

2019 Elwha River Winter Steelhead Escapement Estimate Based on DIDSON/ARIS Multi-Beam SONAR Data



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This report is provided to Olympic National Park (ONP) by the Lower Elwha Klallam Tribe (LEKT) in partial fulfillment of action item 1 (adult enumeration) for monitoring activities based upon the final settlement agreement between the ONP and LEKT

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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 January 24, 2019, through May 28, 2019. 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 1,458 fish; with a coefficient of variation (CV) of 6.0% (95% CI 1,260 – 1,666).

We also provide channel specific estimates of passage for the Hunt Road Channel (HRC), 266 (10.4% CV, 95% CI 226 –306) and the Old Mainstem (OM) 1,192 (6.9% CV, 95% CI 1,112 -1,372). 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 (5.8%), observer error (2.7%), and species composition (1.2%).

The HRC SONAR unit was installed on January 24 and the OM SONAR unit was installed March 6, due to heavy snow that made the site inaccessible. Fish were detected migrating passed the HRC SONAR site on the first day of operation. Fifty-percent of the steelhead passed both SONAR sites by March 31, which was 14 days earlier than the average from 2014-2018. Species composition netting in conjunction with additional upstream net sampling indicated that between 60% and 70 % of the total run, or 875 to 1,020 fish, were of natural-origin with the remaining 437- 583 (30-40%) originating from the Lower Elwha Klallam native broodstock hatchery program. Hatchery and natural origin proportions exhibited significant spatial distribution differences with 55% (39/74) of the fish captured in the lower river being of hatchery origin while 0% (0/24) of the fish captured in the middle and upper river were of hatchery origin. Three summer run steelhead were captured during net sampling between June 25 and July 17, but the number and timing of these samples were not representative enough to produce an escapement estimate of that distinct life history type.

Our only recommendation for next year is to perform more net sampling during the presumed period when most summer steelhead pass the SONAR sites (June) in an effort to more accurately identify their relative abundance and timing in the overall net sampling protocol.

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 Imaging **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). In this study, we enumerate a small, protracted run of steelhead using multi-beam imaging SONAR.

SONAR is 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. This report only covers steelhead enumeration from late January through mid-July (see Denton et al., 2010-2018 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 and subsequent development of hatchery steelhead programs, the diversity of entry timings and life histories of steelhead 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 been terminated and a native broodstock program initiated which aims to mimic the life history patterns of natural-origin fish. Additionally, monitoring following dam removal has identified a 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 20th century, but they were discontinued well before dam removal.

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 resulting from 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.

Annual adult abundance estimates are critical for evaluating the success and rate of recolonization of anadromous fish during and after dam removal (Peters et al. 2014). 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). Much of this area is located in roadless wilderness area that is difficult to access. 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 recovery is important (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 Puget Sound rivers, the Elwha River mainstem has an anastomosing or forested island morphology resulting in multiple channels for fish to migrate through (Beechie et al. 2006). 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. When the flow is consolidated into a single channel near the mouth, it is too wide to accurately monitor with a SONAR unit. 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 winter 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 2019 (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 30% of the flow is transported down the HRC, with the remaining 70% 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 deep in the thalweg, while the OM 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 identify 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 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 March 6 through May 28, 2019. There were no data gaps during this time period (Fig 5a). Steelhead passage was recorded at the HRC site from January 24 through May 28. There were three data gaps during this time period equaling two, three and seven days (Fig 5b). The 38 days between deployment of the HRC site and the OM site was also treated as

a data gap for the OM This extensive gap was caused by “snowmagedon” which dumped over 3 feet of snow on the north Olympic Peninsula on February 8, 2019, and precluded access to the OM site for almost a month.

The SONARs were also in operation after May 28, 2019, to record Chinook salmon passage. Data, analysis, and an estimate of Chinook passage for this time period is available in the project’s Chinook report (Denton et al., in prep.).

Species Composition

We conducted eleven tangle net surveys between March 13 and May 28, 2019, 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 stretch 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 (Fig 6). Additionally, species composition data was used to determine the sex ratio of steelhead. Fish captured during species composition netting in conjunction with fish captured during additional sampling at supplemental upstream sites were used to determine hatchery and native origin proportions for the entire run. Hatchery:natural proportions had significant variability both temporally and spatially. To combat this, additional sampling occurred this year to correct for biases introduced in previous year’s that relied on significant sampling near the LEKT hatchery during the peak of the hatchery return. We sampled an additional 16 sites on 13 different dates upstream of the traditional species composition sites in order to better characterize variability in hatchery:natural origins and thereby provide a more accurate measure of the percentage of natural origin fish. Not all sites were sampled on all days. See Peters et al. 2020 for methods, data, and analysis of this portion of the project.

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 460 mm and 860 mm (Fig. 6). Five bull trout were captured during species composition sampling measuring between 190 mm and 625 mm, with the largest four being well within the length range of steelhead. Based on this data, only SONAR targets recorded as 450 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. Five percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (113/2094). Thirty-seven percent of all downstream passage events were recorded as observer confidence level 2 (516/1,373).

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 put 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 (508 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 2019 winter steelhead escapement only included SONAR targets recorded through May 28 based on findings of the species composition sampling. No “new” or “holding” winter steelhead were captured in our sampling after May 28. No additional steelhead were captured at the species composition sites during the month of June until one spawned out winter steelhead was captured on June 24. In addition, one “new” Chinook was captured on May 21 and four more were captured on May 28, indicating that most of the large bodied salmonids migrating past the SONAR sites after May 28 were likely Chinook salmon (although see discussion about the possibility of summer run steelhead migrating past the sites in June).

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:

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

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. 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 20 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 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. 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 no data gaps for the OM after initial deployment. However, the period of time from when the HRC was initially installed (January 24) to when the OM was installed (March 6) was also considered a data gap that required estimating passage. There were three data gaps for the HRC totaling 12 days during the course of the study. Because of the different nature of these gaps (short gaps with passage data on both sides of the gap (HRC) versus a long gap with data available from only one side of the gap (OM)) two different methods were used to estimate passage during them.

To fill in the short gaps on the HRC that had data available on both sides of them, 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 moved 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.

To fill in the 38 day gap on the OM before its initial deployment we first estimated the proportion of fish migrating up each channel, during the period when data was being collected from each channel. We estimated the existence of any linear or non-linear trends, and found the fraction migrating up the OM channel to be relatively consistent (after accounting for uncertainty and sample sizes). To estimate the fraction of fish migrating up the OM during the time window when only HRC data was being collected, we used this proportion (p) and performed the same

binomial sampling used in the species composition correction. This approach treats the number of fish migrating up the HRC and the total proportion migrating up each channel as known, and simulates the total number of fish migrating up both channels. The number migrating up the HRC channel in a given iteration is the difference between the HRC and simulated total.

Results

Between January 24 and May 28, 2019, 2,616 hours (109 days) of data were recorded on the HRC, and 2,064 hours (86 days) were recorded on the OM which represented 78% of the total possible hours (6,000) in this year's steelhead run. At least one of the channels was monitored for 97% of the run (5,832 hours of a possible 6,000 hours). During this time period, 4,116 fish passage events were recorded and analyzed. The best estimate for the steelhead escapement to the Elwha River in 2019 was 1,458 fish with a coefficient of variation (CV) of 6.0% (95% CI 1,260 – 1,666) (Tables 2 and 3). A total of 266 steelhead (CV 10.4%, 95% CI 226 – 306) went up the HRC, while the remaining 1,192 (6.9% CV, 95% CI 1,112 -1,372) 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 (6.0%), (2) the observer error correction (2.7%), and (3) uncertainty associated with species composition (1.2%) (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 past both sites on the first day of deployment. We initiated species composition sampling on March 13th and caught one steelhead. Weekly species composition sampling through June indicated that winter steelhead ceased migrating past the SONAR sites by May 28. Twenty-five, 50 and 75% of the run had passed the SONAR sites on February 23, March 31, and April 20, respectively (Figs. 11 and 12). Twenty-five, 50, and 75% of the run had passed the HRC by February 24, April 2, and April 20, respectively, and by February 18, March 27, and April 20 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, although relatively low compared to the last five years, reaching a high of 2,000 cfs on May 12 and a low of 448 cfs on March 14.

Sampling at the species composition sites and additional upstream sites netting captured 97 winter run steelhead. Forty of these fish were adipose clipped (hatchery origin) while the other 57 were natural origin. There were significant differences in the proportions of hatchery and natural origin fish captured at lower river sampling sites compared to middle and upper river sites. Thirty-nine of 74 fish (55%) captured in the lower river were of hatchery origin, whereas zero of 24 (0%) fish captured in the middle and upper river were of hatchery origin. After accounting for variable capture probabilities depending on location of capture, as detailed in Peters et al. 2020, the best estimate for PHOS for the entire run was between 30% and 40%. Assuming this represents an unbiased sample of the total run, approximately 875 -1,020 of the 1,458 total returning steelhead were natural-origin recruits (NOR), while the remaining 437-583 were hatchery-origin recruits (HOR). Net sampling from all sites indicated a

male:female sex ratio of approximately 0.7:1 (40 male, 56 female).

Additionally, three summer run steelhead were captured on June 24, July 10, and July 17 all of which were natural origin. Unfortunately, this small sample size coupled with only one summer run steelhead captured during their presumed peak migration period (June) precluded deriving a summer run steelhead escapement estimate using SONAR data for 2019.

Discussion

Our estimate of 1,458 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 January 24 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 for the first week of operation. 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, 6.0%), (2) observer error (CV 2.7%), and (3) correcting for species composition (CV 12%).

The largest source of uncertainty (CV 6.0%) was associated with filling the data gaps that occurred over the course of the study. Once each SONAR site was installed there were very few data gaps, totaling only 12 days, all on the HRC. However, the late install (March 4) of the OM site necessitated estimating a large gap (38 days) with no passage information prior to site installation. We used a new method for estimating passage during this time period, using data from the HRC along with proportional passage data up each channel over the period when both SONAR units were operational. The CV associated with this gap filling procedure had a large effect on the overall CV, as evidenced by the large error bars associated with this portion of the daily passage graph (Fig. 9). In the end, the gap filing procedure added 375 fish, or 25% of the total run estimate. Perhaps the most important aspect of the gap filling procedure to consider is that it estimated more fish passing up the OM during the early portion of the run than in previous years (Fig. 11). This reduced the 50% passage date to its earliest point yet, March 31 versus an average of April 9 (except for 2013 which saw relatively fewer hatchery fish return which significantly affects returning timing) (Fig. 12). It is important to note that measured passage up the HRC during this time period was also the highest during the course of the study, resulting in the earliest date at which passage up the HRC reached 50% (Fig. 9). The final point to consider when evaluating the gap filling procedure for the 38 day passage gap on the OM before initial installation of the SONAR is the differential timing and channel preference of hatchery and natural origin fish. Based on net sampling, natural origin fish represented a higher proportion of the early period of the run (10% hatchery origin fish captured in March versus 45% in April and May) and a higher proportion of the catch in HRC (5/7, 72%) as opposed to the OM (5/25, 20%). This phenomenon could mean that during the early portion of the run (February–March) the proportion of fish that migrate through the HRC could be

higher than the seasonal average of 17% that was used to fill in the missing OM data. This would mean that the current gap filling procedure could have overestimated passage up the OM before March 4.

The second highest source of uncertainty was the observer error correction (CV 2.7%). The regression coefficient (.96) was only marginally different from a 1:1 relationship between technician and expert counts and the r^2 (.80) indicated a 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 1.2 %). The low level of uncertainty associated with this source is attributed to the fact that net sampling indicated that almost all fish passing by the SONAR sites during the course of the study were steelhead. The uncertainty that does exist from this adjustment is almost entirely due to the five bull trout that were captured over the course of the study. The last new or holding steelhead was captured on May 28, only one week after the first Chinook salmon was captured, indicating those two species' run timing overlapped very little in 2019.

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 2019 season. Moses et al. (in prep.) observed 323 steelhead redds from the river mouth to the upstream end of Geyser Valley (RKM 19.9). Using a redd to fish multiplier of 1.8, gives a redd based estimate of 581 fish. When the hatchery collection of 59 fish is added, the total of 640 fish only amounts to about 44% of the SONAR based escapement. This disagreement is not unexpected for multiple reasons. First, due to visibility issues, limited main stem surveys were conducted in 2019. Secondly, while survey effort was extensive, not all areas were surveyed (namely the entire upper watershed upstream of Geyser Valley) and some surveyed areas were not visited consistently. Finally, it appears as though the spatial distribution of observed steelhead redds is moving upstream and survey effort upstream of the former Lake Mills reservoir is very limited. Taken together, there is a high likelihood that numerous redds were uncaptured during these surveys.

We also put this year's steelhead escapement estimate in context with the last five years' SONAR derived estimates (Denton et al. 2013, 2014, 2015, 2016, 2017, 2018). 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). Extensive effort was made this year to produce an unbiased estimate of the proportion of hatchery fish. Significant variability was shown to exist in the proportion of hatchery fish both temporally and spatially. In 2019, we attempted to sample over both a longer spatial distance (mouth of the river to former Lake Mills) and a longer temporal scale (early March through end of June). It is important to note that the species composition sampling protocol of previous years was not designed to provide an unbiased sample of natural vs. hatchery-origin ratios, so numbers prior to 2019 should be used with caution and comparisons of previous years to 2019 are not advisable (see below). This is particularly true of the 2013 and 2015 data. In 2013 species composition sampling only occurred in June solely as an effort to differentiate steelhead from Chinook. In 2015, most of the sampled steelhead were captured within 500 m of the LEKT hatchery and therefore the proportion of natural origin fish is almost certainly biased low. Nevertheless, it is interesting to note that if we compare previous year's estimates of NOR:HOR ratios, excluding 2013 and

2015, we would get an average of approximately 37% NOR which is close to this year's estimate of 45% NOR (22/47) if we only used the same species composition sites that were used in previous years. Furthermore, this year's average of 45% NOR from just the species composition sites is exactly the same as last year's estimate from those same sites. So, the true NOR% from previous years of this study that only used the species composition sites was likely close to this year's estimate of 60-70% NOR.

The date at which 50% of the run had passed the SONAR sites in 2019, March 31, was the earliest the project has recorded, except for 2013 when very few hatchery fish returned which are concentrated in late April. The average 50% return date for 2014-2018 was April 15. Species composition netting indicated the earliest end of the winter steelhead run for the project on May 28, which was only 2 days earlier than 2018 but 19 days earlier than the 2014-2017 average of June 17. Net sampling occurred throughout June in conjunction with the Chinook project and only one additional winter run steelhead was captured (June 24) and it was spawned out.

Snorkel surveys conducted in the upper watershed in late September of 2017 recorded approximately 60 summer run steelhead. Similar surveys in 2018 and 2019 recorded 216 and 341 summer run steelhead, respectively (Sam Brenkman, ONP, Personal Communication). In 2018, we captured nine summer run steelhead over a period of six weeks from May 22 to July 10 and were able to generate an escapement estimate for this distinct timed run. In 2019, we only captured three summer run steelhead between June 24 and July 17. Because of the low sample size and the fact that summer run steelhead's main entry timing is during the month of June and we therefore likely missed capturing the majority of migrating fish, we were not able to generate a population estimate for summer run steelhead based on SONAR data this year. This was due to the low sample size and because the three fish we did sample were captured in late June through mid-July which is after the presumed main entry timing for summer run steelhead, June.

The increased life history diversity of steelhead as evidenced by protracting run timing and the presence of summer run fish bodes well for steelhead recovery in the Elwha River, but it does pose new monitoring challenges, that may be met with other methods. While we miss some portion of the total run by installing the SONAR in late January, low passage in the days 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

We are pleased to report that last year's recommendation of producing a better protocol for estimating PHOS was accomplished. We need to repeat the second of last year's recommendations in regards to more sampling effort for summer run steelhead. 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 effects of downstream migrating kelts during this time period.

Acknowledgements

The species composition sampling was aided by the help of numerous helpers in the field, namely Todd Bennett and Steve Corbett from NOAA and Roger Peters, Jeff Johnson, and Kathryn Sutton from USFWS. The DIDSON SONAR was loaned to the project by NOAA's Northwest Fisheries Science Center and the ARIS SONAR was loaned to the project by Olympic National Park. This report was greatly improved by the review of Anna Geffre and Pat Crain of ONP and John Mahan of LEKT. Olympic National Park provided funding for the 2019 steelhead SONAR project.

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Table 1. Total number of “new” and “holding” steelhead, bull trout, and Chinook over 450 mm captured by date at ten species composition sites during in-river netting operations.

Date	Steelhead	Bulltrout	Chinook	% Steelhead
3/13/2019	1	0	0	100%
3/19/2019	2	0	0	100%
3/26/2019	2	0	0	100%
4/2/2019	0	0	0	0%
4/10/2019	6	0	0	100%
4/15/2019	6	1	0	86%
4/22/2019	3	0	0	100%
4/29/2019	3	0	0	100%
5/6/2019	9	2	0	82%
5/21/2019	1	1	1	33%
5/28/2019	1	0	4	20%

Table 2. Channel specific and total estimates of steelhead passage on the Elwha River in 2019. 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	210	913	1,123
Species Composition	195	821	1,016
Observer Error	247	836	1,083
Gap Fill (Final)	266	1,192	1,458

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	3.0%	1.2%	1.2%
Observer Error	8.5%	2.4%	2.7%
Gap Fill	2.1%	6.7%	5.8%
Total	10.4%	6.9%	6.0%

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, except for 2019 which was based on a more robust sampling protocol intended to estimate %NOR fish. %NOR estimates prior to 2019 should be used with caution.

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%
2019	1,458	1,260 - 1,666	875 - 1,020	437 - 583	60-70%



Figure 1. Map of the lower Elwha. The 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.

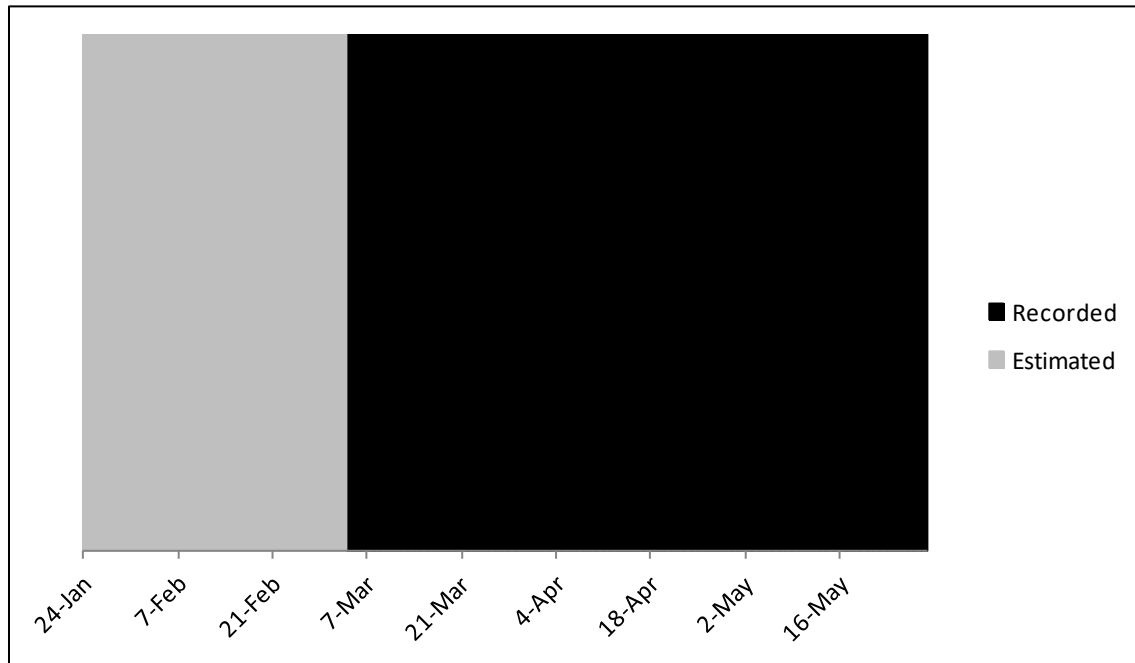


Figure 5a. Dates which had data recorded, black bars, or estimated, grey bars, for the Old Mainstem of the Elwha River in 2019.

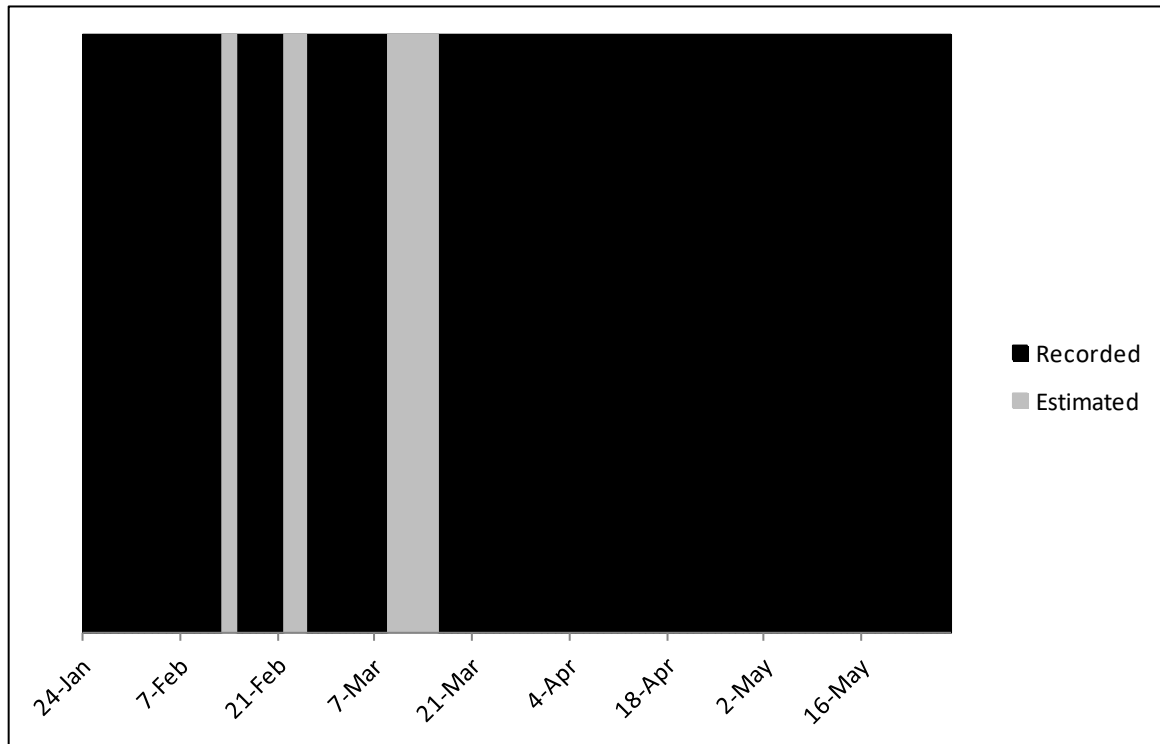


Figure 5b. Dates which had data recorded, black bars, or estimated, grey bars, for the Hunt Road Channel of the Elwha River in 2019.

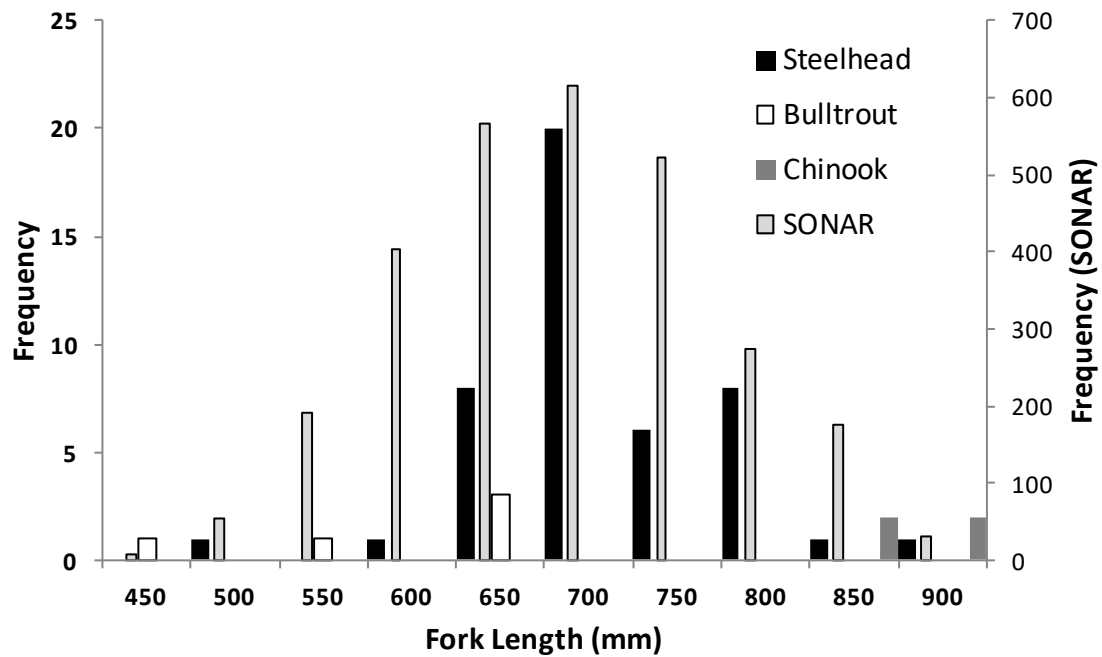


Figure 6. Length frequency histogram of all fish captured during netting operations at eleven locations on the lower Elwha River between March 13 and May 28, 2019 (left hand y-axis). Length frequency histogram of all SONAR measured targets of observer quality 1 (right hand y-axis). One Chinook was captured May 21 and four Chinook salmon were captured on May 28, 2019.

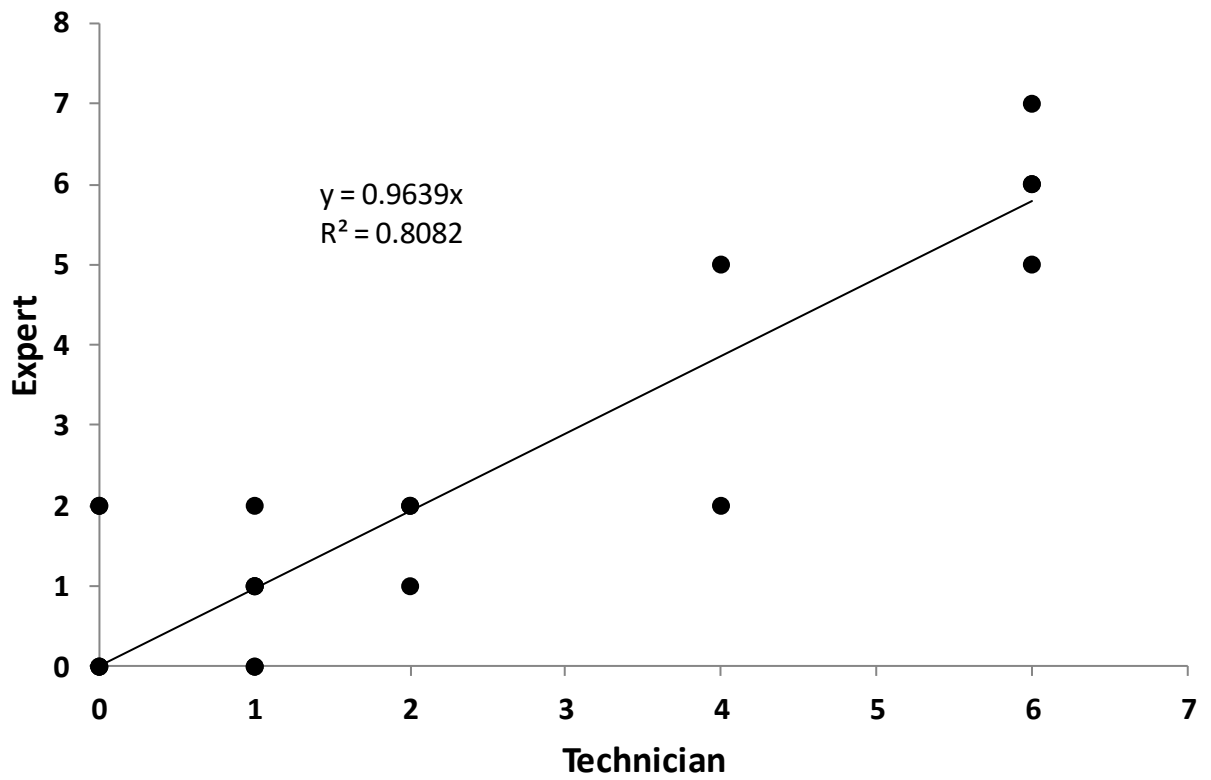


Figure 7. Total upstream passage counted by a technician and an expert for 20 six hour chunks. Points (0,0) and (1,1) have three data points and points (2,2), (2,0) and (6,6) each have two data points.

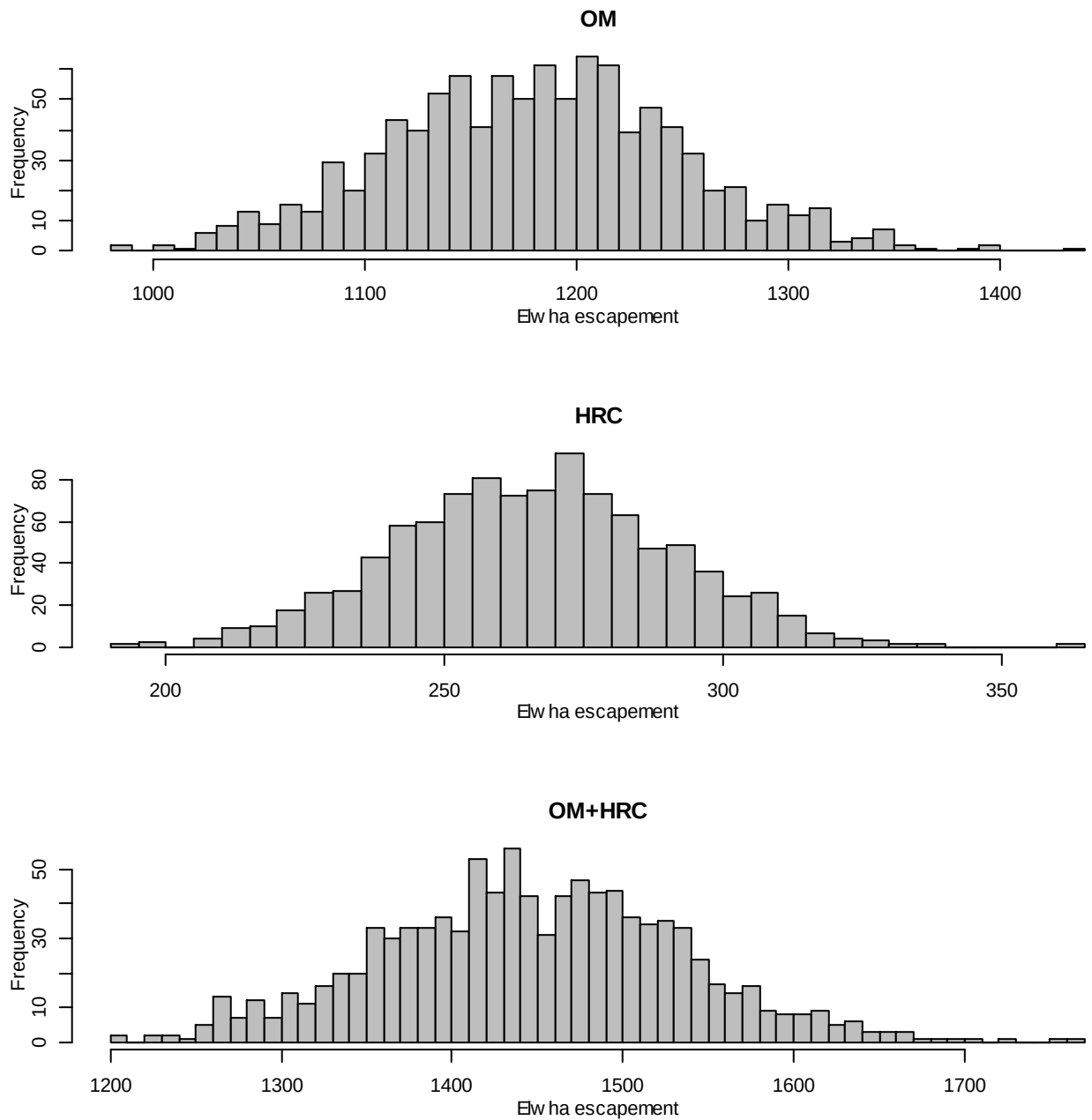


Figure 8. Run size frequency histograms for the steelhead in the Old Mainstem (OM), Hunt Road Channel (HRC) and combined run (OM + HRC) for the Elwha River in 2019.

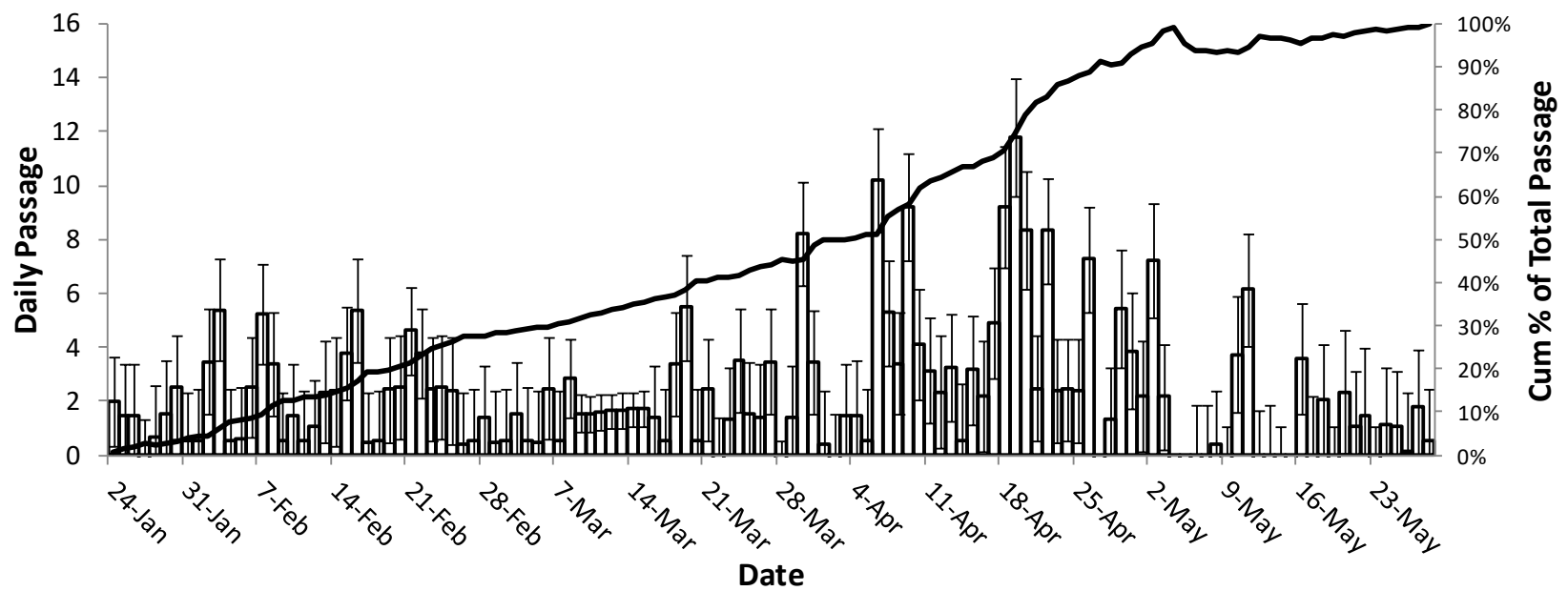


Figure 9. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Hunt Road Channel of the Elwha River in 2019. Total passage for this channel was 266 fish.

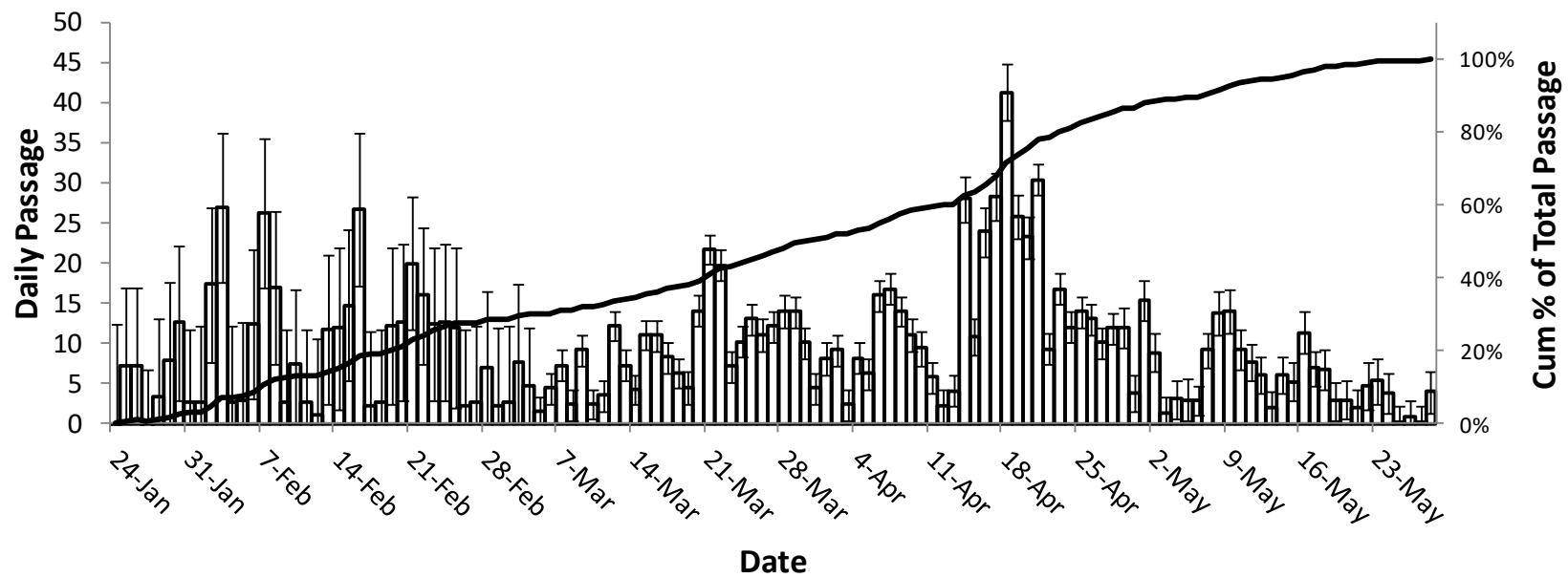


Figure 10. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Old Mainstem of the Elwha River in 2019. Total passage for this channel was 1,192 fish.

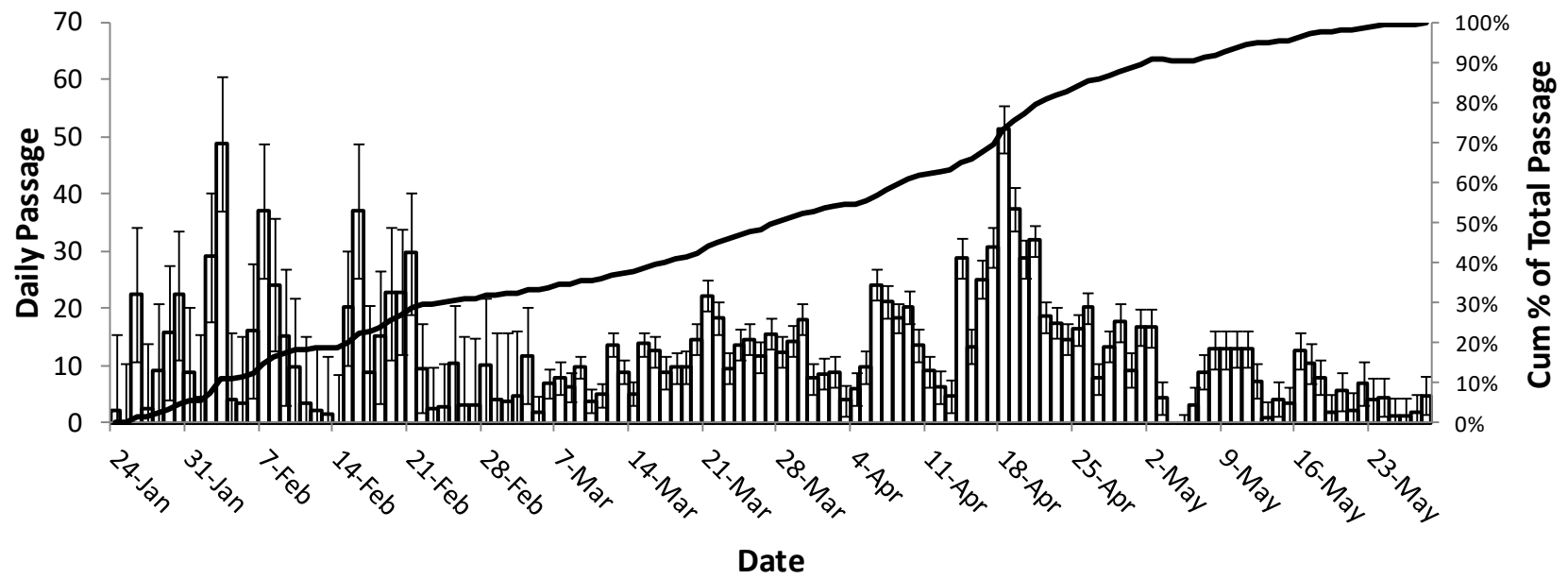


Figure 11. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for both channels the Elwha River in 2019. Total passage estimate was 1,458 fish.

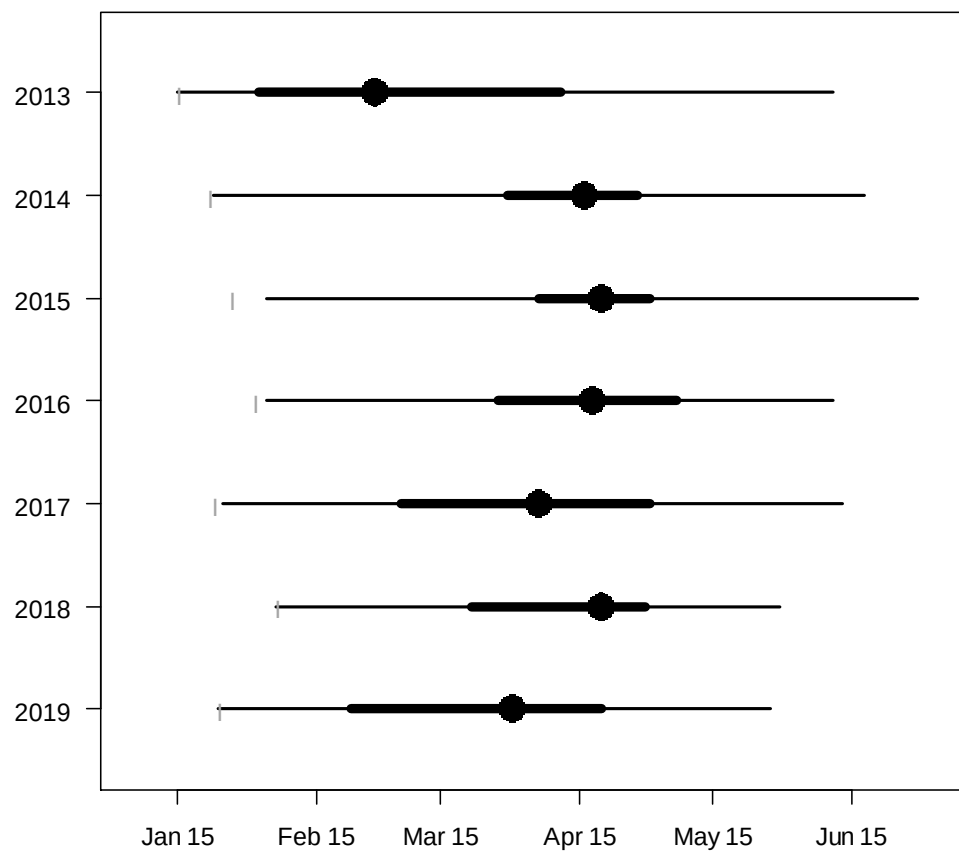


Figure 12. Run timing of steelhead in the Elwha River from 2013 to 2019. For each year the small vertical gray line shows the install date, the long thin black line encompasses the first fish detection until the end of the run. The thick black line shows the time period during which 25% to 75% of the run passed the SONAR sites. The black dot shows when 50% of the run had passed.

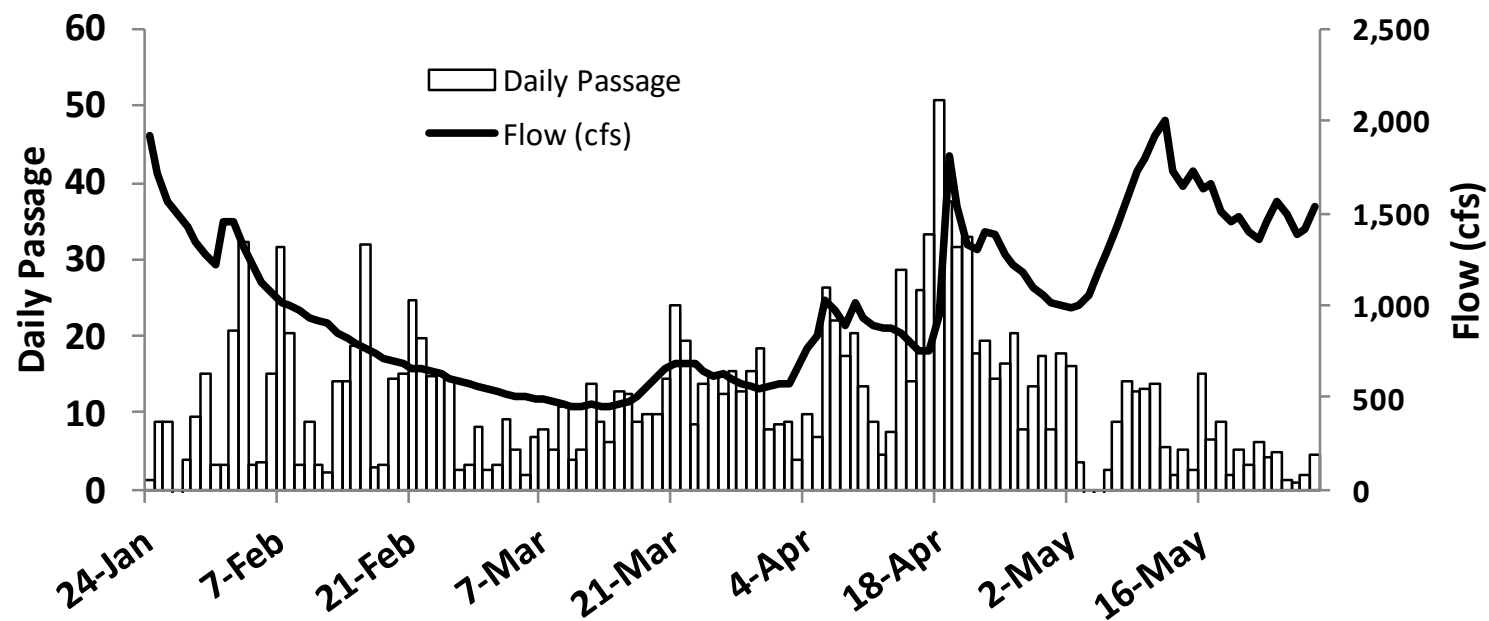


Figure 13. Daily passage of steelhead and flow (cfs) in the Elwha River in 2019.

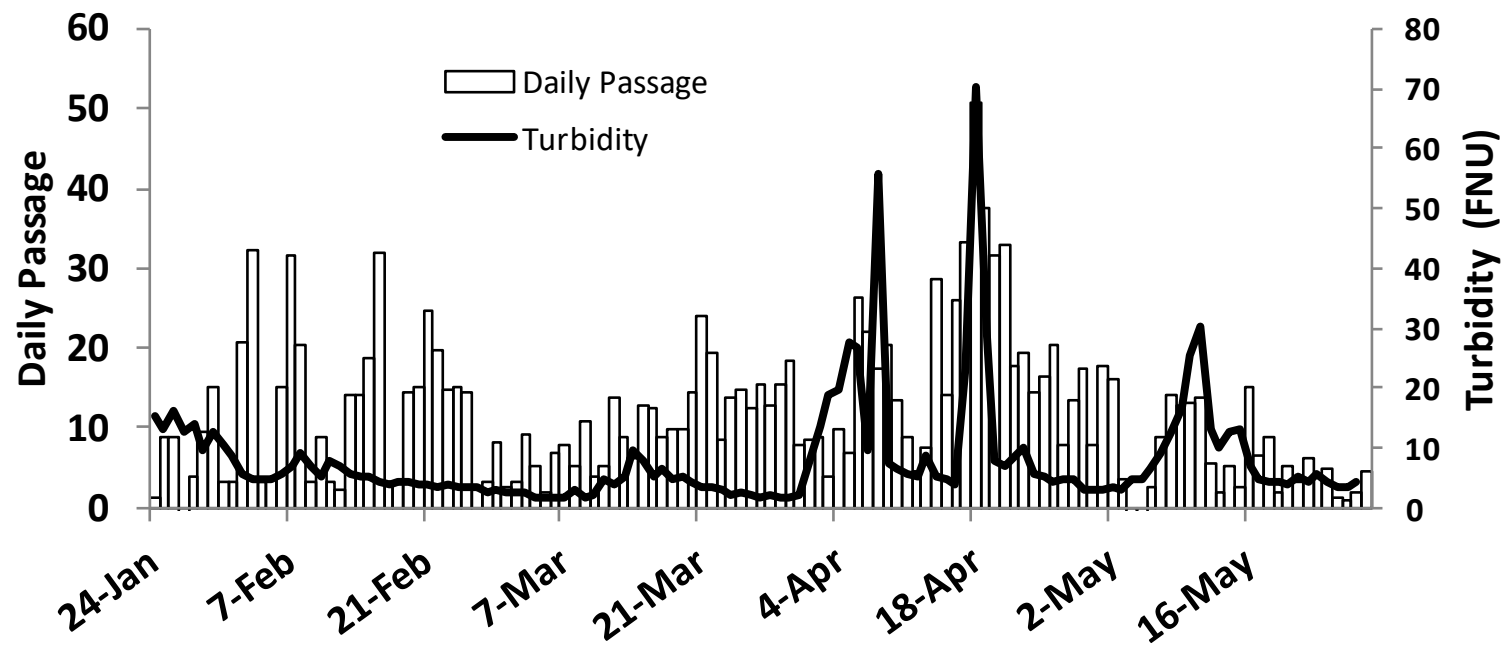


Figure 14. Daily passage of steelhead and turbidity (FNUs) for the Elwha River in 2019.