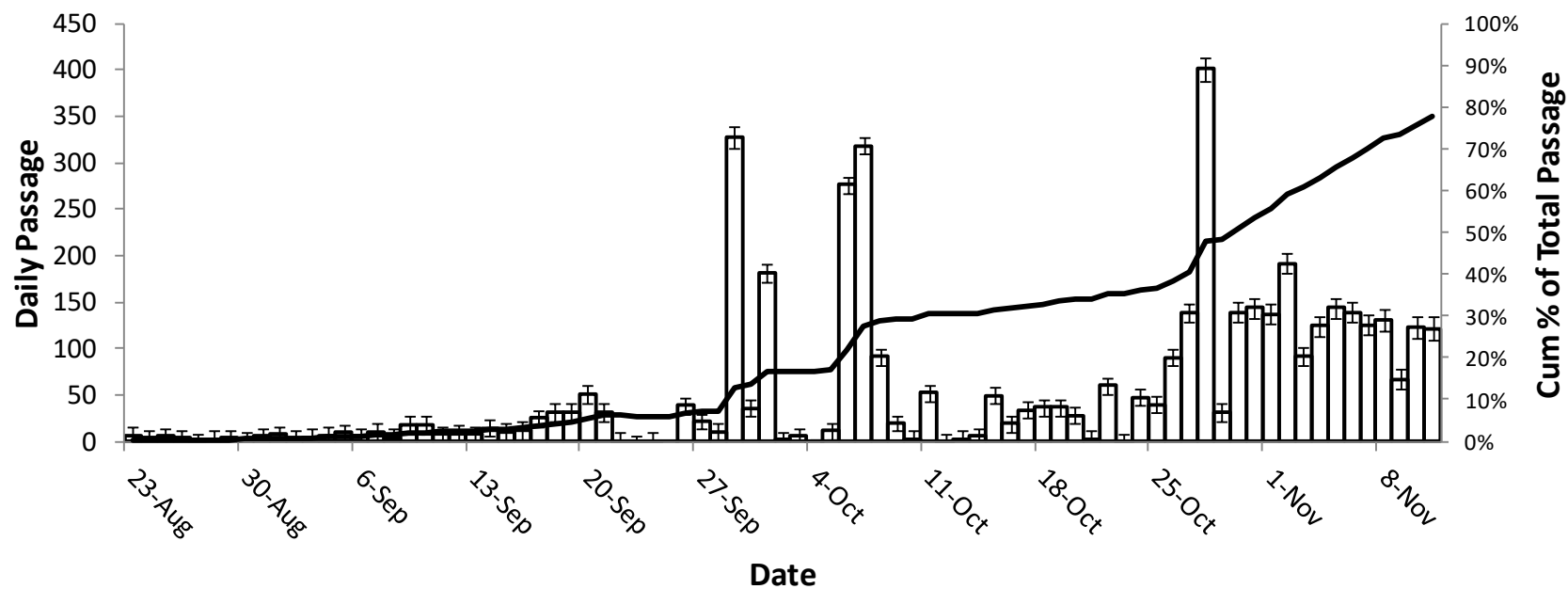


Figure 9. Daily coho salmon passage (> 500 mm) and cumulative percent of total run for the East Channel (EC) in the Elwha River in 2022. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. Total passage estimate for the EC was 5,600 coho salmon.

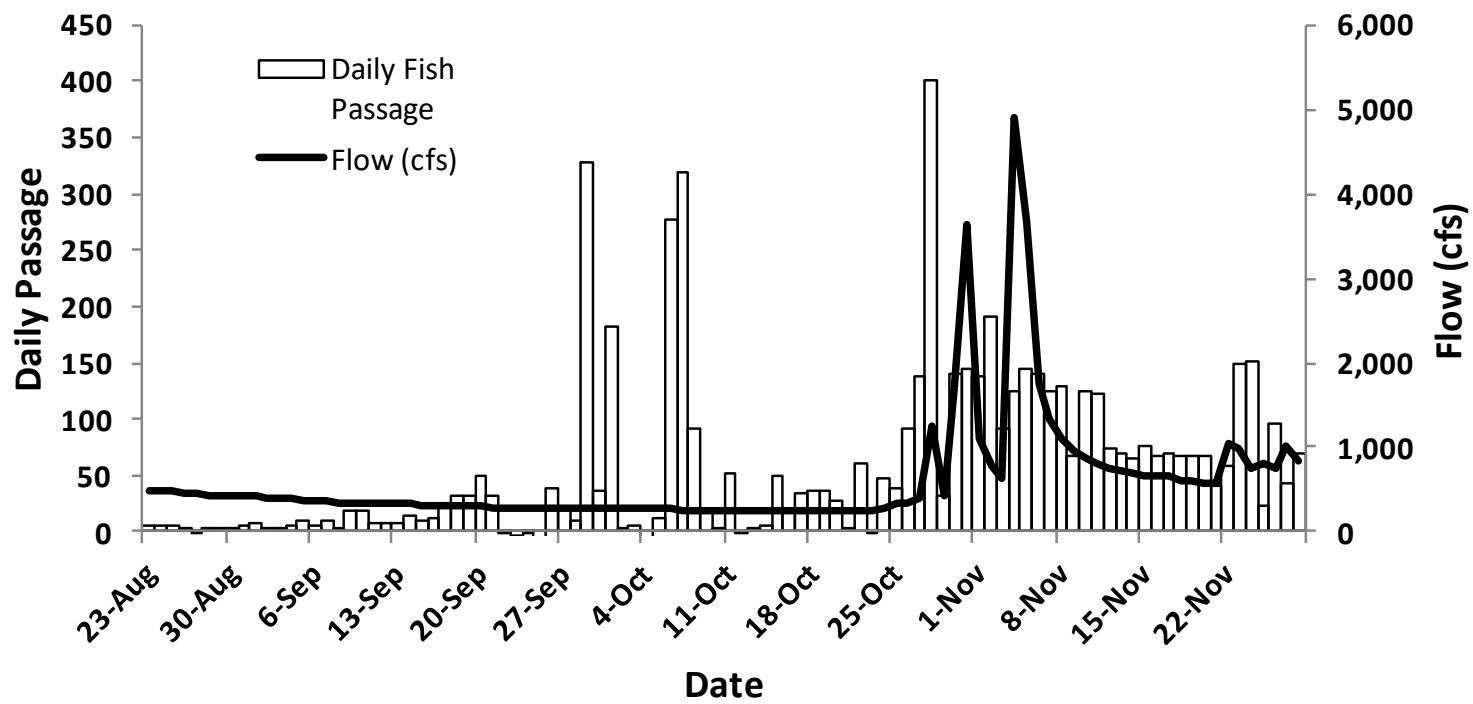


Figure 10. Daily coho passage and flow (cfs) for the Elwha River in 2022. This graph only represents passage up the EC channel.

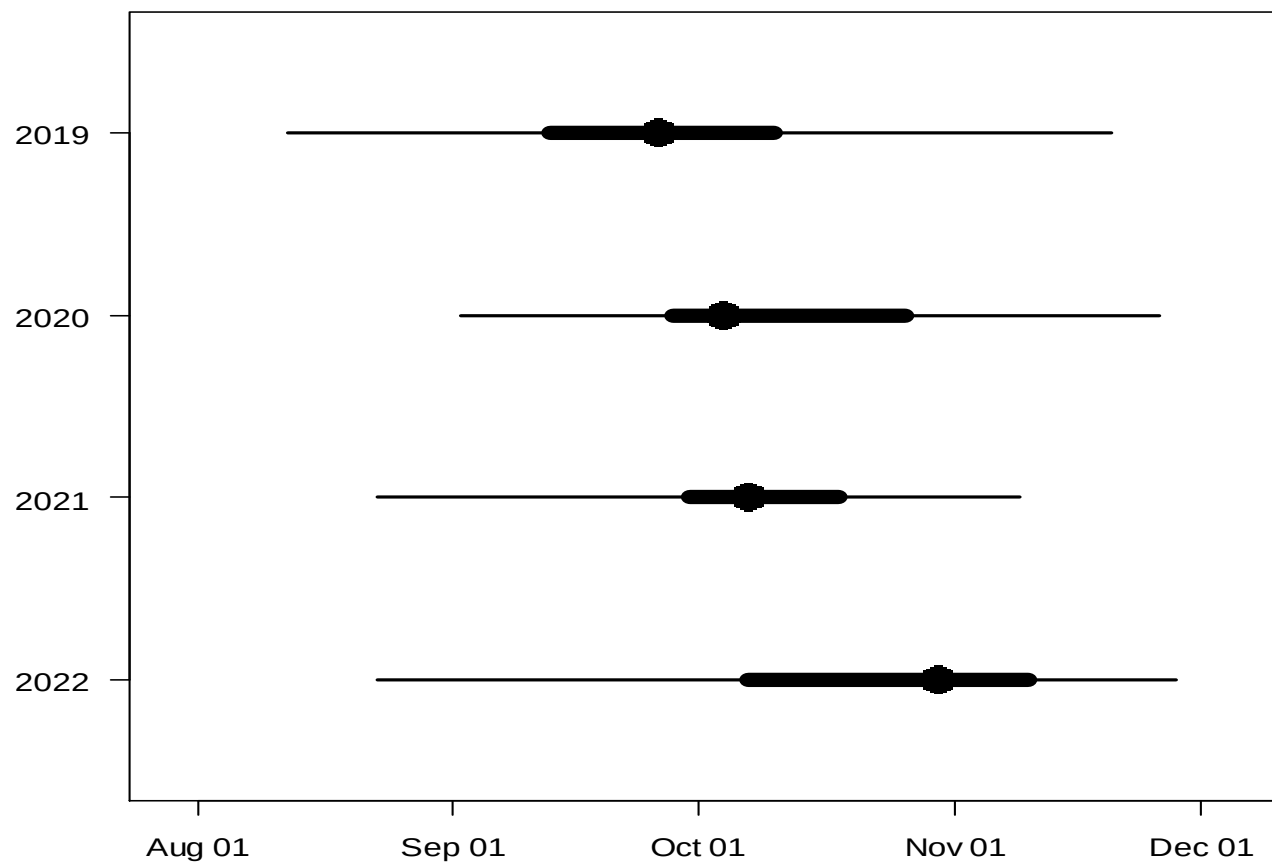


Figure 11. Run timing of coho salmon in the Elwha River from 2019 to 2022. For each year, the long thin black line encompasses the first coho sampled until the end of the run. The thick black line shows the time period during which 25% to 75% of the run passed the SONAR sites. The black dot shows when 50% of the run had passed.

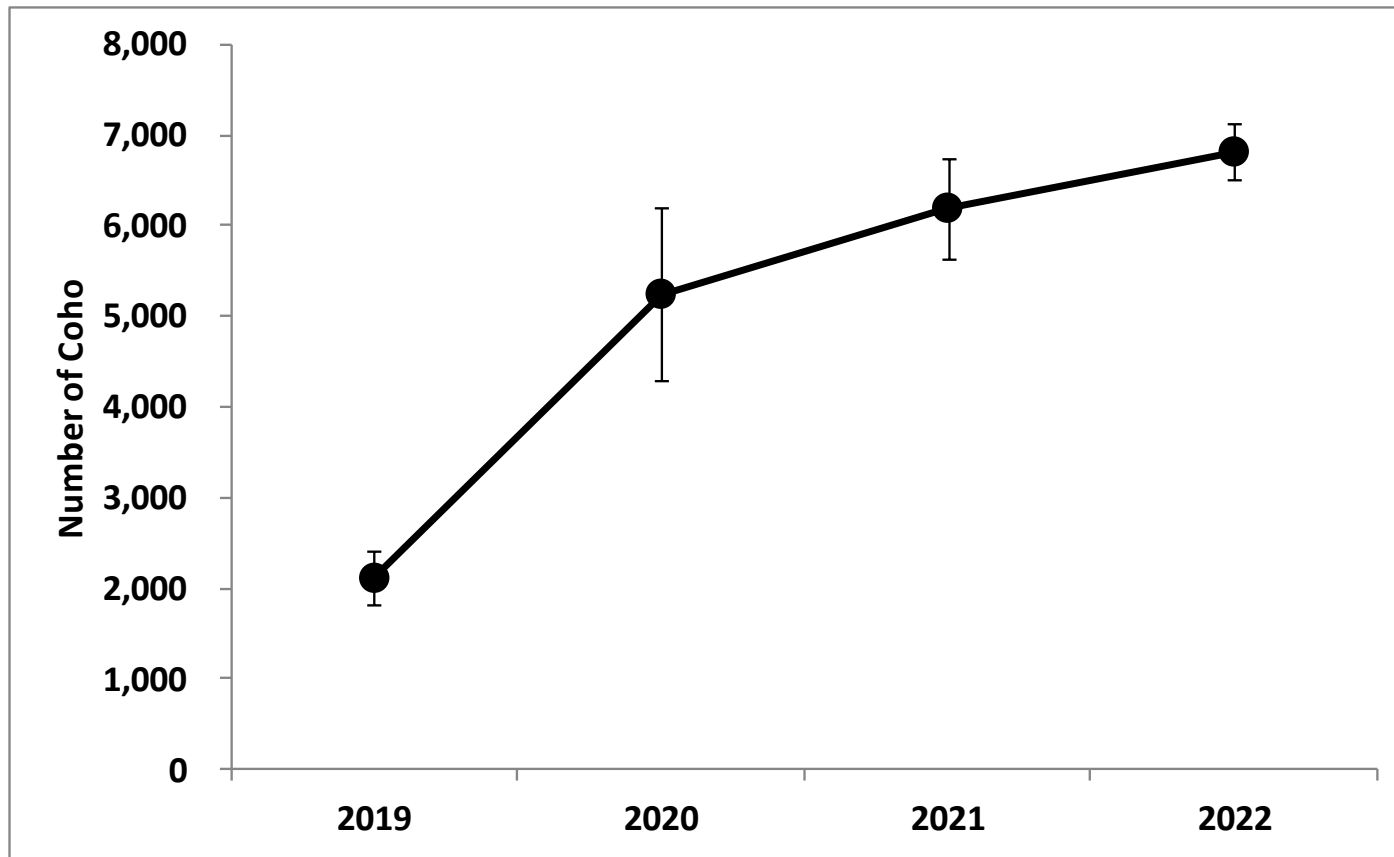


Figure 12. Escapement estimates for coho salmon greater than 500 mm to the Elwha River from 2019-2022. Error bars show upper and lower bounds of each estimate based on year specific methods.