

Estimating coho salmon escapement and mark rates in the Elwha River in 2019 using multi-beam SONAR technology



Photo Credit: John McMillan

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

Prepared By: Keith Denton and Oleksandr Stefankiv

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 12, 2019 through December 3, 2019. 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 escapement estimate above the EC SONAR site of 2,880 fish, with a coefficient of variation of 3.6% (95% CI 2,670 – 3,015). We also operated a DIDSON (LR) SONAR in the Hunt Road channel for three different time periods totaling 12 days over the course of the run and provide a low, medium, and high estimate of passage up that channel of 150, 260, and 575 fish respectively. Taking the EC estimate and the medium estimate for the HRC yields a total escapement estimate of 3,140 coho to the Elwha River in 2019. Running the model again, using only SONAR measured targets over 550 mm, yielded a non-jack escapement estimate above the EC site of 1,939 coho (CV 5.6%, 95% CI 1,728 – 2,154) Adding on the middle non-jack estimate for the HRC would yield a total non-jack escapement estimate of 2,114 fish.

Fifty percent of the coho salmon run passed the SONAR sites by September 25. The first coho was captured in species composition sampling on August 12 and the last was captured on November 20. Species composition sampling produced 159 coho for mark rate tabulation with adipose clip only, CWT only, and both marks representing 62%, 17%, and 21% of marked fish, respectively. Additionally, 30% of all captured fish were not marked in any way and can be considered natural origin fish. When only considering adult coho measuring over 550 mm, mark rates were 79%, 9%, and 13% respectively, with 39% of all adult coho not marked in any way. The male:female ratio for non-jack coho from the net sampling was 0.93:1 (43:46). Subtracting the non-jack hatchery returns (437) from our non-jack total return estimate produces a total non-jack return to the river of 1,677 coho, with approximately 866 of those in river spawners being female.

Recommendations for future years include stabilizing the power infrastructure on the EC, performing a cost/benefit analysis for full time operation of the HRC site, and a refinement of the goals and sampling procedure for the mark rate portion of the project.

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 early late January/early February through late September since 2010 (Denton et al. 2010-2019). This is the first attempt to continue operations throughout the fall and into the winter in an attempt to enumerate coho salmon (*O. kisutch*).

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 high flows and low visibility during their spawn timing has led to this current effort to improve enumeration. 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 CWT tag. Information on the relative proportions that these mark rates represented 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 jack and non-jack coho salmon migrating passed the SONAR sites; 2) provide run timing information; 3) incorporate and describe various sources of error in the estimate; 4) determine the proportion of coho and other species in the river during the course of the run; 5) provide mark rate information on all captured coho; 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 passage in 2019 as the river splits into two significant channels (Fig. 1). The primary enumeration site was located in the Mainstem, or East Channel (EC) (formally referred to as the Old Mainstem) while a secondary site was located in the Hunt Road Channel (HRC). Both sites were located at approximately RKM 0.8. While current data does not exist on the proportion of flow down each channel, during the flows experienced during the majority of the coho run, approximately 25% of the flow is transported down the HRC, with the remaining 75% traveling down the EC (Personal communication, Mike McHenry 2018). 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 15 and 20 m across and 1.8 meters deep in the thalweg, while the EC site was 15-28 meters wide and 2.2 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).

We constructed a picket weir approximately three meters downstream of the DIDSON that extended from the bank to 3 m beyond the SONAR (Fig. 3). This weir directed fish to an area of the channel more effectively covered by the sonar beams, producing greatly improved imagery and minimizing the possibility of fish passing directly underneath the beam and avoiding detection.

The HRC site was connected to line power, which ensured a constant power supply. The EC site

was powered by a 24-volt, 200 amp hour battery bank that was continually charged by an array of solar panels. A weir was also constructed at the EC site to direct upstream passage of adult fish (Fig 4).

Coho salmon passage was recorded at the EC site from August 12 through December 3 with nine short recording gaps ranging in length from one to four days (Fig. 5a). These gaps were generally infrastructure (power) related with the gap due to high flow. Data was recorded on the HRC for three time periods, September 15 through 20, October 8 through 11, and October 17 through 21 (Fig. 5b). The gaps were a product of both low flows in that channel for extended periods of time and the limited scope of work of the project.

Because of the limited amount of data present 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 thirteen tangle net surveys between August 12 and November 20, 2019 to capture live adult salmonids at seven different sites in the lower three kilometers of the river. We also conducted two snorkel surveys from ~RKM 4 to the mouth of the river on November 12 and December 2. We did this to differentiate species of salmonids over the course of the run timing and to determine the end of the coho 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. The net was approximately 18 m long and 2 m deep with loosely hung 10 cm stretch mesh.

We also used the in-stream netting data to determine a minimum and maximum threshold for SONAR measured targets to be included in the final escapement estimation by comparing the lengths of coho to all other salmonids and SONAR measured fish (Fig 6). 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.

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. The entire 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, length (mm) and observer confidence. Length was measured in centimeters using software specific procedures. Observer confidence was a qualitative value about the likelihood that the target was indeed a fish. The reviewer recorded a 1 if they were extremely confident that the target was indeed a fish passing in the specified direction or a 2 if they are not confident that the target was a fish passing in the specified direction.

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 hour long file, we first had to determine which passage events to include in our analysis, namely the minimum length threshold and which observer confidence categories. A length frequency histogram of the in-stream netting data revealed that steelhead were between 330 mm and 770 mm (Fig. 6). Based on this data, only SONAR targets recorded as 800 mm or smaller were included in the final escapement analysis. We also ran the model using only SONAR targets that measured in between 550 mm and 800 mm in an effort to produce a non-jack escapement estimate. We only used passage events of observer confidence level 1 in the final escapement analysis. Less than one percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (14/1,851). Fifteen percent of all downstream passage events were recorded as observer confidence level 2 (123/812).

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 three 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; 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 (464 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 11 six hour chunks for the EC (Fig 7). We regressed these 60 minute counts against those predicted from the first 20-minutes of the same six hour chunks to create a vector of residuals. Each raw 20 minute count was then adjusted by multiplying by 3, and adding a randomly sampled value from the residual vector. The CV for escapement for this step was calculated by summing all 6-hour chunks for each iteration, yielding 10,000 estimates. Then, the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates.

Species Composition

Calculation of the 2019 coho salmon escapement only included SONAR targets recorded from August 12, the date of first coho capture, through December 3 based on findings of the species composition sampling and a season end snorkel survey on December 2. No coho were captured in our species composition sampling after November 5 and none were observed in a snorkel survey after November 12. On November 20, twenty-four holding or spawned out coho were captured upstream of the species composition sites (WDFW hatchery outlet), while three “new” chum were captured downstream in our species composition sites (High Bluffs). Finally, no salmonids, coho or otherwise, were observed in a snorkel of the lower 4 KM on December 3 definitively indicating that any significant coho entry had ceased.

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. For the EC, we simulated the proportion of coho for a given iteration and day as:

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

where i represents the iteration (1 – 10,000), j indexes the 6-hour chunk (1 – 464) and k indexes the channel. The total number of fish, $N_{i,j,k}^{total}$, and total number of steelhead, $N_{i,j,k}^{coho}$, 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:

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

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 11 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. 8). A trend line was fitted to the data with an intercept of 0 and then a vector of observer error residuals was generated. Each cell of the steelhead 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 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.

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. For all methods, the percentage of fish migrating up the HRC was calculated on a daily basis for each day both channels were monitored and then averaged. This resulted in three different time periods totaling 12 days whose percentage of passage on a daily basis ranged from 0% to 39% and averaged 16%. The other major parameter beyond a variable percent daily passage was the flow. The percentage of flow down each channel and presumably the percentage of daily fish passage up each channel is highly dependent on the full river flow as measured at the McDonald bridge gauge, whereby, when flows were below approximately 400 cfs, flows in the HRC were too low to allow significant coho passage. Additionally, significantly more passage was measured up the HRC when flows were above approximately 500 cfs. So, the three methods involved changing the percent passage up the HRC in conjunction with changing the dates to which it was applied. The low estimate assumed 10% of the coho moved up the HRC and only when flows were above 450 cfs. The medium estimate assumed that 17% of the coho moved up the HRC, but only when flows were above 400 cfs. The high estimate assumed that 20% of the coho moved up the HRC at all flows.

Estimating non-jack coho escapement

We also provide a non-jack, or adult, coho escapement estimate for passage up the EC and the HRC. We calculated this by only including SONAR measured targets greater than 550 mm. Similarly, we also only used fish captured in the species composition sampling that measured over 550 mm. The rest of the model was run in the same manner. Non-jack passage estimates up the HRC was calculated by taking the ratio of total passage to non-jack passage up the EC and applying that ratio to the three HRC estimates to down weight them.

Results

Between August 12 and December 3, 2020 there were a total of 1,536 hours (64 days) recorded on the EC and 360 hours (15 days) recorded on HRC. At least one of the channels was monitored for 1,584 hours out of a total of 2,040 hours, or 78% of the total possible hours. During this time period 2,742 fish passage events were recorded and analyzed. The best estimate for the coho passage up the EC of the Elwha River in 2020 was 2,880 fish with a coefficient of variation (CV) of 3.6% (95% CI 2,670 – 3,075) (Fig. 10, Table 2). The three estimates of passage up the HRC were 150 fish, 260 fish, and 575 fish (Fig. 11). Using the middle estimate of passage up the HRC in conjunction with the estimate up the EC, we estimated that total coho escapement to the Elwha River in 2019 was 3,140 fish. We calculated four sources of uncertainty for the estimate of passage up the EC, in decreasing order they are: (1) the

uncertainty associated with adjusting for observer error (3.8%), (2) error in the gap filling procedure (3.7%), (3) adjusting for species composition (2.5%), and (4) expanding 20 minute counts to full hour counts (2.0%) (Table 2).

Running the simulation model a second time using only targets and samples measuring over 550 mm yielded a non jack coho escapement estimate up the EC of 1,939 coho. The three non-jack passage estimates up the HRC were 100, 175, and 390 coho. Combining the non-jack passage estimate up the EC with the middle non-jack estimate up the HRC yielded a total non-jack escapement estimate of 2,114 coho.

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 12 and 25%, 50%, and 75% of the run had passed the EC SONAR site by September 13, September 26, and October 10, respectively. Daily coho passage was also plotted against flow (Fig. 12). The run appeared to begin in earnest during the second week of September when the hydrograph initially increased after summer low flow.

In stream netting also provided 159 total coho for mark rate tabulation, of which 89 were adults. Of the 159 total coho, 69 fish (62% of marked fish) were ad-clipped only, 19 fish (16% of marked fish) were CWT marked only, and 24 fish (22 of all marked fish) were marked with both methods. An additional 47 fish (30% of the total captured) were not marked in any manner (Table 3a). Of the 89 adult coho assessed for mark rate, 44 (79% of marked fish) were ad-clipped only, 5 fish (9%) were CWT marked only, and 7 (13%) were marked with both methods. An additional 35 fish (39% of the total adults sampled) were not marked in any manner (Table 3b).

Subtracting the non-jack hatchery return of 437 fish from our non-jack estimate of 2,114 would produce an estimate of approximately 1,677 non-jack coho spawning in the river. In stream netting revealed a non-jack male to female ratio of 43:46 or .93:1. This would equate to a return of approximately 866 females to the river (Table 4).

Discussion

We believe our escapement estimate of 3,140 coho salmon is robust for several reasons. Most importantly we recorded data from the main passage channel (EC) for what was likely the entirety 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 captured zero coho two weeks before data recording stopped. Additionally, a snorkel survey of the lower 5Km of the river the day before operations ceased revealed zero adult salmonids. High flows and an unknown end of the coho run were significant concerns from the outset of the project but a mild fall rain period and an apparently contracted run timing compared to nearby rivers enabled us to collect data from presumably the entire run. We were also able to produce coefficients of variation on the four measured sources of uncertainty in our estimate. In decreasing order these sources were, (1) the uncertainty associated with adjusting for observer error (3.8%), (2) error in the gap filling procedure (3.7%), (3) adjusting for species composition (2.5%), and (4) expanding 20 minute counts to full hour counts (2.0%) (Table 3).

The highest source of measured uncertainty came from the adjustment for observer error. At 3.8% it was still relatively minor largely because this project used the same counting technician that the

Chinook and steelhead projects have been using for more than five years. While the procedure for counting coho salmon is the same as counting any other fish, the small size of jack coho with some less than 400 mm (Fig. 6) presents more of a challenge to accurate counting. Particularly during periods of high water or when fish are traveling up the far bank at a distance of almost 30 meters, targets less than 400 mm can be harder to identify than an 800 mm Chinook passing within 10 m of the SONAR head. This phenomenon is a reality of monitoring smaller bodied fish during times of the year when the active width of the channel is wider and likely cannot be mitigated. However, the CV associated with this adjustment is still quite low, indicating that any error associated with enumerating smaller fish at greater distances is acceptable. It is possible that some unknown portion of the smallest coho jacks were not recorded by either counter and were therefore not accounted for in this uncertainty analysis.

The second highest source of uncertainty came from the gap filling procedure (3.7%). It is important to note that the measured uncertainty 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 but not enough data was collected from that channel to provide an estimate of the uncertainty surrounding those estimates. Two factors likely make the proportion of fish traveling up each channel vary through time and therefore difficult to estimate. First, widely variable flows (10,000 cfs – 295 cfs) affect the proportion of fish travelling up the HRC from 0% to 39%. The three passage scenarios presented attempt to take that variability into account. Second, the ratio of HOR:NOR fish migrating upstream likely have different migratory patterns because of the tendency of HOR fish to home to the tribal hatchery on the EC. This is evident in a pHOS (percentage of hatchery origin) of 87% from the sites directly adjacent to the LEKT hatchery as opposed to the pHOS from the sites below the river split (before fish make a channel choice) of 59%. Also, NOR:HOR ratios change through time with 80% (41/51) of the coho sampled in September being HOR while only 48% (20/41) of the coho sampled in October were HOR. This source of variability in passage proportions up the HRC was not accounted for in our three scenarios. The uncertainty associated with gap filling on the EC was acceptably low (CV 3.7%) mainly due to the short nature of each gap which makes filling them much easier.

The third highest source of uncertainty was associated with adjusting raw passage totals to reflect just coho passage. 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 several of them were larger than 800 mm length cutoff we applied to the data and even more were in spawning condition and were also eliminated from the model input data. While some chum salmon were present in net catches starting on September 24, they didn't make up more than 15% of the catch until October 21st, after the majority of coho entry had already occurred.

The smallest source of uncertainty was due to expanding 20 minute counts to full hour counts. This is expected 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.

Our non-jack escapement estimate of ~2,000 fish for the EC represents approximately 67% (1,939/2,880) of our total escapement estimate. However, non-jack coho salmon (fish > 550 mm) only represented approximately 55% (94/169) of our species composition samples. The lower rate of capture

in our net sampling is likely caused by two factors, mesh size of the tangle net and differential HOR:NOR ratios of jack coho. First, our tangle net uses relatively small 4 inch mesh which tangles adults salmonids but can actually gill smaller fish (< ~450 mm). Therefore, some portion of adult salmonids certainly bounce off of the net whereas most very small salmonids become gilled and very stuck in the net. Secondly, because many of our net sampling sites are in close proximity to the LEKT hatchery, we are potentially sampling HOR fish at a higher rate than NOR fish. Furthermore, jack coho salmon (fish < 550 mm) have a higher ratio of HOR:NOR (85%, 59/69) than adult coho salmon (fish > 550 mm) (62%, 61/98). Therefore, jack coho are more likely to be caught in our net sampling than adult coho salmon because of the net itself and the likelihood that they are more prevalent in our sampling sites than the river at large.

Extensive redd surveys were conducted on some middle and upper river tributaries during the 2019 coho season and may be useful to compare to our escapement estimate. Olympic National Park staff counted a total of 162 redds in these tributaries in the middle and upper river, the most since dam removal. While this number is in no way comparable to the escapement estimate presented here, similar surveys in the future may provide a relative index of abundance to be compared to future SONAR estimates.

Our estimates can also be compared to returns to the Lower Elwha Hatchery. A total of 437 adult coho salmon returned to the facility in 2019, along with approximately 1000 coho jacks. Taken together, this would represent approximately 45% of our total escapement estimate, or 25% if only adults are considered. Thirty percent of our samples from the species composition netting were NOR (47/159). This would represent a return of approximately 950 NOR coho. However this number is certainly low 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 bias towards HOR fish in other species on the Elwha (Peters et al. 2020), and in fact, NOR fish represented only 13% (6/47) of the fish captured at the sites near the hatchery during this study, substantially lower than the 30% (47/159) of all sites combined. Perhaps the most unbiased measure of HOR:NOR proportions available from this year's data is to only consider fish captured at the three lowest sites in the river which are located below the HRC/EC channel split and therefore presumably limit the bias introduced by the LEKT hatchery. NOR fish represented 40% (23/57) of the fish captured in these three sites.

Our timing information can be compared to the entry timing data from the LEKT hatchery. The first adult coho was recorded as entering the hatchery on September 26, which is within two weeks of the first significant passage recorded by the SONARs. Timing data was not recorded for jack returns to the hatchery. Additionally, fifty percent of the returns to the hatchery had occurred by October 9 which is also within two weeks of the 50% passage date for the SONAR of September 26. With HOR fish making up significantly higher than 50% of the total return at this point in coho recolonization since dam removal it is not surprising to see timing data from the SONAR roughly match entry timing to the hatchery. However, as NOR fish continue to recolonize the upper river and successfully reproduce we would expect coho run timing to shift later in the year and more closely resemble the timing of NOR stocks in Western Juan de Fuca streams. 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 month of November, more than a month later than our 50% return date. It is likely that we missed some NOR

returns after we stopped operations in early December. This number of late migrating coho we missed this year is likely tiny, but as the natural populations rebuild it will certainly rise.

Recommendations

This was the latest into the fall/winter that the SONAR project has ever attempted to operate. The largest difficulty encountered was insufficient power at the EC solar powered site due to decreasing day length, increased cloud cover and the presence of leaves on surrounding trees until early November. The simple recommendation for mitigating this situation is to invest in a new set of deep cycle batteries and two additional solar panels. These items have already been purchased.

The project was very fortunate to have relatively low flows through the entirety of the coho run in 2019. This both limited data gaps and appeared to limit passage up the HRC which was only sporadically monitored. If the project continues in 2020, serious consideration should be given to the cost/benefit of operating the HRC for more days in an effort to lower uncertainty associated with estimating passage up that channel.

Species composition netting provided 157 coho for mark rate tabulation (Table 3). How these mark rates compare to the mark rates of fish released either six months (jacks) or 18 months (adults) previously is outside the scope of this report and would require comparing multiple age classes of juvenile releases to multiple age classes of adult returners. Because splitting the total number of fish sampled into multiple groups (marks and age classes) will necessarily reduce sample sizes, co-managers should be explicit about the goals of that analysis to ensure that enough samples are taken to draw meaningful comparisons. Additionally, the current sampling protocol of sampling near the SONAR sites to apportion raw SONAR targets to species may be biased to different mark rates, particularly marked and unmarked fish.

Acknowledgements

The authors would like to thank several people who helped with the species composition netting portion of this project, including Jonathon Grindall from USFWS, and Ray Moses and Wilson Wells from the LEKT. Wilson Wells also assisted with data review. Anna Geffre of Olympic National Park collated the redd survey data. Mike McHenry and John Mahan from the LEKT provided valuable edits to the final manuscript.

Literature Cited

- Belcher, E. O., B. Matsuyama, and G. M. Trimble. 2001. Object identification with acoustic lenses. Pages 6–11 in Conference proceedings MTS/IEEE oceans, volume 1, session 1. Honolulu, Hawaii.
- Belcher, E. O., W. Hanot, and J. Burch. 2002. Dual-frequency identification sonar. Pages 187–192 in Proceedings of the 2002 International Symposium on underwater technology. Tokyo, Japan.
- Cousens, N.B., Thomas, G. A., Swann, C. G., and Healy, M. C. 1982. A review of salmon estimation techniques. Can. Tech. Rep. Fish. Aquat. Sci. No. 1108.
- Cronkite, G. W., Enzenhofer, Ridley, T. Holmes, J., Lilja, J. and Benner, K. 2006. Use of high-frequency imaging sonar to estimate adult sockeye salmon escapement in the Horsefly River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2647: vi + 47p.
- Cronkite, G.M.W., Enzenhofer, H.J., and Holmes, J.A. 2008. Evaluation of the BlueView ProViewer 900 Imaging Sonar as a tool for counting adult sockeye salmon in the Adams River, British Columbia. Can. Tech. Rep. Fish. Aquat. Sci. 2798: iv + 21 p.
- Denton, K.P. and Liermann, M.M. 2010. Estimation of the 2010 Summer Chinook Escapement in the Elwha River Using BlueView Multi-beam Sonar Technology. Prepared for the Lower Elwha Tribe.
- Denton, K.P. and Liermann, M.M. 2012. Estimation of the 2012 Chinook Escapement in the Elwha River Using DIDSON Multi-beam Sonar Technology. Prepared for the Lower Elwha Tribe.
- Denton, K.P., Moses, R., McHenry, M., McMillan, J., Liermann, M., Pess, G. 2013. Final Report: 2013 Elwha River Chinook escapement estimation based on DIDSON multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., McMillan, J., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2014. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., McMillan, J., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2015. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Denton, K., Moses, R., McHenry, M., McMillan, J., Ward, E., Stefankiv O., Wells, W. Liermann, M., Pess, G. 2016. Elwha River Chinook escapement estimate based on DIDSON/ARIS multi-beam SONAR data. Prepared for the Lower Elwha Tribe.
- Dunbar, R. 2001. Copper River Hydroacoustic Salmon Enumeration Studies, 2000 and 2001. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A01-3, Anchorage.

- Dunbar, R. 2003. Anvik River sonar chum salmon escapement study, 2003. Regional Information Report No. 3A03-14. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.
- Dunbar, R. and C.T. Pfisterer. 2004. Sonar estimation of fall chum salmon abundance in the Sheenjek River, 2002. Regional Information Report No. 3A04-10. Alaska Department of Fish and Game, Division of Commercial Fisheries, Anchorage.
- Enzenhofer, H. J., Olsen N., Mulligan, T. J. 1998. Fixed-location riverine hydroacoustics as a method of enumerating migrating adult Pacific salmon: comparison of split-beam acoustics vs. visual counting. *Aquat. Living Resour.* 11:61-74.
- Enzenhofer, H.J., and Cronkite, G. 2005. A simple adjustable pole mount for deploying DIDSON and split-beam transducers. *Can. Tech. Rep. Fish. Aquat. Sci.* 2570: iv + 14 p.
- Enzenhofer, H. J., Cronkite, G. M. W., Holmes, J. A. 2010 Application of DIDSON Imagins SONAR at Qualark Creek on the Fraser River for Enumeration of Adult Pacific Salmon: An Operation Manual. *Can. Tech. Rep. Fish. Aquat. Sci.* 2869.
- Holmes, J. A., Cronkite, G. W., Enzenhofer, H. J., Mulligan, T. J. 2006. Accuracy and precision of fish-count data from a “dual-frequency identification sonar” (DIDSON) imaging system. *Journal of Marine Science.* 63:543-555.
- Levy, D. A., Nealson, P. A., and Cheng, P. 1991. Fixed-aspect hydroacoustic estimation of Fraser River sockeye salmon abundance and distribution at Mission, B. C. *in* 1986. *Pac. Salmon Comm. Tech. Rep. No. 4.*
- Lilja, J, Ridley, T., Cronkite, G. M., Enzenhofer, H. J., and Holmes, J. A. 2008. Optimizing sampling effort within a systematic design for estimating abundant escapement of sockeye salmon (*Oncorhynchus nerka*) in their natal river. *Fisheries Research* 90:118-127
- Maxwell, S. L. 2008. Hydroacoustics: Rivers. Pgs 133-152 *in* *Salmonid Field Protocols Handbook Techniques for Assessing Status and Trends in Salmon and Trout Populations.* Amer. Fish. Soc., Bethesda, MD.
- McKinley, W.L. 2002. Sonar enumeration of Pacific salmon into the Nushagak River, 2001. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report No. 2A02-25, Anchorage.
- Pess, G., McHenry, M., Ehinger, W., Bennett, T., Hanson, K., Liermann, M. 2020. Strait of Juan de Fuca Intensively Monitored Watersheds 2019 Annual Report. Prepared for the Salmon Recovery Funding Board. 52 pgs.
- Peters, R.J., Denton, K., Liermann, M. 2020. Proportion of Hatchery Origin Steelhead and Broodstock Collection in the Elwha River: 2019. Report to the Lower Elwha Klallam Tribe.

Westerman, D. L., and T. M. Willette. 2003. Upper Cook Inlet salmon escapement studies, 2002. Alaska Department of Fish and Game, Commercial Fisheries Division, Regional Information Report 2A03-24, Anchorage.

Xie, Y., A. P. Gray, F. J. Martens, J. L. Boffey and J. D. Cave. 2005. Use of Dual-Frequency Identification Sonar to Verify Salmon Flux and to Examine Fish Behaviour in the Fraser River. Pacific Salmon Comm. Tech. Rep. No. 16: 58 p.

Table 1. Total number of “new” and “holding” coho and other salmonids by date at 6 sites during in-river netting operations in the lower 3KM of the Elwha River in 2019. Data from November 12 was from a snorkel survey which occurred continuously through the lower 3KM of river.

Date	Coho	Other	% Coho
8/12/2019	1	7	13%
8/21/2019	1	8	11%
9/4/2019	1	5	17%
9/10/2019	0	2	0%
9/17/2019	27	3	90%
9/24/2019	33	1	97%
10/1/2019	9	0	100%
10/8/2019	14	0	100%
10/15/2019	7	1	88%
10/21/2019	2	2	50%
10/29/2019	9	1	90%
11/5/2019	1	1	50%
11/12/2019	8	12	40%
11/20/2019	0	3	0%

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	2.0%
Species Composition	2.5%
Observer Error	3.8%
Gap Fill	3.7%
Overall	3.6%

Table 3a. Mark rates for all coho captured in the lower 5 KM of the Elwha River between August 12 and November 5, 2019.

All Fish					
Mark	Ad Clip Only	CWT Only	Both	Neither	Total
Raw Number	69	19	24	47	159
Percentage of Marked Fish	62%	17%	21%		
Percentage of Total	43%	12%	15%	30%	

Table 3b. Mark rates for coho greater than 550 mm captured in the lower 5 KM of the Elwha River between August 12 and November 5, 2019.

Fish > 550 mm					
Mark	Ad Clip Only	CWT Only	Both	Neither	Total
Raw Number	44	5	7	35	89
Percentage of Marked Fish	79%	9%	13%		
Percentage of Total	49%	6%	8%	39%	

Table 4. Four different estimates of coho returns to the Elwha River in 2019, all of which include passage up both channels. The first estimate is for coho of all sizes. The second is for coho measuring over 550 mm. The third uses the number from the second and subtracts out the non-jack hatchery returns (437). The final estimate applies the male:female ratio to the third estimate.

Estimate

Total Return	3,140
Total Non-Jack Return	2,114
Total Non-Jack Return to River	1,677
Total Non-Jack Female Return to River	866

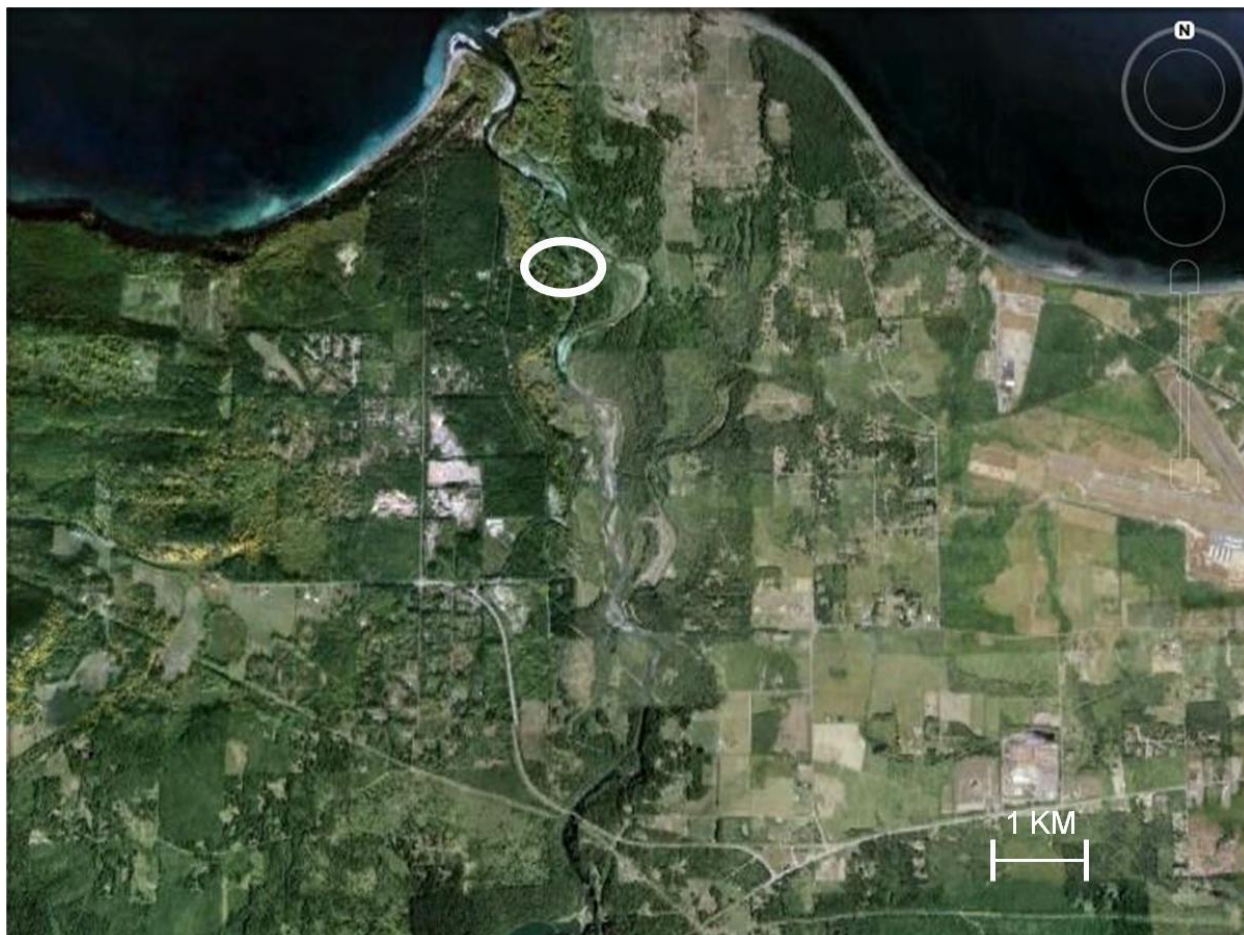


Figure 1. Map of the lower Elwha. Former Elwha dam site is located at the bottom of the figure, with the Strait of Juan de Fuca at the top. White oval depicts the location of the Hunt Road Side Channel DIDSON site. The East Channel site is located approximately adjacent to the upper right hand portion of the white oval.



Figure 2. Photo of the HRC DIDSON site. Note low water that limited fish passage up this channel in 2019.



Figure 3. Ladder and pole mounted DIDSON multi-beam imaging SONAR. The SONAR is housed in the black silt box at the bottom of the pole.



Figure 4. East Channel SONAR site. The SONAR is attached to the pole mount which is in turn attached to the ladder. The PVC picket weir immediately downstream from the ladder directs fish away from the bank so they pass at least 3 m from the SONAR head.

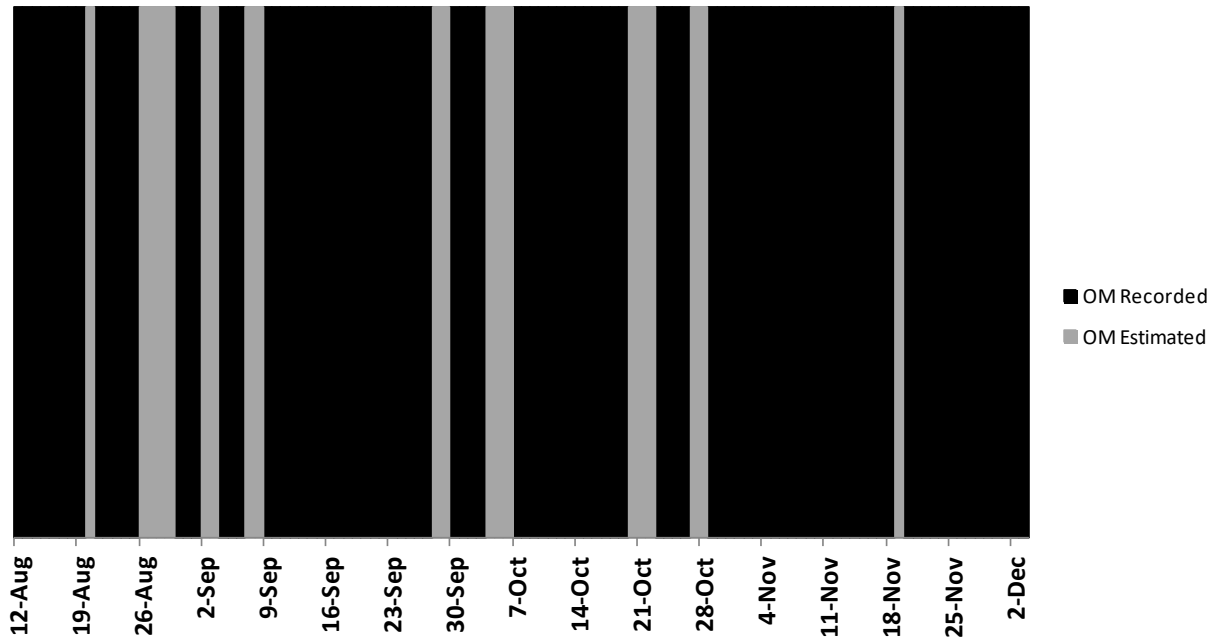


Figure 5a. Dates for which data was recorded or estimated in the East Channel during the coho season on the Elwha River in 2019.

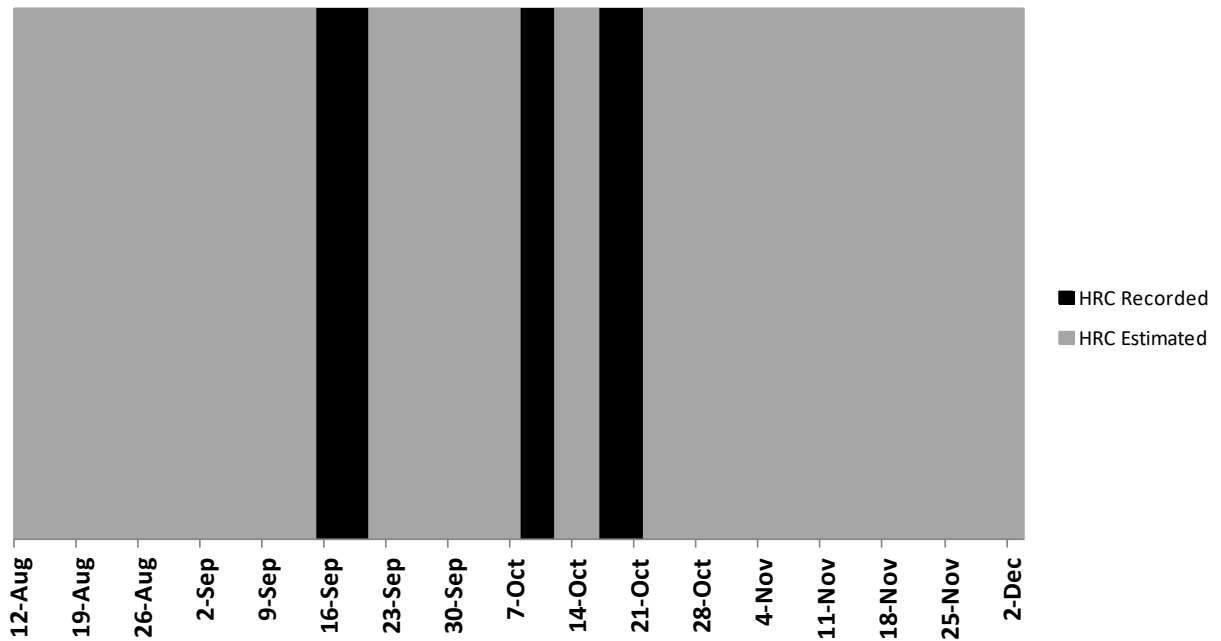


Figure 5b. Dates for which data was recorded or estimated in the Hunt Road channel during the coho season on the Elwha River in 2019.

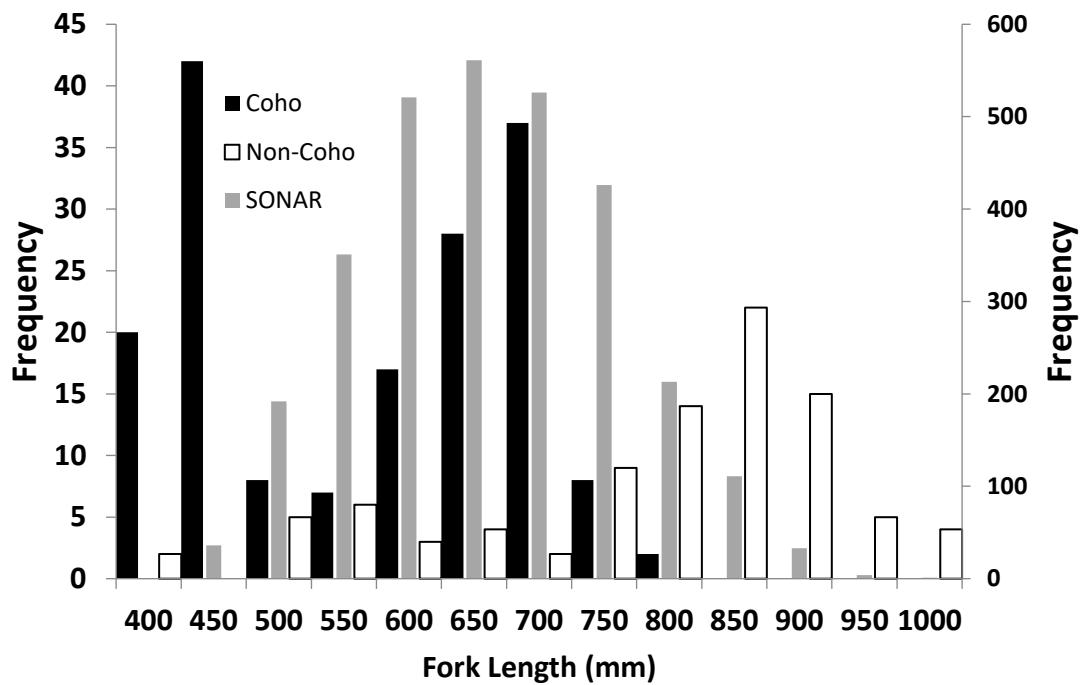


Figure 6. Length frequency histogram for all salmonids caught during 13 different sampling days between August 12, 2019 and December 3, 2019 in the Elwha River. SONAR measured lengths for all targets recorded between those two dates are also presented.

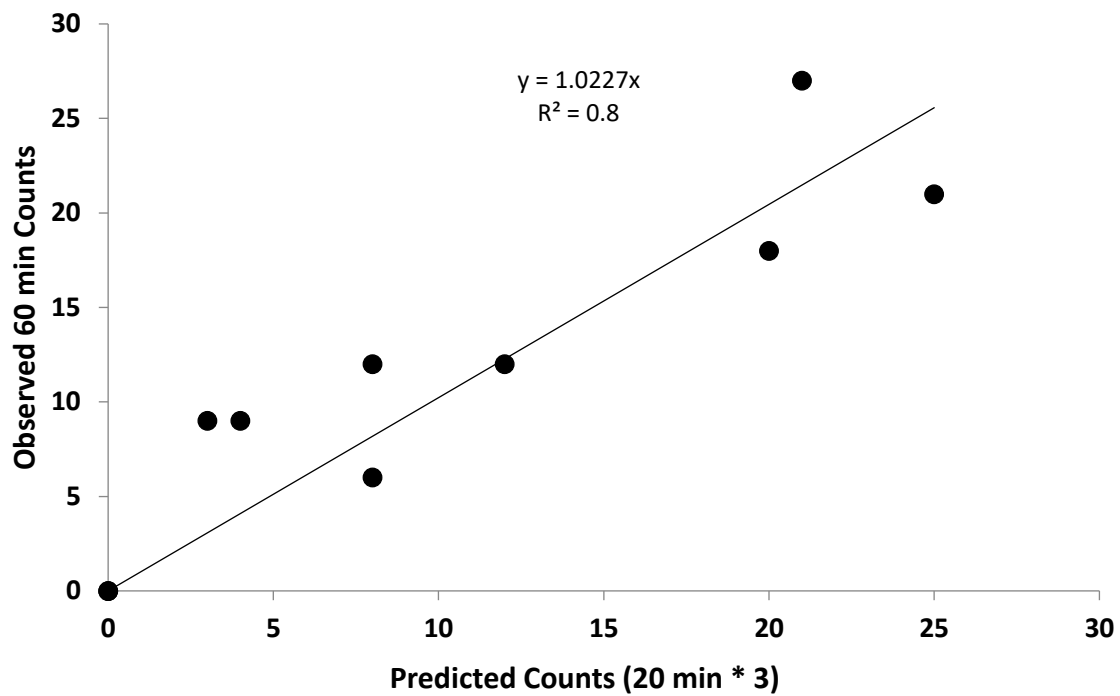


Figure 7. Predicted (20 minutes * 3) vs. observed (actual 60 minute counts) for 10 six-hour chunks of full hour counts for the East Channel (EC). Point (0,0) has two data points.

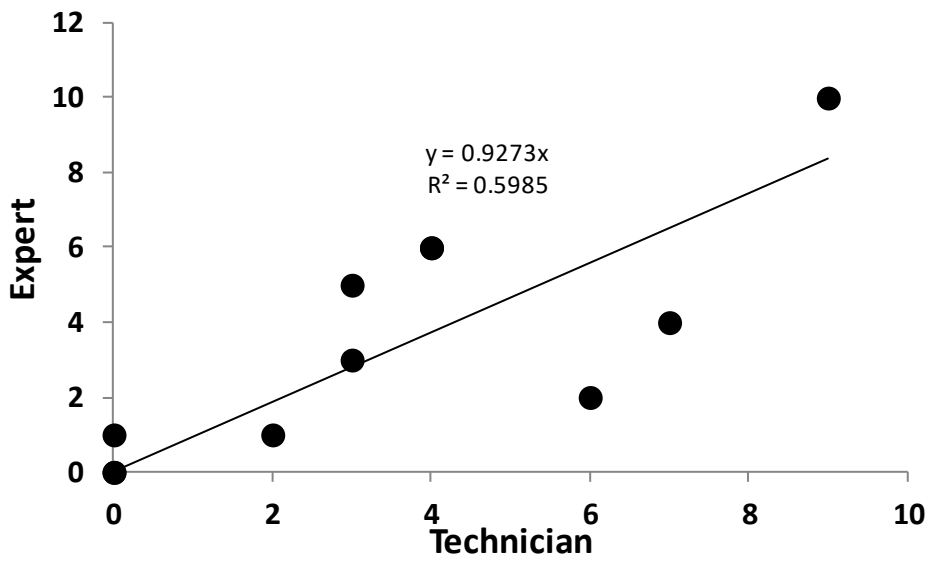


Figure 8. Total upstream passage counted by a technician and expert for 11 six-hour chunks . Points (0,0) and (4,6) both have two data points.

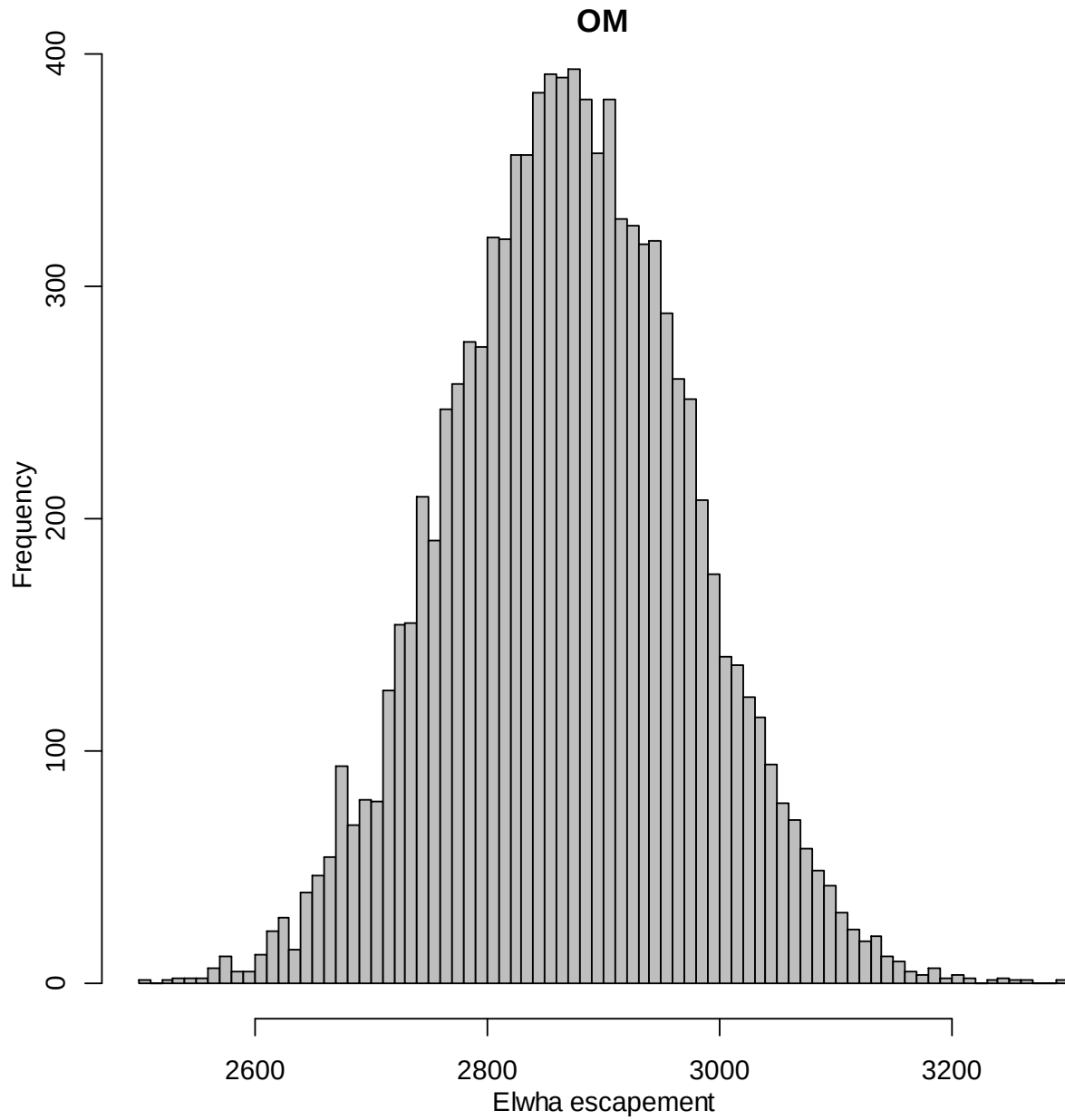


Figure 9. East Channel (EC) coho run size estimates for the Elwha River in 2019 based on 10,000 model runs. This shows both non-jack and jack coho salmon numbers.

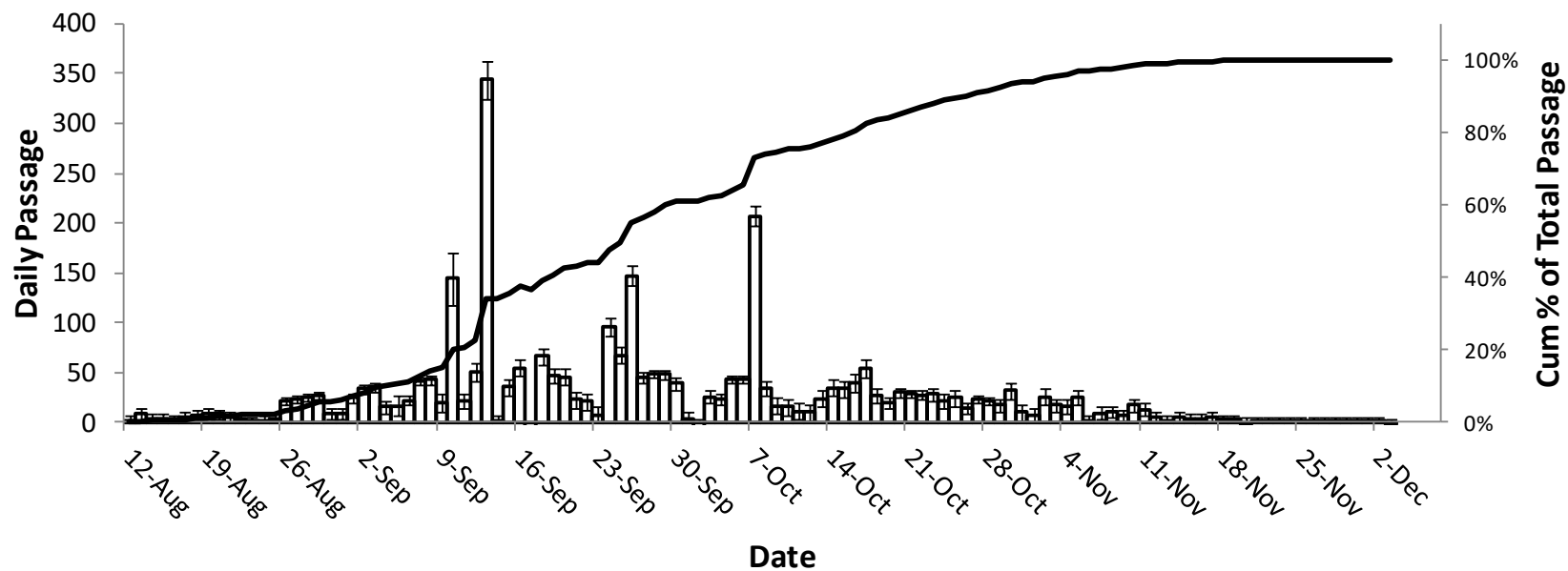


Figure 10. Daily coho passage and cumulative percent of total run for the East Channel (EC) in the Elwha River in 2019. Daily passage values have been adjusted for subsampling expansion, species composition, observer error, and data gaps. Error bars represent the standard deviation of passage for each day. Total passage estimate for the EC was 2,880 coho salmon. This shows both non-jack and jack coho salmon numbers.

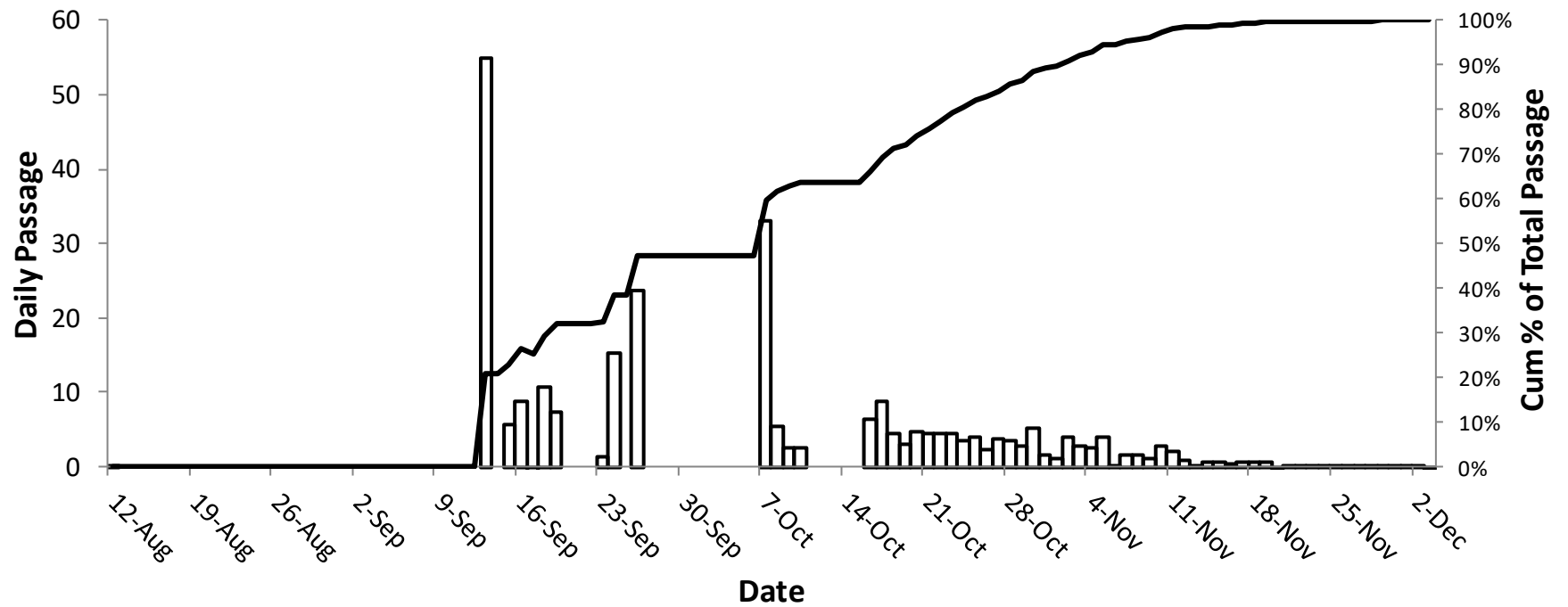


Figure 11. Daily coho passage and cumulative percent of total run for the Hunt Road Channel (HRC) in the Elwha River in 2019 as predicted by the medium estimation method. The medium passage estimate for this channel and method was 260 fish. This shows both non-jack and jack coho salmon numbers.

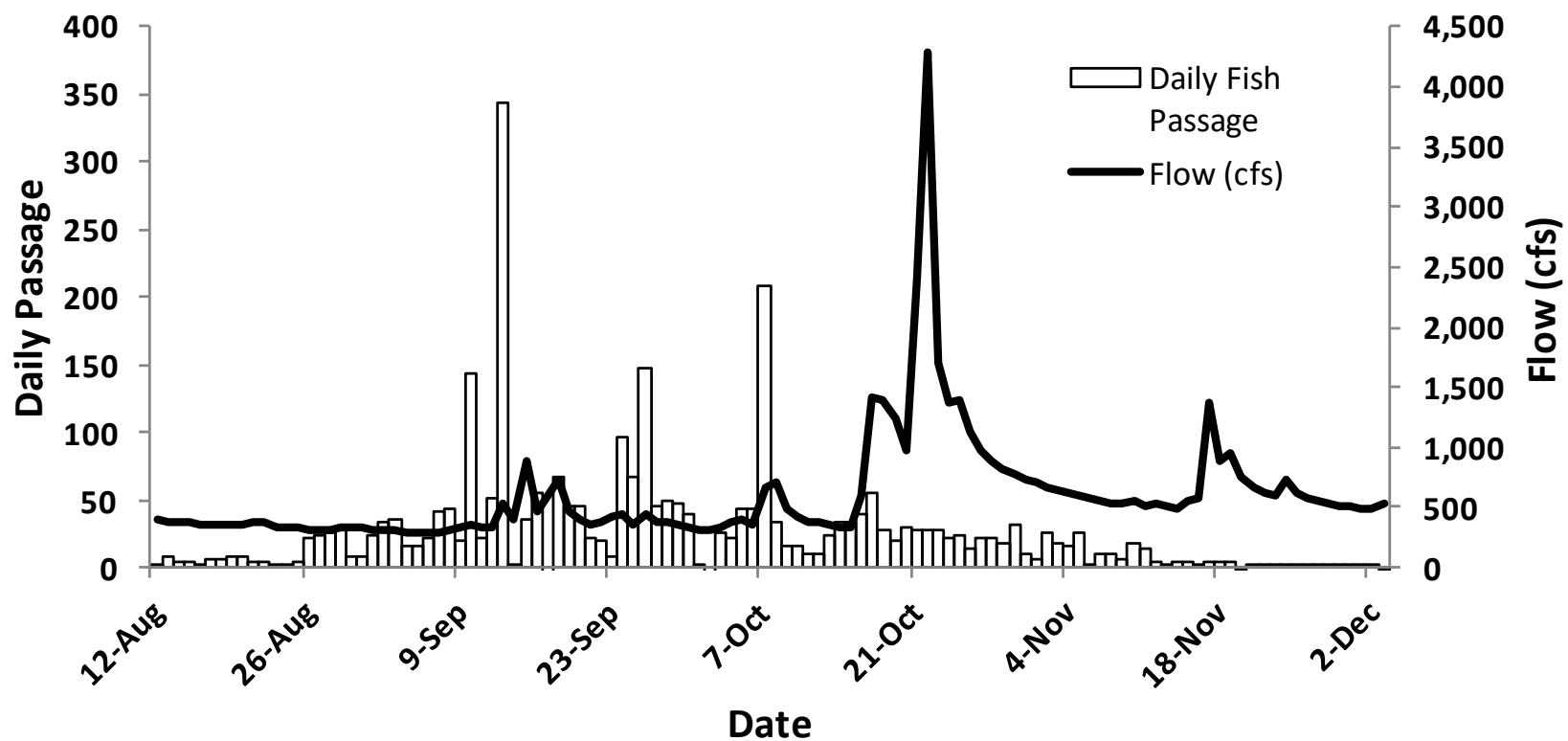


Figure 12. Daily coho passage and flow (cfs) for the Elwha River in 2019. This graph only represents passage up the EC channel.