

2018 Elwha River Steelhead Escapement Estimate Based on DIDSON/ARIS Multi-Beam SONAR Data



Photo: John McMillan

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Executive Summary

We used an ARIS 1800 and a DIDSON (LR) multi-beam SONAR unit to monitor winter run steelhead escapement in the Elwha River on a daily basis from February 6, 2018 through May 30, 2018. We reviewed each hour-long file in its entirety and then adjusted these raw counts for species composition, observer error, and data gaps. This process yielded a steelhead escapement estimate above the SONAR sites of 1,625 fish; with a coefficient of variation (CV) of 3.8% (95% CI 1,489 –1,768).

We also provide channel specific estimates of passage for the Hunt Road Channel (HRC), 710 (7.6% CV, 95% CI 610 - 819) and the Old Mainstem (OM) 915 (3.3% CV, 95% CI 857 - 975). In addition, we calculated CV's for all three sources of uncertainty associated with estimating total escapement and passage through both channels, including gap filling (3.4%), observer error (2.1%), and species composition (0.7%).

Fifty-percent of the steelhead passed the SONAR sites by April 20, which was 14 days later than last year but similar to the three years prior. Species composition netting indicated that approximately 45% of the total run, or 731 fish, were of natural-origin with the remaining 894 (55%) originating from the Lower Elwha Klallam native broodstock hatchery program. This is the highest return since the start of the project in 2013 with the natural-origin part of the run representing almost a doubling of the next closest year (400 in 2014).

In addition to the winter steelhead, we captured nine adult summer run steelhead during species composition net sampling between May 22 and July 10, 2018, which allowed us to generate an escapement of approximately 300 summer run steelhead, which is striking considering summer runs were at very low population levels prior to dam removal.

Our first recommendation for next year is to determine whether to modify/add to the species composition protocol to produce a more unbiased estimate of the natural-origin:hatchery-origin ratio of the run. Secondly, we recommend performing more net sampling during the presumed summer steelhead run and devoting more resources to improving analytical methods to provide a more robust escapement estimate for this unique population of fish.

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 have been focused on large salmon runs that transpire over the course of only a few short weeks, which requires large technical staffs and operating budgets (eg. Lilja et al. 2008, Enzenhofer et al. 2010). In this study, we enumerate a small, protracted run of steelhead using multi-beam imaging SONAR.

SONAR is used for the enumeration of winter timed steelhead (*Oncorhynchus mykiss*) and summer/fall Chinook salmon (*Oncorhynchus tshawytscha*) in the Elwha River, Washington from early late January/early February through late September. This report only covers steelhead enumeration from early-February through mid-July (see Denton et al., 2010, 2012, 2013, 2014, 2015 for reports and data on Chinook salmon). It should be noted that historically the Elwha River had different life histories of steelhead that entered the river throughout the year (Personal Communication, Dick Goin, 2014). Following dam construction, the diversity of entry timings and life histories were simplified over time. At the time of dam removal, steelhead populations consisted of an early timed non-native hatchery run (Chambers Creek) and a remnant winter population with a later run timing, although the two overlapped from late December through March (Winter, 1989). The Chambers Creek program has since been terminated and a native broodstock program has begun which aims to mimic the life history patterns of natural-origin fish. Additionally, research during and after dam removal has identified a small but growing summer steelhead run with adults being identified in the lower, middle and upper river during the summer months (Sam Brenkman, Personal Communication). Historically, the summer

run steelhead population in the Elwha was at a very low abundance. Small (~20,000 fish/year) outplants of Skamania stock summer timed steelhead were made during the last few decades of the 21st century, but they were discontinued well before dam removal. This is the first year of this project with enough data to allow us to provide an escapement estimate of the distinct summer run steelhead population.

The Elwha River, located on the north Olympic Peninsula in Washington State, provides a unique opportunity for fish enumeration using a multi-beam sonar system. Two dams had blocked fish passage to nearly 146 KM of main stem and tributary habitat since 1911, but removal of both dams began in September 2011 (Elwha River Fisheries and Ecosystem Restoration Act, 1992). The lower dam (Elwha) was completely removed by the spring of 2012. Large scale removal operations were completed at the upper dam (Glines) in August of 2014, but a subsequent rockfall in the fall of 2014 impeded passage at that site. Systematic blasting of the in-stream boulders due to the rockfall occurred in the summers of 2015 and 2016 and passage conditions appear to be improving, with multiple observations of a variety of fish species, including steelhead, upstream of the former dam site.

As highlighted in the Guidelines for Monitoring and Adaptively Managing Restoration of Chinook salmon and steelhead on the Elwha River (Peters et al. 2014), critical to evaluating the success and rate of recolonization of anadromous fish during and after dam removal is to estimate the abundance of adults returning to the river system each year. While the major goal of the Elwha and Glines dam removals is to eventually increase salmon and steelhead populations, the act of removing the dams has released large amounts of trapped sediment. The resultant turbidity severely limits visibility and makes the use of traditional enumeration methods (i.e. redd surveys) for specific species and time periods nearly impossible (Magirl et al. 2014). In addition, the removal of both dams opens up access to approximately 90% of the watershed that was previously inaccessible to anadromous fish (Pess et al. 2008). Therefore, SONAR is the best technique for producing basin-wide escapement estimates for anadromous salmon populations during and after dam removal.

Due to their ESA listing status of “threatened” and chronically low adult abundance, Elwha River steelhead are of great concern (Brenkman et al. 2008). Estimating adult steelhead returns on the Elwha River presents both a unique and common set of challenges. First, and unique to the Elwha River, is maintaining in-stream infrastructure in a constantly shifting environment due to the extreme sediment loads created by dam removal operations. Second, and applicable to many streams in the Pacific Northwest, is that due to highly variable streamflows during the steelhead migration upstream, the SONAR sites require constant maintenance, including removal and re-installation to avoid loss or damage to the equipment. Lastly, like other rivers in the PNW, the Elwha River mainstem has an anastomosing or forested island morphology resulting in multiple channels for fish to migrate through (Beechie et al. 2006). Adult steelhead may migrate up one of two distinct channels that split near the mouth of the river, and as a result, each channel must be monitored with independent SONAR devices. The sediment loads and dynamic, multiple channels provide a unique opportunity to evaluate the performance of SONAR to estimate adult escapements and run timing, examine sources of estimation error, and increase our understanding of SONAR in future monitoring efforts. To that end, the objectives of this study are to: 1) provide an estimate of both winter run and summer run steelhead escapement to the Elwha River; 2) provide run timing information; 3) incorporate and describe various sources of error

in the estimate; 4) determine the proportion of steelhead and other species of salmon in the river during the course of the run; 5) provide an estimate of the proportion of natural to hatchery-origin steelhead in the river; and 6) make recommendations on how to improve the use of SONAR to enumerate adult salmon in the Elwha River in the future.

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 steelhead passage in 2018 (Fig. 1). The primary enumeration site was located in the Old Mainstem (OM) 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 steelhead run, approximately 40% of the flow is transported down the HRC, with the remaining 60% traveling down the OM (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 steelhead 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 in the thalweg, while the OM site was 15-28 meters wide and 2.2 meters in the thalweg.

Each SONAR was attached to a pole mount (Enzenhofer and Cronkite 2005) that was mounted on a reinforced 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 identify the far bank (see Enzenhofer 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 OM 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 OM site to direct upstream passage of adult fish (Fig 4).

Winter steelhead passage was recorded at the OM site from February 6 through May 30, 2018. There were four data gaps during this time period, none of which were longer than 3 days (Fig 5a). Steelhead passage was recorded at the HRC site from February 21 through May 30. There were two data gaps during this time period neither of which was longer than 2 days (Fig 5b). The 15 days between

deployment of the HRC site and the OM site was also treated as a data gap for the HRC.

The SONARs were also in operation after May 30, 2018 to record Chinook salmon passage and an estimate of Chinook passage for this time period is available in the project's Chinook report (Denton et al., in prep.). Data from May 22 through July 10 was also used to estimate summer run steelhead passage. As species composition netting indicated that they were present in the river during this time period.

Species Composition

We conducted five tangle net surveys between April 18 and May 30 to capture live adult salmonids at seven different sites in the lower five kilometers of the river. We did this to differentiate species of salmonids over the course of the run timing and to determine the end of the steelhead 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 already spawned. The tangle-net was designed to snare fish from the jaw 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 mesh.

We also used the in-stream netting data to determine a minimal threshold for SONAR measured targets to be included in the final escapement estimation by comparing the lengths of steelhead to bull trout and SONAR measured fish, although only one bull trout was captured during species composition sampling (Fig 6). Additionally, species composition data was used to determine the sex ratio of steelhead.

Finally, we categorized captured steelhead as hatchery or natural-origin by checking for the presence or absence of an adipose fin, and the condition of their dorsal and pectoral fins. During the course of this study, concurrent tangle net sampling was performed by Olympic National Park and U.S. Fish and Wildlife staff upstream of the species composition sampling sites for a different project. Data from this sampling was used to inform natural/hatchery-origin proportions and sex ratio for steelhead, but was not used for species composition adjustments since it could not be determined when these fish passed by the SONARs.

These tangle net surveys in addition to ones aimed at characterizing the run composition throughout the Chinook run were used to determine the run timing and escapement estimate of the summer run steelhead population.

Data Analysis

Post Processing

All DIDSON data was processed using DIDSON proprietary software (V5.25.26). 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 will be detected in the echogram.

An echogram is a graph of the data with distance from the SONAR head on the y-axis and time on the x-axis. If no targets are present, the echogram will be blank. If a fish swims through the ensonified area, the echogram will have a series of targets connected along the x-axis, whose overall length correlates with the length of time it took the fish to pass through the ensonified area. The string of targets along the x-axis may trend up or down along the y-axis if the fish was swimming diagonally away or towards the sonar head during its passage. To count fish passage events, target echograms were simultaneously reviewed along with the raw video file. This enabled the reviewer to quickly scan through an echogram until a target pattern that could potentially represent a fish was encountered. 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. The final characteristic was a qualitative value. The reviewer recorded a 1 if they were extremely confident that the target was indeed a fish passing in the specified direction or a 2 if they are somewhat confident that the target was a fish passing in the specified direction.

Escapement Estimation and Uncertainty Tabulation

Basic fish passage 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 510 mm and 780 mm (Fig. 6). Only one bull trout was captured during species composition sampling and it measured 610 mm, well within the range of steelhead. Based on this data, only SONAR targets recorded as 510 mm or greater were included in the final escapement analysis. We only used passage events of observer confidence level 1 in the final escapement analysis. Twelve percent of all upstream passage events that met the length criteria were

recorded as observer confidence level 2 (212/2,545). Forty-one percent of all downstream passage events were recorded as observer confidence level 2 (546/1,314).

Raw targets meeting the above criteria were then aggregated into channel specific six-hour chunks, four per day. Each channel specific six hour chunk was then pushed through a three 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) down weighting the raw counts to reflect the proportion of SONAR targets that were steelhead; 2) adjusting the steelhead counts to account for observer error; and 3) filling in passage data for gaps in the corrected steelhead data.

We used a simulation based approach and replicated this simulation procedure a large number of times (10,000) for each channel individually. We initialized the values in each cell (452 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 three steps in the adjustment procedure described below, we were able to generate updated channel specific estimates of escapement, and at varying temporal scales (6-hour estimates, daily estimates, and annual estimates). Each step of this process was done for each channel and then the channel data was summed to provide total estimates and a coefficient of variation (CV). To determine the coefficient of variation for the final escapement, the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates. To generate CV estimates for each of the four individual adjustment procedures, we also applied each step of the procedure individually to the raw six-hour chunk counts from each channel.

Species Composition

Calculation of the 2018 winter steelhead escapement only included SONAR targets recorded through May 30th based on findings of the species composition sampling. No “new” or “holding” winter steelhead were captured in our sampling after May 30. Two spawned out winter steelhead were captured on June 13 and two presumed summer run steelhead in “new” condition were captured on June 6 . In addition, three “new” Chinook salmon were captured on June 6th and three more were captured during the June 13 sampling event, indicating that most, if not all, of the large bodied salmonids migrating past the SONAR sites after May 30 were likely summer run steelhead or Chinook salmon.

In-river netting also provided the necessary data to adjust the raw counts to reflect just the number of steelhead 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 steelhead caught. For each channel, we simulated the proportion of steelhead for a given iteration and day as:

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

where i represents the iteration (1 – 10,000), j indexes the 6-hour chunk (1 – 452) and k indexes the channel. The total number of fish, $N_{i,j,k}^{\text{total}}$, and total number of steelhead, $N_{i,j,k}^{\text{steelhead}}$, 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 steelhead as a random draw from a Binomial distribution:

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

where X is the number of steelhead 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 as opposed to the expanded data used by the simulation. Then the counts of all 6-hour chunks were summed for each iteration, yielding 10,000 estimates. Finally, the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates.

Observer Error

It is generally recommended to account for the possibility of observer error in SONAR counts (Holmes et al. 2006). We quantified observation error by comparing counts for 14 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 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 expanded data used by the simulation. Then the counts of each 6-hour chunks were summed 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.

Filling Data Gaps

As stated above, there were four data gaps, totaling 9 days, for the OM during the course of this study. In addition, there were two data gaps in the HRC during the course of the study. The period of time from when the OM was initially installed (February 6) to when the HRC was installed (February 21) was also considered a data gap that required estimating passage. Therefore, there were a total of 18 missing days of data for the HRC during the course of this study.

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 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 each iteration of the simulation, we first fit the GAM to fill in the data gaps, then for each day drew a random number from a normal distribution centered on the fitted value estimated

from the GAM, with corresponding standard error. This approach ignores autocorrelation in missing values, but also represents upper bounds of uncertainty estimates.

Summer Steelhead Escapement Estimation

A bright and unripe steelhead that morphologically resembled a summer steelhead was captured during species composition net sampling on May 22, 2018. Nine other similar fish were caught during 7 other sampling events up to and including July 10 (Table 7). Genetic samples were taken from these fish and whether or not they were in fact summer run steelhead will be confirmed by the expression of the chromosome Omy28 in the region of GREB1L (K. Nichols, in prep). Assuming they are all in fact summer run steelhead and were caught over the course of a six week period during which we also have continuous passage data from the SONARs allows us to produce an escapement estimate for this distinct run of steelhead in the Elwha.

We estimated the escapement of summer run steelhead to the Elwha River in 2018 in two different but similar ways, both of which were much more basic than the full model runs used to estimate the winter steelhead escapement. Both methods involved simply applying the Xie (2005) formula ($N = U - D$) to raw passage data from May 22 through July 10 and then adjusting those passage counts on a daily basis to account for species composition (Table 7). The two methods differed by changing the length criteria of which raw passage events and which fish captured in the species composition netting that were included. In the first method, we included all raw passage events and all fish captured in the species composition sampling that were over 520 mm, the length of the smallest summer run steelhead. In the second method we only included raw passage events and fish captured in the species composition sampling, which were over 520 mm but below 720 mm, the length of the largest summer steelhead captured.

Results

Between February 6 and May 31, 2018, 2,520 hours (105 days) of data were recorded on the HRC, and 2,544 hours (106 days) were recorded on the OM which represented 92% of the total possible hours (5,520) in this year's steelhead run. At least one of the channels was monitored for 100% of the run (5,520 hours of a possible 5,520 hours). During this time period, 4,208 fish passage events were recorded and analyzed. The best estimate for the steelhead escapement to the Elwha River in 2018 is 1,625 fish with a coefficient of variation (CV) of 3.8% (95% CI 1,489 – 1,768) (Tables 2 and 3). A total of 710 steelhead (CV 7.6%, 95% CI 610 - 819) went up the HRC, while the remaining 915 (CV 3.3%, 95% CI 857 – 975) steelhead went up the OM (Figure 8). In order of decreasing variance, the largest sources of error were (1) filling in data for missing time periods (3.4%), (2) the observer error correction (2.1%), and (3) uncertainty associated with species composition (0.7%) (Table 3).

The nature of the SONAR data in combination with in-stream species composition netting provides detailed information on run timing. Fish passage was detected passed both sites on the first day of deployment. We initiated species composition sampling on April 18th and caught one steelhead and one bull trout. Weekly species composition sampling through June indicated that winter steelhead ceased migrating past the SONAR sites by May 30. Twenty five, 50 and 75% of the run had passed the

SONAR sites on March 22, April 20, and April 30, respectively (Figs. 10 and 12). Twenty five, 50, and 75% of the run had passed the HRC by March 18, April 11, and April 29, respectively, and by March 26, April 24, and May 2 for the OM, respectively (Figs. 9 and 10).

In general, daily passage seemed to be independent of flow or turbidity, although the biggest entry of fish occurred in Late April and early May, right before the onset of flow increases due to snowmelt (Figs. 13 and 14). The hydrograph was variable over the course of the study reaching a high of 4,100 cfs on May 16 and a low of 1,130 cfs on the April 3.

Species composition netting revealed that 45% (13/29) of the captured fish that were assumed to be winter-run steelhead were natural-origin fish. Assuming this represents an unbiased sample of the total run (see discussion), approximately 731 of the 1,625 total returning steelhead were natural-origin recruits (NOR), while the remaining 894 were hatchery-origin recruits (HOR). Additionally, species composition sampling indicated a male:female sex ratio of approximately 1:2 (10 male, 19 female). All presumed summer steelhead were natural-origin.

Finally, our escapement estimate for summer run steelhead to the Elwha River in 2018 is approximately 300 fish. The first method, including all raw passage events of fish over 525 mm and included all captured fish in the species composition correction resulted in an estimate of 296 summer steelhead. The second method, only including raw passage events and species composition captures between 525 mm and 720 mm, resulted in an estimate of 298 summer steelhead. The first summer steelhead was captured on May 22 and the last one was captured on July 10.

Discussion

Our estimate of 1,625 winter steelhead represents a robust measure of steelhead escapement to the Elwha River for several reasons. Most importantly, we collected data over what was likely the majority of the temporal period of the run. Although it is likely some steelhead moved past the SONAR sites before installation on February 6 based on the observance of fish passage on the first day of recording at both sites, daily passage at the beginning of the run was relatively small when compared to April and May. Species composition netting throughout the months of May and June confirmed that we accurately identified the end of the run. We were able to encompass the major sources of uncertainty in our final estimate and thereby provided a robust range of possible escapement totals, giving managers and stakeholder's reliable information upon which to base management decisions. This uncertainty comes from three main sources, (1) filling in gaps for missing time periods (CV, 3.4%), (2) observer error (CV 2.1%), and (3) correcting for species composition (CV 0.7%).

The largest source of uncertainty (CV 3.4%) was associated with filling the multiple data gaps that occurred during the course of the study. Compared to previous years, there were relatively few data gaps this year. However, most of the gaps occurred in late April and early May, which have days with the most variable fish passage days, which adds to the CV when estimating the gaps. Estimating passage from the initial install of the OM (February 6th) until the installation of the HRC (February 21) had the greatest impact on the CV associated with the gap filling procedure, as evidenced by the large error bars associate with this portion of the daily passage graph (Fig. 9). This was due to increasing

uncertainty as the data gap increases and having only data on one side to estimate the data gap. In the end, the gap filing procedure added 238 fish, or 15% of the total run estimate. Unfortunately, collecting passage data with relatively fragile and expensive in-stream equipment in a Pacific Northwest river during late winter through spring will inevitably require removing the equipment during periods of high flow in order to protect the long-term viability of the project. This situation is accentuated in the Elwha River as it responds to recent dam removal activities with increased woody debris and sediment loads. Thus, data gaps, sometimes lengthy, during steelhead season are inevitable.

The second highest source of uncertainty was the observer error correction (CV 2.1%). The regression coefficient (.95) was only marginally different from a 1:1 relationship between technician and expert counts and the r^2 (.65) indicated a reasonably good fit of the regression. The project has employed the same technician for several years, resulting in reliable and accurate data review.

The final and smallest source of uncertainty was associated with the species composition (CV 0.7%). The low level of uncertainty associated with this source is attributed to the one bull trout that was captured during the species composition sampling. It is important to note that this bull trout was captured on the first sampling event of the year (April 18th). All dates prior to this sampling event were assumed to be 100% steelhead based on previous years sampling. It is possible that some portion of the raw SONAR targets previous to April 18th were actually bull trout. Additionally, as in previous years, several sampling events caught either no or few steelhead. Capturing just one bull trout during one of these periods would have had a relatively large impact on both the species composition correction and the uncertainty associated with it.

Although there is no other independent estimate of steelhead escapement on the Elwha, our estimate can be put into context with redd surveys conducted in several tributaries and the main stem channel during the 2018 season. Moses et al. (in prep.) observed a total of 237 steelhead redds from the river mouth to the top of Geyser Valley (RKM 19.9). Using a redd to fish multiplier of 1.8, gives a redd based estimate of 427 fish. When the hatchery collection of 43 fish is added, the total of 470 fish only amounts to about 30% SONAR base escapement. This disagreement is not unexpected for multiple reasons. First, due to visibility issues, limited main stem surveys were conducted in 2018. Secondly, while survey effort was extensive, not all areas were surveyed and some surveyed areas were not visited consistently. Finally, it appears as though passage has become relatively easier at the former Glines Canyon Dam as compared to previous years, based on a lack of redd clusters at the base of the former dam and increased redd numbers in the former Mills reservoir (McMillan et al, 2017). This highlights the likelihood that steelhead may now be spawning in the upper watershed that is not surveyed.

We also put this year's steelhead escapement estimate in context of the last five years' SONAR derived estimates (Denton et al. 2013, 2014, 2015, 2016, and 2017). The escapement estimate has varied from a low of 385 (2013) to a high of 1,625 (2018) while the proportion of natural origin fish has ranged from a low of 13% (2015) to a high of 75% (2013) (Table 4). It is important to note that the species composition sampling protocol is not designed to provide an unbiased sample of natural vs. hatchery-origin ratios, so these numbers should be used with caution (see recommendations below). This is particularly true of the 2013 data, as species composition sampling only occurred in June solely as an effort to differentiate steelhead from Chinook. Specifically relevant to 2018, species composition sampling did not occur during the early portion of the run (prior to April 18). Previous years sampling

indicates that a higher proportion of NOR fish return during the early portion of the run so this year's estimate may be biased towards HOR fish because the early portion of the run was not sampled.

The date at which 50% of the run had passed the SONAR sites in 2018, April 20, was similar to 2014-2016, but two weeks later than 2017. Species composition netting indicated the earliest end of the winter steelhead run for the project on May 30. This resulted in the most contracted run timing of the project to date, which is surprising in light of last year's run displaying the most protracted run timing. There are two potential explanations for this phenomenon. First, fish were recorded actively moving past both the SONARs immediately after installation indicating that fish were also migrating past the sites before installation. It is possible that dozens of fish moved past the SONARS before installation. This would bias the timing curve later as well as result in a low estimate of total fish. Secondly, the hydrograph was unusually low during the winter/spring of 2018 with flows below 1,000 cfs through the entire month of March and into early April (Figure 13). It is possible that these low flows delayed upstream migration thus pushing the run timing curve later.

Snorkel surveys conducted in the upper watershed in late September of 2017 recorded approximately 60 summer run steelhead. Similar surveys in 2018 recorded 216 summer run steelhead (Sam Brenkman, Personal Communication). In 2017 we did not capture any summer steelhead migrating past the SONAR sites so could not apportion any of the raw SONAR targets to summer steelhead. In 2018, we captured nine summer run steelhead over a period of six weeks from May 22 to July 10 (Table 5). These fish were assumed to be summer-run fish for several reasons. First, they were "chrome" bright without any hint of coloration, which indicated they had just entered the river within a week or two. Second, they did not appear mature. For example, their abdomens were not swollen with eggs like a mature winter run female would be that late in the season, and their vents were not protruding. Third, their morphology was slightly different. They had longer caudal peduncles and were more fusiform and streamlined. Lastly, post-spawn steelhead (kelts) may also appear bright and have thin bellies, but these fish were different from kelts because their fins were not eroded from excavating a redd and their bellies were tight, not shrunken and soft. Of course, while the fish outwardly appear to be summer runs, tissue analyses will be required to confirm our initial determination. Notwithstanding, because we captured the fish and recorded their size we were able to calculate an escapement estimate of 300 summer run steelhead.

This estimate should be considered as a conservative estimate for two reasons. First, we captured the first summer steelhead in species composition sampling on May 22. We were not able to conduct net sampling for the three weeks before May 22 due to high flows from snowmelt. It is likely that some summer-run steelhead migrated past the SONAR sites before May 22 before we first detected them in the net sampling. Additionally, we captured the last summer run steelhead on July 10th which was also the first date we caught significant numbers of Chinook salmon (12). It is likely that additional summer run steelhead migrated past the SONAR sites after July 10, but we were not able to capture any due to the very large numbers of Chinook salmon in the system. The second reason our estimate is potentially biased low is due to the issue of winter run steelhead kelting downstream past the SONAR sites at the same time summer run steelhead are actively migrating upstream passed the same sites. Based on the condition of steelhead in the net sampling, June is the primary time period of downstream migration by kelting winter-run steelhead in the Elwha River. The current method of estimating steelhead on the Elwha subtracts any downstream passage from the final escapement estimate, assuming they are milling fish that eventually pass upstream and not kelts, which have

already been counted on their upstream migration weeks or months previously. While this assumption is likely valid for the bulk of the winter steelhead migration, it is likely not valid during the month of June when the bulk of summer steelhead are migrating upstream. Treating any downstream passage events in June as kelts and not subtracting them from the final escapement estimate would have added approximately 100 fish to the final estimate of summer run steelhead.

The increased life history diversity of steelhead bodes well for steelhead recovery in the Elwha River, but it does propose new difficulties for monitoring them. While we miss some portion of the total run by installing the SONAR in late January, low passage in the weeks immediately after installation makes us confident that we are not missing many early fish. This year however, similar to last years, passage up the HRC was evident soon after installation (Fig 9). If this trend continues, we may have to consider installing the SONAR earlier in January or even December if possible. Historically a significant portion of the run was thought to enter the river in December and January (Dick Goin, pers. comm. 2014). Finally, if the project intends to monitor summer steelhead populations, additional work will need to occur, as described in the recommendations section.

Recommendations

Our first recommendation for next year is the same as last year: additional work should be undertaken to produce a sampling protocol that will result in an unbiased estimate of the NOR:HOR ratio of the steelhead return both temporally and longitudinally. As previously mentioned, the current sampling design was developed to accurately sample the species composition of fish migrating past the SONAR sites. It does not focus on capturing an equal number of fish from each channel and certainly does not focus on capturing fish from throughout the watershed.

We were extremely successful at accomplishing last year's recommendation of capturing more summer-run steelhead during our species composition sampling. This allowed us to provide a basic escapement estimate of this run. However, this estimate came along with a few major caveats and did not include any confidence intervals. In order to provide a better estimate of the summer-run steelhead population more species composition sampling should occur from mid-May through mid-July. Additionally, resources need to be committed to dealing with the increased analyses required to devise a statistically defensible method for dealing with the effect of downstream migrating kelts, and to provide a more robust escapement estimate complete with confidence intervals.

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Table 1. Total number of “new” and “holding” steelhead and bulltrout captured by date at 7 sites during in-river netting operations. HOR:NOR ratios for each date are also presented. One steelhead captured on 4/25/2018 could not be assessed for origin. One summer run steelhead was captured on 5/22/2018.

Date	Steelhead	Bulltrout	% Steelhead	HOR:NOR
4/18/2018	1	1	50%	0:1
4/25/2018	9	0	100%	4:4
5/2/2018	3	0	100%	3:0
5/22/2018	0	0	NA	NA
5/30/2018	1	0	100%	0:1

Table 2. Channel specific and total estimates of steelhead passage on the Elwha River in 2018. Each step is an adjustment of the previous step, i.e. they are not stand alone estimates except for the final one.

Type of Count (Adjustment)	HRC	OM	Total
Raw Passage	607	819	1,426
Species Composition	582	773	1,355
Observer Error	602	785	1,387
Gap Fill (Final)	710	915	1,625

Table 3. Channel and source specific coefficients of variation (CV) for the three sources of uncertainty individually and for all of them combined. The individual source CV's are the result of applying each correction to the raw data while the total CV reflects the total CV from all sources.

Source	HRC	OM	Total
Species Comp	1.2%	1.0%	0.7%
Observer Error	3.4%	2.6%	2.1%
Gap Fill	7.1%	2.8%	3.4%
Total	7.6%	3.3%	3.8%

Table 4. Yearly escapement estimates for Elwha River steelhead with 95% confidence intervals and number of natural-origin recruits (NOR) and hatchery-origin recruits (HOR) based on species composition sampling.

Year	Estimate	95% CI	NOR	HOR	% NOR
2013	385	NA	290	95	75%
2014	1,200	1,140 - 1,250	400	800	33%
2015	1,450	1,220 - 1,675	190	1,260	13%
2016	890	810 - 976	320	570	36%
2017	1,130	1,060 - 1,226	375	755	33%
2018	1,625	1,489 - 1,768	731	894	45%

Table 5. Total number of fish by species for each capture date during the summer steelhead run. This table includes fish of all conditions and lengths captured in the lower river.

Date	Summer Steelhead	Bulltrout	Winter Steelhead	Chinook
5/22/2018	1	0	6	0
5/30/2018	0	0	1	0
6/6/2018	3	0	0	3
6/13/2018	1	0	2	3
6/19/2018	0	1	0	0
6/27/2018	2	0	0	5
7/10/2018	2	0	0	12



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 Old Mainstem site is located approximately adjacent to the upper right hand portion of the white oval.



Figure 2. Photo of the HRC DIDSON site showing the picket weir and the ladder on which the DIDSON is mounted.



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. Old Mainstem SONAR site. The SONAR itself 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.

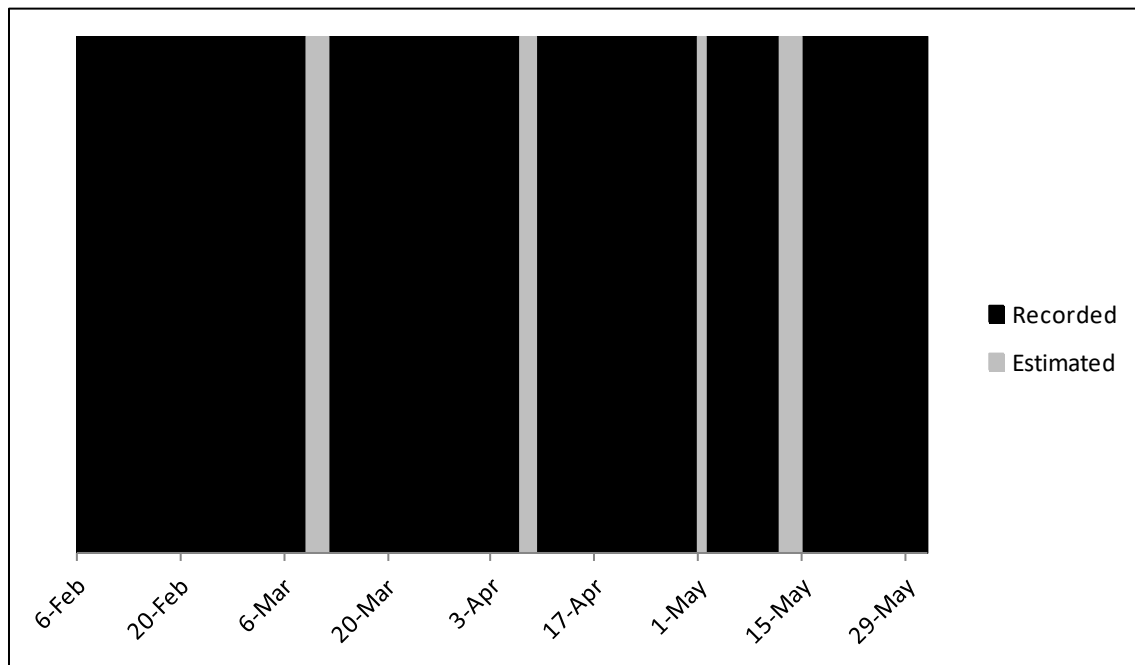


Figure 5a. Dates which had data recorded, black bars, or estimated, grey bars, for the Old Mainstem of the Elwha River in 2018.

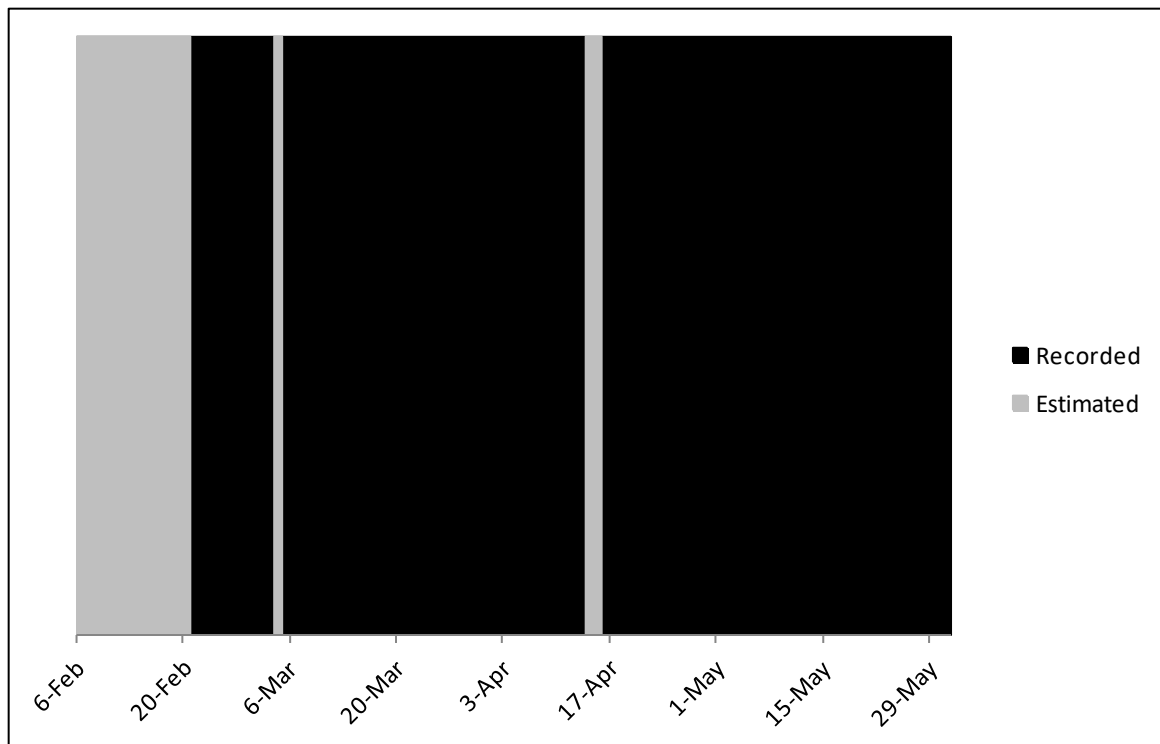


Figure 5b. Dates which had data recorded, black bars, or estimated, grey bars, for the Hunt Road Channel of the Elwha River in 2018.

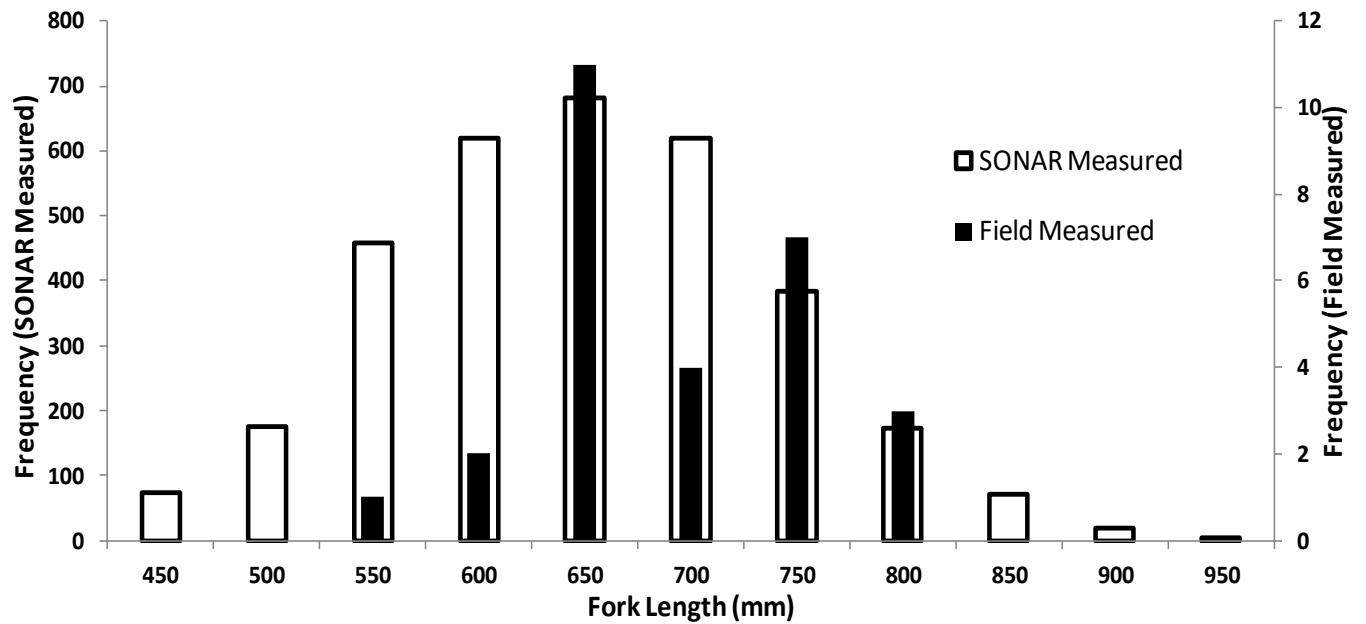


Figure 6. Length frequency histogram of all steelhead captured during netting operations between April 18, 2018 and May 30, 2018 (secondary y-axis) and all SONAR measured targets of quality 1 during the same time period. One bull trout, measuring 610 mm was captured during netting operations on April 18, 2018.

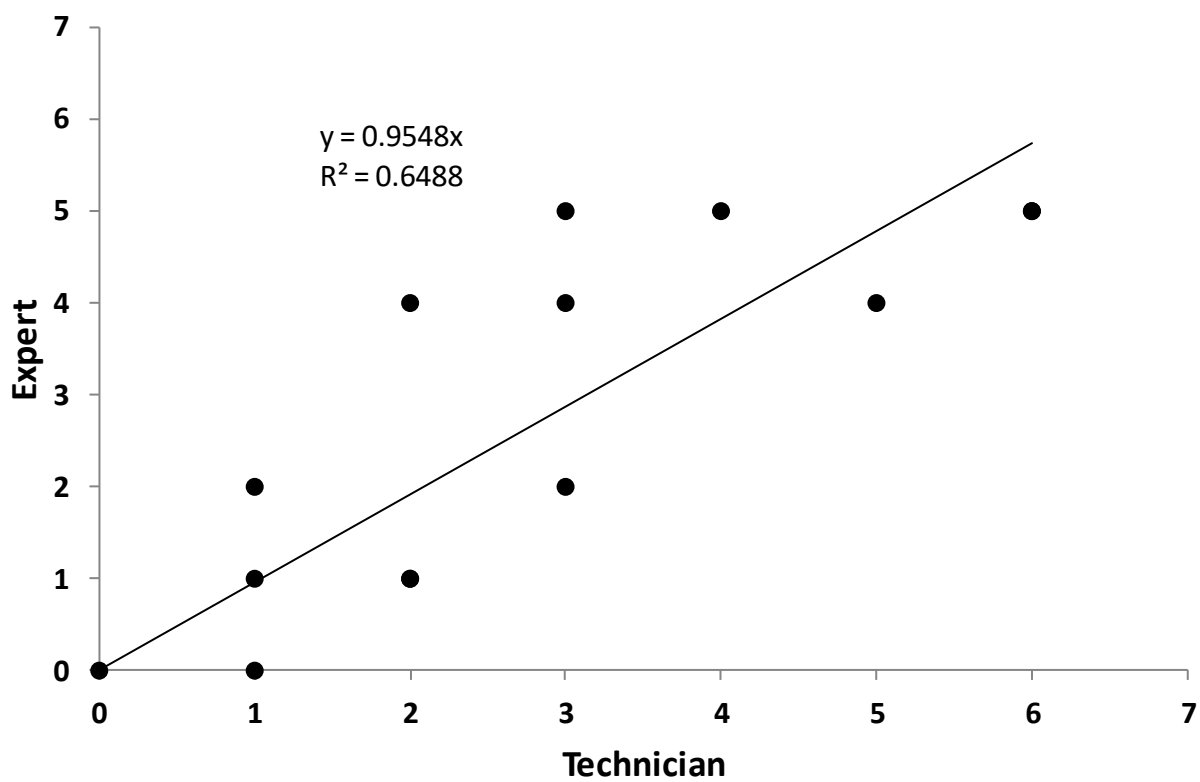


Figure 7. Total upstream passage counted by a technician and an expert for 14 six hour chunks. Points (2,1) and (6,5) each have two data points.

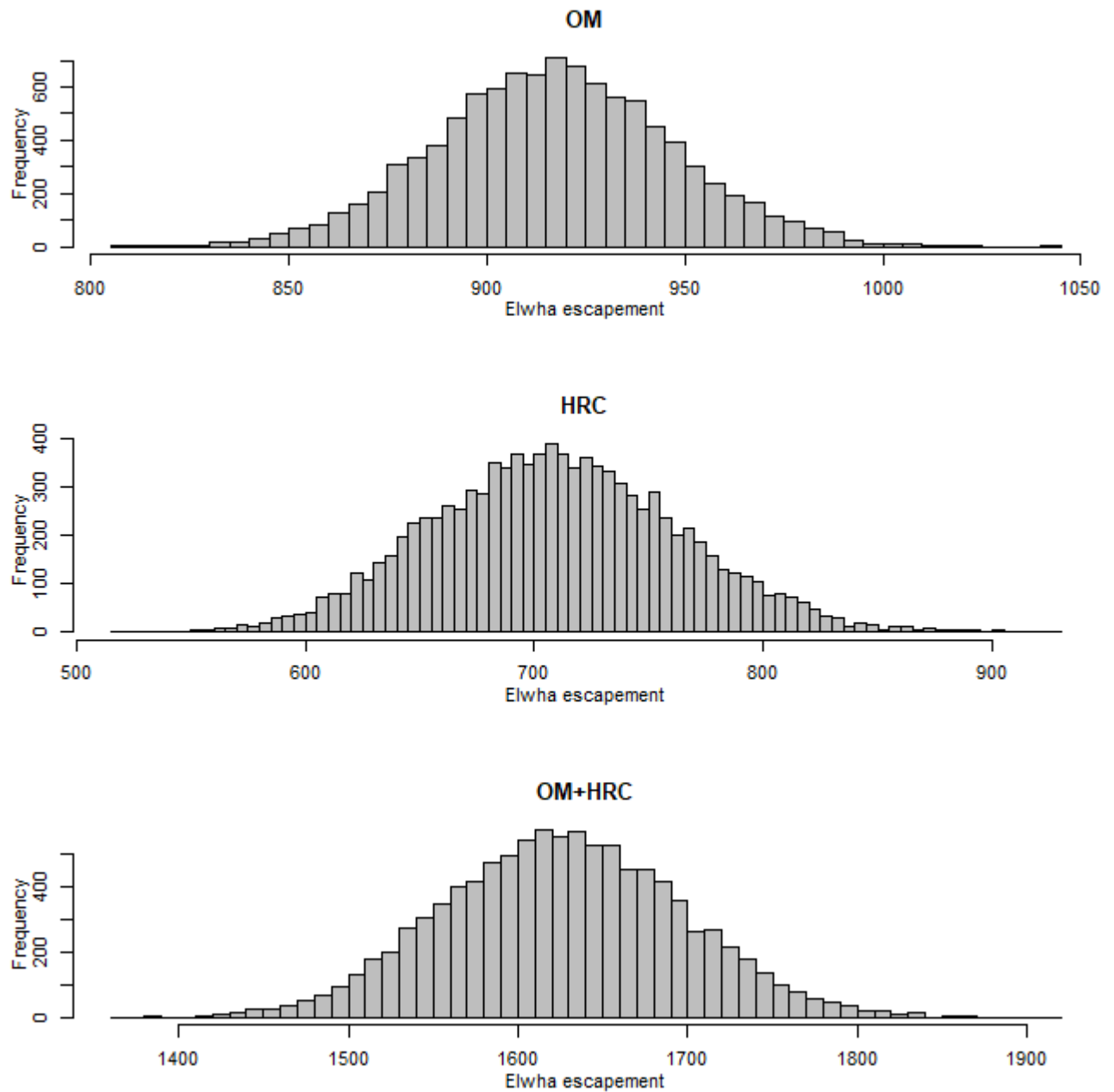


Figure 8. Run size frequency histograms for the steelhead in the Old Mainstem (OM), Hunt Road Channel (HRC) and combined run (OM + HRC) for the Elwha River in 2018.

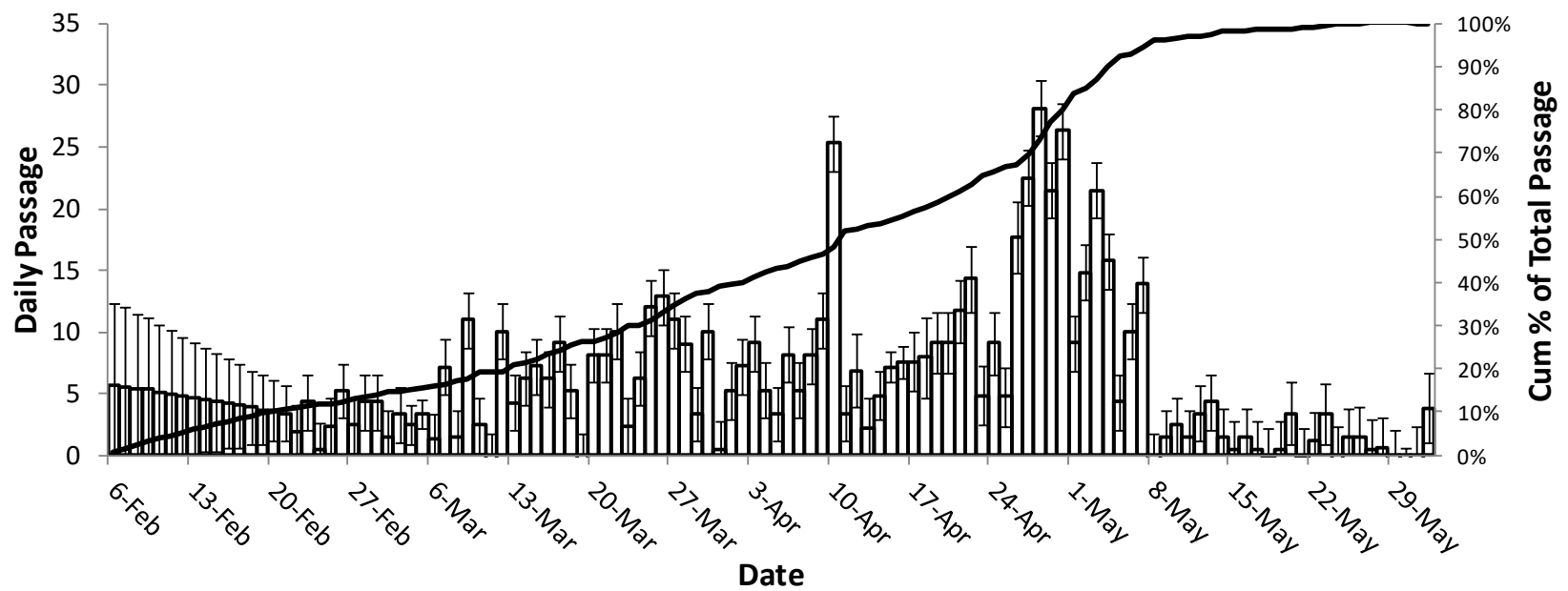


Figure 9. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Hunt Road Channel of the Elwha River in 2018. Total passage for this channel was 710 fish.

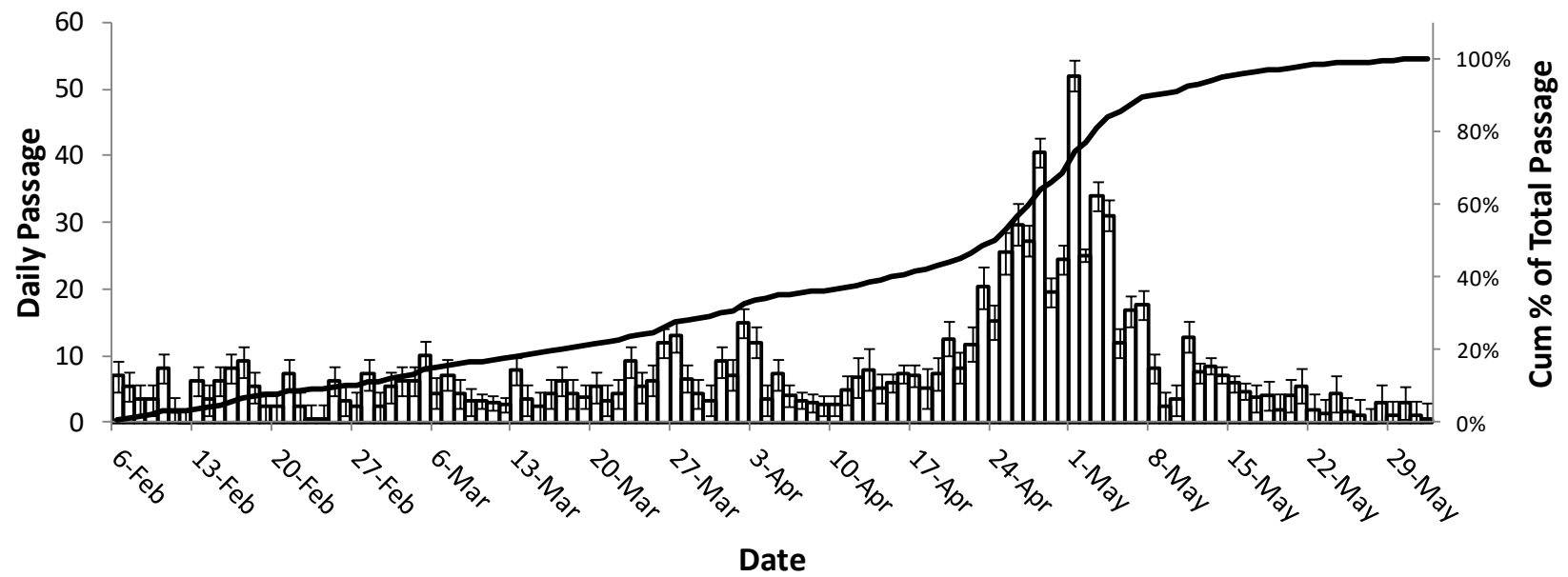


Figure 10. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Old Mainstem of the Elwha River in 2017. Total passage for this channel was 915 fish.

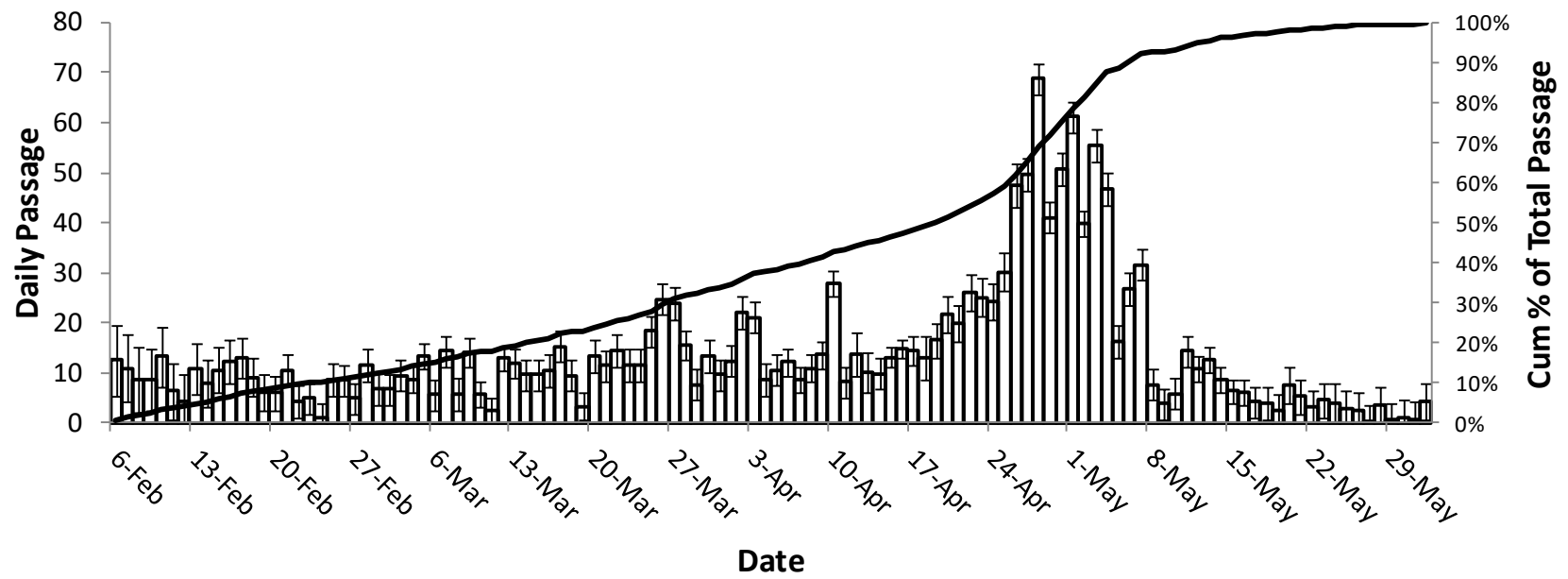


Figure 11. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for both channels the Elwha River in 2018. Total passage estimate was 1,625 fish.

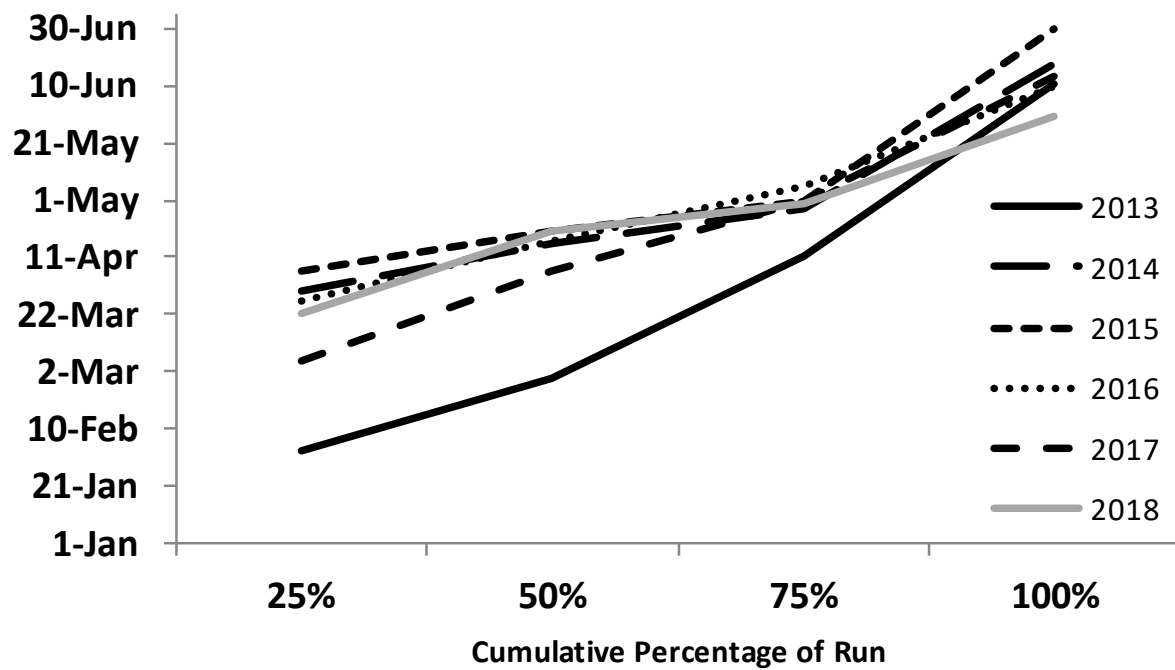


Figure 12. Run timing of steelhead in the Elwha River depicting the date at which 25, 50, 75, and 100% of the run had passed the SONAR sites.

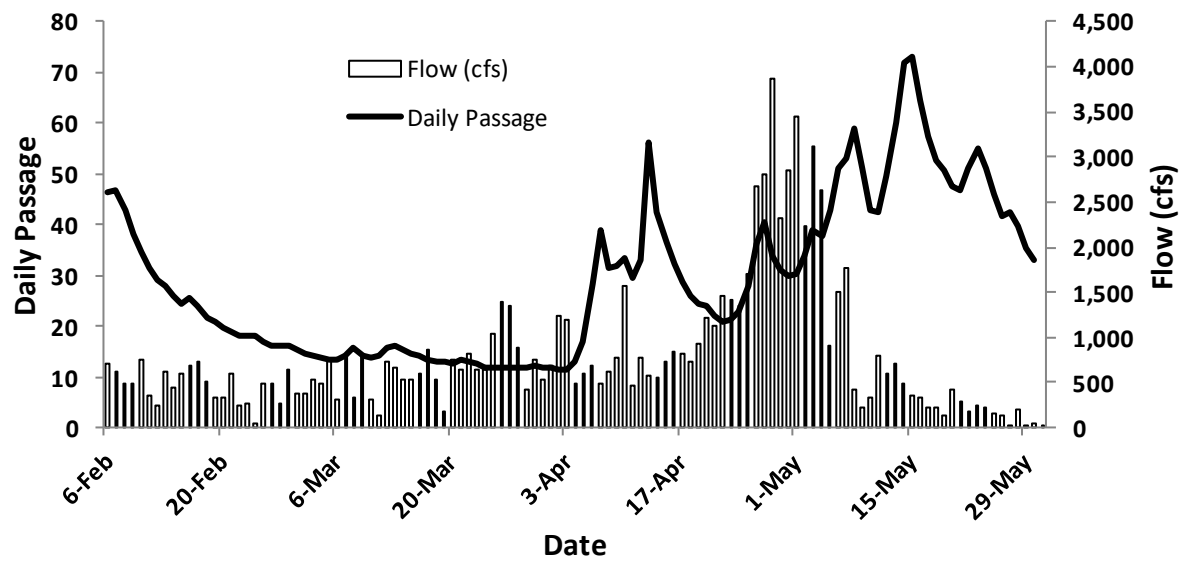


Figure 13. Daily passage of steelhead and flow (cfs) in the Elwha River in 2018.

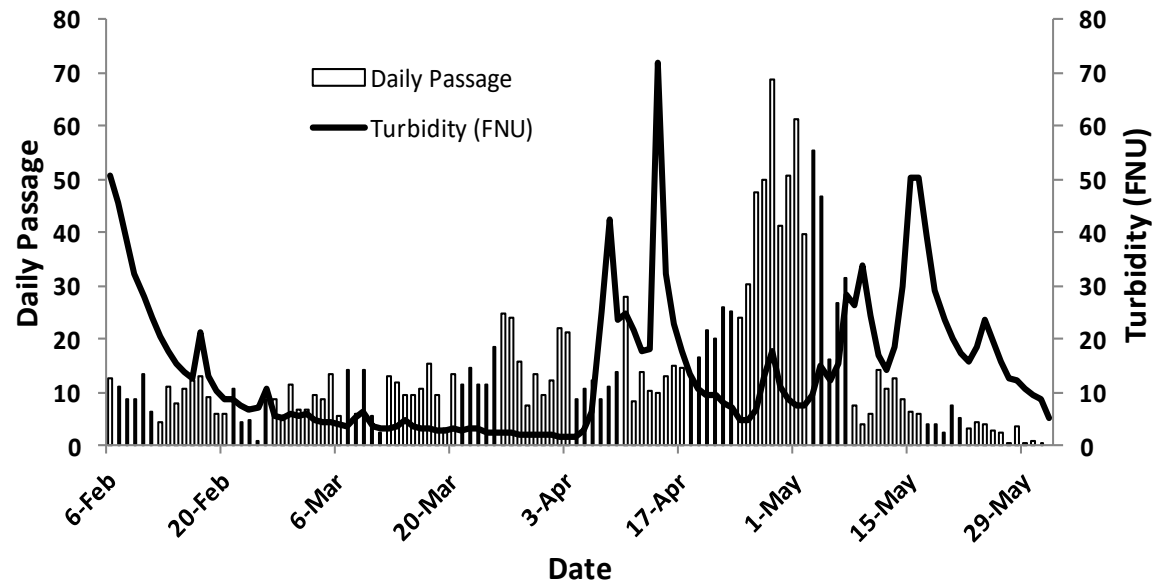


Figure 14. Daily passage of steelhead and turbidity (FNUs) for the Elwha River in 2018.