

2021 Elwha River Winter Steelhead Escapement Estimate Based on DIDSON/ARIS Multi-Beam SONAR Data



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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 20, 2021, through June 8, 2021. 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 2,293 fish; with a coefficient of variation (CV) of 4.8% (95% CI 2,074 – 2,523). This is the highest escapement of winter steelhead to the Elwha since the SONAR project began in 2013.

We also provide channel specific estimates of passage for the Hunt Road Channel (HRC) (412, 7.0% CV, 95% CI 355-465) and the Old Mainstem (OM) (1,881, 4.6% CV, 95% CI 1,729–2,048). 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 (4.3%), observer error (1.4%), and species composition (0.8%).

The HRC SONAR unit was installed on January 20 and the OM SONAR unit was installed on January 23. Fish were detected migrating passed both SONAR sites on the first day of operation. Fifty-percent of the steelhead passed both SONAR sites by April 7th, which was 14 days earlier than the average from 2014-2019. Species composition netting in conjunction with additional upstream net sampling indicated that between 35% and 68% of the total run, or 803 to 1,560 fish, were of natural-origin (NOR) with the remaining 733-1,490 (32-65%) originating from the Lower Elwha Klallam native broodstock hatchery program (HOR). Hatchery and natural origin proportions exhibited significant spatial and temporal distribution differences: 100% (38/38) of the fish captured in the middle and upper river were NOR, while 46% of fish captured in the lower river (50/92) were NOR. Temporal shifts ranged from 100% natural origin in January and February (12/12) to 0% natural origin in June (0/3).

Two of our three recommendations for next year are the same as last year: perform net sampling throughout January even if the SONARs cannot be installed that early and to perform more net sampling during the presumed period when most summer steelhead pass the SONAR sites (June and July) in an effort to more accurately identify their relative abundance and timing. The third recommendation is to search for alternative sources of funding as the National Park Service's ten year commitment to funding adult enumeration following dam removal will expire after the 2022 steelhead season. Although there is currently no harvest of winter steelhead on the Elwha, accurate information on run size and NOR:HOR proportions will be vital to managing harvest in the future.

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 (e.g. 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 has been used to enumerate winter-timed steelhead (*Oncorhynchus mykiss*) since 2013 and summer/fall Chinook salmon (*O. tshawytscha*) since 2008 in the Elwha River, Washington from early late January/early February through late September. SONAR has also been used to enumerate coho salmon (*O. kisutch*) since 2019 from early September through late November. This report only covers steelhead enumeration from late January through early June (see Denton et al., 2010-2020 for reports and data on Chinook and coho 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 (Pess et al., 2008). 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. These two programs had their last and first outplants, respectively, in 2011. 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 (Duda et. al., in press). For the last fifty years, 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 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 road less 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 2021 (Fig. 1). The primary enumeration site was located in the Old Mainstem (OM, also referred to as the East channel) while a secondary site was located in the Hunt Road Channel (HRC, also referred to as the West Channel). 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 2020). 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 25-30 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).

In previous years we have utilized a picket weir to move fish far enough in front of the SONAR units to accurately ensonify them. Sediment changes at both sites have produced a shallow gravel bar gently sloping across to the thalweg at the far bank. Data review also revealed no “fish shadows” moving close by the SONAR heads. Therefore, no picket weirs were installed in 2021.

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 January 23 through June 8, 2021. There were two data gaps during this time period totaling 12 days (Fig 5a). The three day period between installation of the HRC site and the OM site was also treated as a data gap. Steelhead passage was recorded at the HRC site from January 20 through June 8. There were five data gaps during this time period totaling 20 days (Fig 5b). There was also a seven day period (April 9 through 15) where flows were too low in the HRC to install the SONAR and passage was assumed to be zero during this time period.

The SONARs were also in operation after June 8, 2021, 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., 2021).

Species Composition

We conducted twenty tangle net surveys between January 11 and June 8, 2021, to capture live adult salmonids at eleven 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, to determine the end of the steelhead run and to estimate hatchery:natural proportions (or p_{HOS}, the percentage of hatchery origin spawners). Captured fish were measured for fork length and qualitatively categorized as “new” if they appeared to have entered the river within the previous 2 weeks, “holding” if they appeared to have been in the river for more than 2 weeks, or “spawned out” if they appeared to have initiated or completed spawning. The tangle-net was designed to snare fish from the jaw not the gills in order to reduce encounter effects and also to eliminate the size and/or sex bias of captured fish. The net was approximately 18 m long and 3 m deep with loosely hung 10 cm stretch mesh.

We also used the in-stream netting data to determine a minimal threshold for SONAR measured targets to be included in the final escapement estimation by comparing the lengths of steelhead to bull trout, Chinook 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. p_{HOS} has been shown to vary significantly both temporally and spatially. To combat this, additional sampling has occurred since 2019 to correct for biases introduced in pre-2019 sampling that relied on significant sampling near the LEKT hatchery during the peak of the hatchery return. We sampled an additional 10 sites on 6 different dates upstream of the traditional species composition sites in order to better characterize variability in p_{HOS} 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. 2021 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. Although see discussion below for discussion about accounting for kelts (post spawn, downstream migrants).

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 920 mm (Fig. 6). Fourteen bull trout were captured during species composition sampling measuring between 370 mm and 780 mm, leading to overlap between the smallest steelhead and the largest bull trout. Based on this data, only SONAR targets recorded as 460 mm or greater were included in the final escapement analysis. This cutoff theoretically included all steelhead sized SONAR targets while including approximately 57% of the bull trout sized SONAR targets. We only used passage events of observer confidence level 1 in the final escapement analysis. Ten percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (304/3,304). Thirty-five percent of all downstream passage events were recorded as observer confidence level 2 (451/1,290).

Net sampling in 2021 indicated the presence of spawned out steelhead migrating back out to the ocean, also known as kelts. While the project has encountered spawned out steelhead in previous years, they have been few in number, mostly sampled after the end of the upstream migration, and in a condition of extreme deterioration that would make successful outmigration unlikely. In 2021, seven percent (5/73) of categorized steelhead sampled during the run from the species composition sites were categorized as “spawned”, with the first one being sampled on April 13. To account for downstream migrating steelhead that had already spawned we did not subtract downstream moving targets for any 24-hour period that had a net total downstream passage. This adjustment strikes a balance between accounting for kelts leaving the system that should not be subtracted from the total escapement estimate versus subtracting downstream passage events that are likely due to milling or spawning behavior in the vicinity of the SONAR site. This adjustment resulted in not subtracting (effectively adding) 128 fish to the final escapement estimate. Most of this kelt adjustment occurred in the HRC in May. Interestingly, kelts were captured during net sampling in the HRC, but not in the OM, thus providing field verification to the SONAR observations .

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 (572 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 2021 winter steelhead escapement only included SONAR targets recorded through June 8 based on findings of the species composition sampling. No “new” or “holding” winter steelhead were captured in our sampling after June 8. Two additional steelhead were captured at the species composition sites after June 8, both on June 17. Both were spawned out and of hatchery origin. In addition, one “new” Chinook was captured on both June 7 and June 8, with an additional “new” Chinook captured on June 17, indicating that most of the large bodied salmonids migrating past the SONAR sites after June 8 were likely 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:

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

where i represents the iteration (1 – 10,000), j indexes the 6-hour chunk (1 – 572) and k indexes the channel. The total number of fish, $N_{i,j,k}^{total}$, and total number of steelhead, $N_{i,j,k}^{steelhead}$, 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:

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

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. 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 16 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 two data gaps for the OM after initial deployment totaling 12 days. There were five data gaps totaling 20 days for the HRC after initial deployment. To fill in these gaps, 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.

Results

Between January 20 and June 8, 2021, 2,800 hours (120 days) of data were recorded on the HRC, and 3,000 hours (125 days) were recorded on the OM which represented 88% of the total possible hours in this year’s steelhead run. At least one of the channels was monitored for 98% of the run. During this time period, 4,485 fish passage events were recorded and analyzed. The best estimate for the steelhead escapement to the Elwha River in 2021 was 2,293 fish with a coefficient of variation (CV) of 4.8% (95% CI 2,074 – 2,523) (Tables 2 and 3). A total of 412 steelhead (7.0% CV, 95% CI 355 -465) went up the HRC, while the remaining 1,881 (4.6% CV, 95% CI 1,729 – 2,048) 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 (1.8%), (2) the observer error correction (1.4%), and (3) uncertainty associated with species composition (0.8%) (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 January 26 and caught four steelhead. Weekly species composition sampling through June indicated that winter steelhead ceased migrating past the SONAR sites by June 8. Twenty-five, 50 and 75% of the run had passed the SONAR sites on

March 20, April 7, and April 24, respectively (Figs. 11 and 12). Twenty-five, 50, and 75% of the run had passed the HRC by March 22, April 24, and May 12, respectively, and by March 19, April 4, and April 21 for the OM, respectively (Figs. 9 and 10).

In general, daily passage seemed to be independent of flow, but interestingly the period of highest passage, late April, occurred after a significant increase in flows following a long period of relatively low flow (Fig. 13). The hydrograph was variable over the course of the study, reaching a high of 3,000 cfs from snowmelt in late May and a sustained period of flows below 900 cfs through early April.

Sampling at the species composition sites and additional upstream sites captured 126 unique (non-recaps) winter run steelhead. Thirty-nine of these fish were adipose clipped (hatchery origin) while the other 87 were natural origin. There were significant differences in the pHOS both spatially and temporally (Table 4a and 4b). Most of the spatial variability in pHOS can be attributed to sampling in the lower river (pHOS 44%, 39/88) compared to sampling the middle and upper river (pHOS 0%, 0/38). Much different than 2019 and 2020, sampling among groups in the lower river was relatively similar in 2021 with pHOS ranging from 53% (8/15) in the hatchery channel (OM) to 29% (4/14) in the non-hatchery channel (HRC). PHOS also varied temporally, with natural origin fish comprising a greater proportion of the early portion of the run and hatchery origin fish dominating the later portion of the run (Table 4b). Using only fish captured before the channel split, as detailed in Peters et al. (in prep), the best estimate for pHOS for the entire run was between 32% and 65%. Assuming this represents an unbiased sample of the total run, approximately 803–1,506 of the 2,293 total returning steelhead were natural-origin recruits (NOR), while the remaining 733–1,490 were hatchery-origin recruits (HOR). Net sampling from lower river sites indicated a male:female sex ratio of approximately 0.8:1 (38 male, 49 female). The sex ratio of the middle and upper river sites was heavily skewed towards females at 0.15:1 (5 male, 33 female). Additionally, the sex ratio of NOR fish was dominated by females at .35:1 (21 male, 61 female) while it was close to equal for HOR fish (18 male, 19 female).

Discussion

Our estimate of 2,293 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 20 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, 4.3%), (2) observer error (CV 1.4%), and (3) correcting for species composition (CV 0.8%).

The largest source of uncertainty (CV 4.6%) was associated with filling the data gaps that occurred over the course of the study. Once each SONAR site was installed there were several small data gaps, but passage on both sides of them were similar which limits the uncertainty around filling those gaps. A relatively mild late winter/early spring storm season in 2021 enabled us to keep both SONARs in the water and recording for almost the entire run. It is important to note that, as in 2019 and 2020, fish passage was detected on the first day of installation for both channels, indicating that steelhead almost certainly moved passed the SONARs before installation. The gap filling procedure makes no attempt to account for fish that passed by before SONAR installation. Given that 19 and 23 steelhead passed by the HRC and OM SONARs, respectively, during the first week of operation, it is plausible that more than 100 steelhead passed by before installation that were not part of our ~2,300 fish estimate. Historically, winter steelhead entered the Elwha River in significant numbers throughout December and January and then entry slowed down during the month of February until the run built again in March and April (Dick Goin, personal communication, 7/16/05). While it is unlikely that the historical run timing of winter steelhead in the Elwha is still intact or will recover in the near future, it is worth noting that it is difficult to predict the number of fish entering the Elwha before SONAR installation based solely on passage shortly after installation. In 2021, the SONAR was installed the earliest of the 9 year history of the project (January 20) although most other weeks were within a week of this year's install date.

The second highest source of uncertainty was the observer error correction (CV 1.4%). The regression coefficient (.93) was close to a 1:1 relationship between technician and expert counts and the r^2 (.72) 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 0.8%). 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 bulk of fish passage were steelhead. Fourteen bull trout were captured during netting operations during the course of the steelhead run but eight of them were smaller than the smallest steelhead and one was a recap. Four of the five bull trout whose size overlapped with steelhead were captured on or before March 2, when only 13% of the steelhead run had passed the SONAR sites. Therefore, any species composition correction during this time period would have a relatively small impact on the overall steelhead run size and consequently the uncertainty associated with this adjustment. Interestingly, the largest bull trout captured, 780 mm on April 6, was by far the largest bull trout ever caught in the nine years of species composition netting and larger than ~90% of the steelhead sampled in 2021. Limited additional uncertainty from the species composition correction was introduced by the overlap between the end of the steelhead run and the beginning of the Chinook run. The last "new" or "holding" steelhead was captured on the same day as the first two Chinook, June 8.

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 2021 season. Moses et al. (in prep) observed 190 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 342 fish. When the hatchery collection of 81 fish is added (including 12 fish taken below the SONAR sites), the total of 423 fish only amounts to about 20% 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 2021 as in most other years. Secondly, survey effort was opportunistic, 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 uncounted 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, 2019, 2020). In previous years, the escapement estimate has varied from a low of 385 (2013) to a high of 1,985 (2020) while the proportion of natural origin (NOR) fish has ranged from a low of 13% (2015) to a high of 58-91% (2020) although pHOS estimate pre-2019 should be used with extreme caution (Table 5, Fig 14). Our escapement estimate of 2,293 steelhead this year marks the highest return of steelhead to the Elwha since the start of the SONAR project in 2013. The middle point estimate of NOR steelhead in 2021, 1,182 is the second highest on record (1,478, 2020).

Similar to 2019 and 2020, extensive effort was made this year to produce an unbiased estimate of the proportion of hatchery fish (HOR). Since 2019, we have attempted to sample over both a longer spatial distance (mouth of the river to former Lake Mills) and a longer temporal scale (late January/early February through end of June). In 2021, 31 sites were sampled and 126 steelhead were captured (an additional 6 fish were recaptured). It is important to note that the species composition sampling protocol from before 2019 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 2019-2021 are not advisable. This is particularly true of the 2015 data. 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.

The increased sampling from 2019-2021 has shown significant variability in the proportion of hatchery fish both temporally and spatially (Table 4a and 4b). As in previous years, HOR:NOR proportions were highest close to the LEKT hatchery facility that raises and releases winter timed steelhead (50%) and lowest at sites in the middle and upper river (0%). In the lower river HOR:NOR proportions were lowest in the channel that mostly bypasses the LEKT hatchery (29%). The HRC channel bypasses the LEKT hatchery facility and therefore would presumably not contain olfactory cues for HOR fish, although one small overflow channel connects the OM with the bottom 100m of the HRC. PHOS in sites throughout the lower river were actually much more similar this year as compared to 2019 and 2020 when ~70-80% of the fish captured near the LEKT hatchery were HOR but only ~15-30% were HOR below the channel split. This is the third year in a row that no HOR fish were captured in the middle or upper river (although there was very limited sampling in 2020). It is unclear why pHOS was far more

homogenous throughout the lower river in 2021 than in 2019 or 2020, but it could be linked to a higher return of HOR fish compressed into the same relatively limited area of the watershed as previous years as none were sampled in the middle or upper river. Temporal variability was also apparent in pHOS, with no HOR fish being sampled in January or February, and then HOR fish making up ~50% of the remainder of the run (Table 4a).

The date at which 50% of the run had passed the SONAR sites in 2021, April 7, was earlier than most other years except for 2019 and 2013 (Fig. 12). In 2013 very few native broodstock hatchery fish returned which are concentrated in late April. In general, the run timing of the Elwha steelhead appears to be slowly shifting earlier. The two outlier years from this trend, 2018 and 2020 had later SONAR install dates than all other years. If the SONAR had been installed a few weeks earlier on these years it is likely they would have recorded dozens if not a hundred fish moving passed in January which would have shifted the run timing earlier. Additionally, from 2014-2017 we did not detect the first fish moving passed the SONARs until a few days after installation. In every year since then we have detected multiple fish migrating immediately after install. While we provide run timing data for each channel, it is important to focus on the combined run timing of both channels taken together. As less flow enters the HRC in each successive year, the portion of the run where there is not enough flow to pass up the HRC increases, changing the run timing up that channel independently from the OM. The overall run timing of a specific year will be highly dependent on the proportion of hatchery fish in the run that year as hatchery fish return timing is concentrated later than NOR fish (Table 4b). Therefore, any attempt to track steelhead run timing through time needs to take annual variations in pHOS into account. Species composition netting indicated an end of the winter steelhead run (June 8) very similar to the 2014-2020 average of June 10. Net sampling occurred throughout June and July in conjunction with the Chinook project and only two additional steelhead were captured after June 8, both on June 17 and both spawned out hatchery fish.

The increased life history diversity of steelhead as evidenced by protracting run timing, resurgence of summer steelhead and the increasing number of kelts bodes well for recovery in the Elwha but does provide challenges to monitoring activities. While we miss some portion of the total run by installing the SONAR in late January (or even early February, as happened in 2020), low passage in the days immediately after installation for year's 2014-2018 gave us confidence that we were not missing many early fish. This year however, similar to 2019 and 2020, passage up both channels 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. 7/16/05). Finally, if net sampling continues to show an increase in the number of outmigrating kelts, more nuanced analytical procedures may be necessary to account for them.

Recommendations

It is becoming apparent that the run timing of winter steelhead in the Elwha is becoming more protracted, with migrating fish being detected immediately after SONAR installation. The project generally always installs the SONARs as early as possible in January/February so earlier installation is likely not possible. However, it is possible that a flow window would allow for some net sampling in early January even though the SONARs may not be installed. Therefore, even if the SONARs are not yet installed, we recommend net sampling at least once in early January.

We need to repeat the second of last year's recommendations in regards to increasing 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. Finally, 2022 will mark the end of the Park Service's ten year funding commitment to enumerate adult winter steelhead in the Elwha River, therefore alternative funding sources for the SONAR project need to be identified. It is clear that redd surveys are not a viable proxy for run size and that existing redd surveys only occur in the portion of the watershed occupied by NOR fish so would yield no information on the HOR run size. Any attempt to manage future harvest of steelhead on the Elwha River will require basic information on run size and HOR:NOR proportions.

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

Date	Steelhead	Chinook	Bulltrout	% Steelhead
1/11/2021	0	0	0	NA
1/19/2021	0	0	0	NA
1/26/2021	4	0	1	80%
2/2/2021	1	0	2	33%
2/9/2021	1	0	0	100%
2/16/2021	2	0	0	100%
2/24/2021	6	0	0	100%
3/2/2021	3	0	1	75%
3/10/2021	3	0	0	100%
3/16/2021	1	0	0	100%
3/22/2021	6	0	0	100%
3/30/2021	2	0	0	100%
4/6/2021	4	0	1	80%
4/13/2021	6	0	0	100%
4/21/2021	10	0	0	100%
4/27/2021	7	0	0	100%
5/4/2021	5	0	0	100%
5/11/2021	3	0	0	100%
5/25/2021	1	0	0	100%
6/8/2021	1	2	0	33%

Table 2. Channel specific and total estimates of steelhead passage on the Elwha River in 2021. 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	372	1,788	2,160
Species Composition	328	1,655	1,983
Observer Error	330	1,575	1,905
Gap Fill (Final)	412	1,881	2,293

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	1.6%	0.9%	0.8%
Observer Error	5.1%	1.3%	1.4%
Gap Fill	6.1%	4.2%	4.3%
Total	7.0%	4.6%	4.8%

Table 4a. Number and proportion of natural and hatchery origin steelhead in different sampling areas of the lower Elwha River in 2021. The river splits at RKM 0.5, with one channel passing by the LEKT hatchery facility (OM) that releases winter run steelhead and the other channel by-passing the facility, except for a small overflow channel that connects the two (HRC). Lower River includes an additional 21 steelhead that were captured in the lower river upstream of the two channel's reconnection (~RKM 5.0). Middle and Upper River refer to multiple sites spread throughout the middle river and former Lake Mills in the upper river.

Sites	Natural	Hatchery	% Hatchery
All	87	39	31%
Below Split	19	19	50%
HRC (non-hatchery channel)	10	4	29%
OM (hatchery channel)	8	7	47%
Lower River	49	39	44%
Middle and Upper River	38	0	0%

Table 4b. Number and proportion of natural and hatchery origin winter run steelhead caught by month in the lower Elwha River in 2021. This table includes all fish from table 4b except for the 38 NOR fish captured in the middle and upper river sites.

Month	Natural	Hatchery	% Hatchery
January	4	0	0%
February	8	0	0%
March	15	12	44%
April	15	19	56%
May	7	7	50%
June	0	1	100%

Table 5. 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 and 2020 which was based on a more robust sampling protocol intended to estimate %NOR fish. %NOR estimates prior to 2019 should be used with caution and likely do not accurately represent true NOR:HOR proportions.

Year	Estimate	95% CI	NOR	HOR	% NOR
2013	385	NA	NA	NA	NA
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%
2020	1,985	1,765 - 2,231	1,151 - 1,806	175 - 834	91 - 58%
2021	2,293	2,074 - 2,523	803 - 1,560	733 - 1,490	35 - 68%



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.

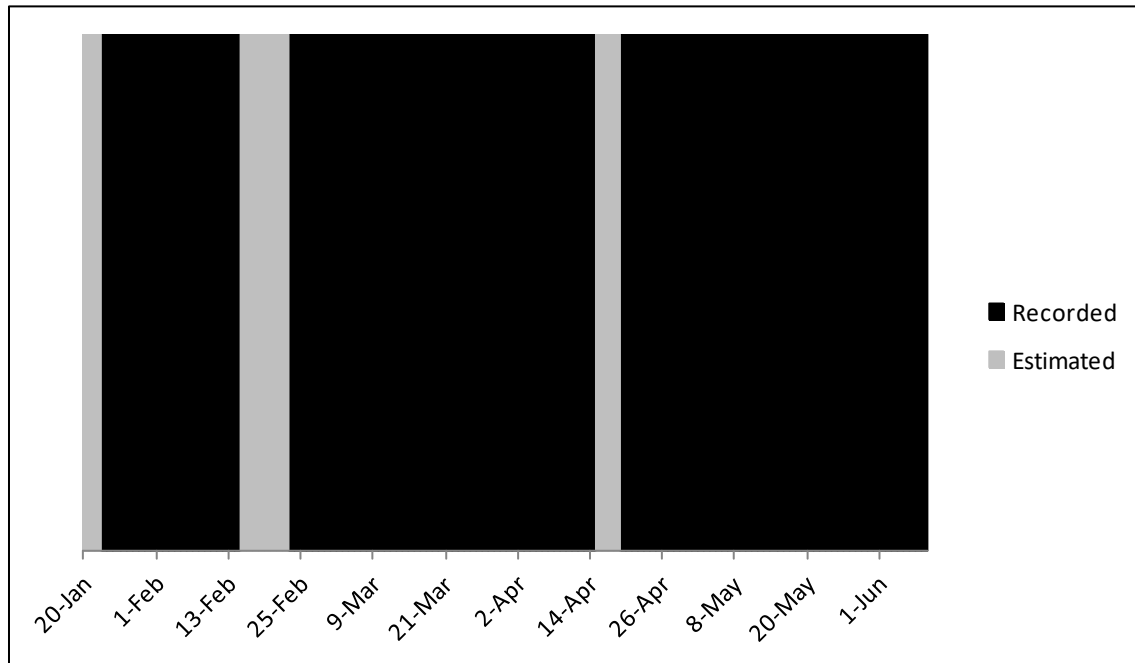


Figure 5a. Dates which had data recorded, black bars, or estimated, grey bars, for the Old Mainstem of the Elwha River in 2021.

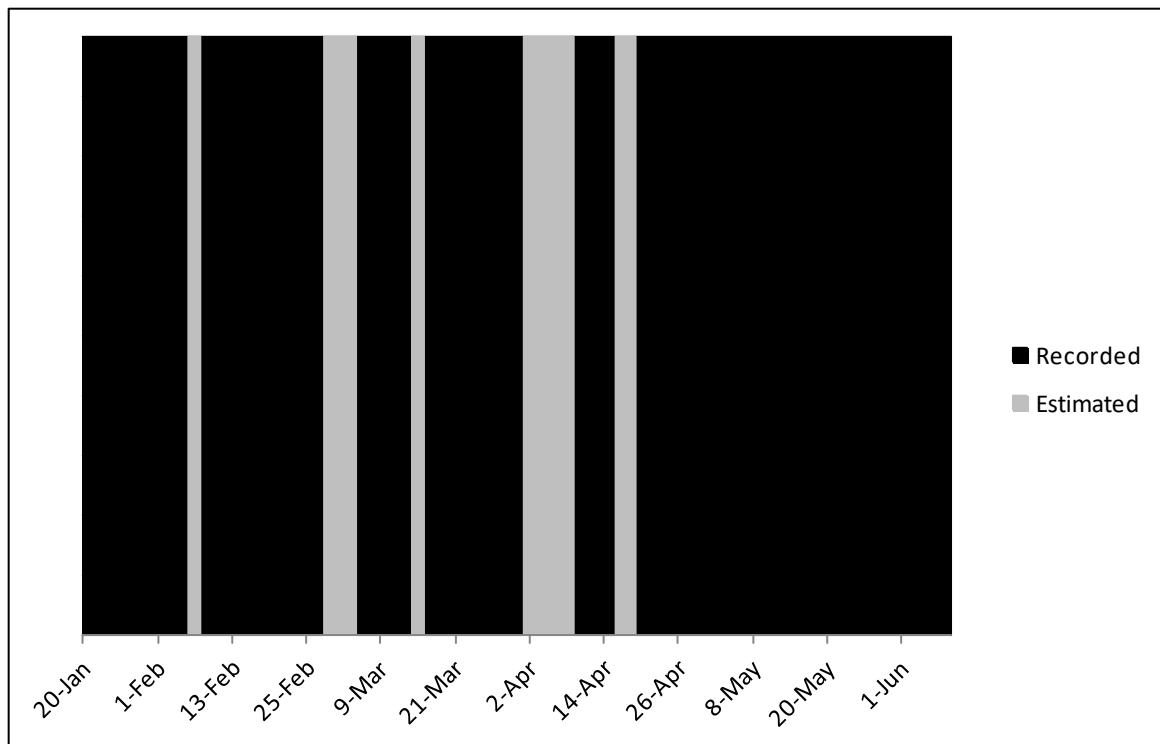


Figure 5b. Dates which had data recorded, black bars, or estimated, grey bars, for the Hunt Road Channel of the Elwha River in 2021.

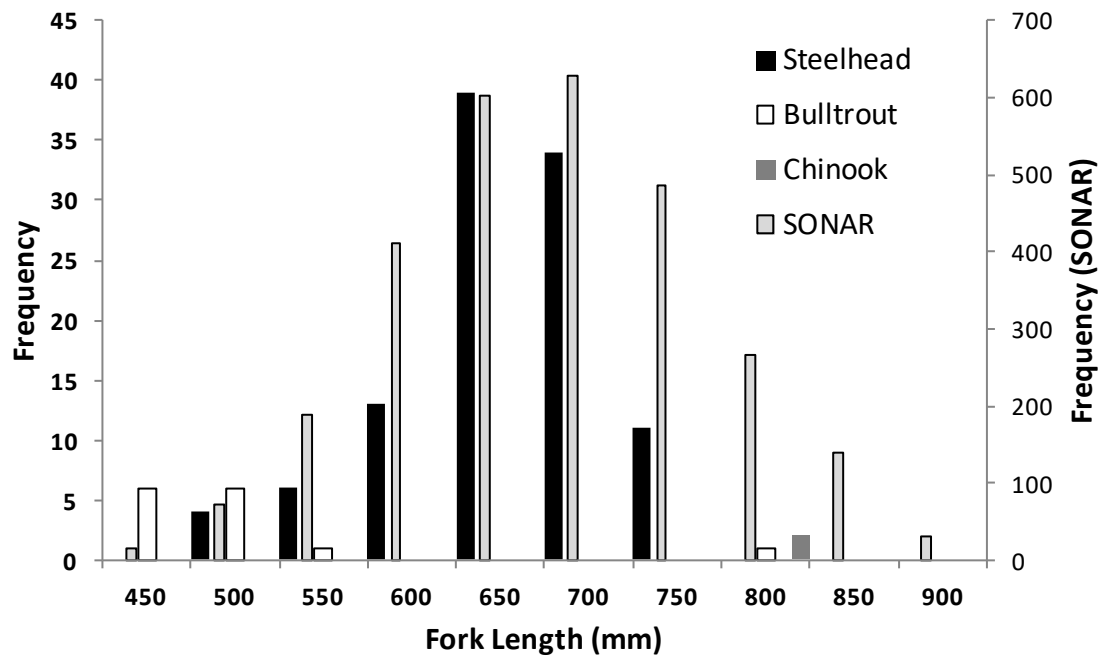


Figure 6. Length frequency histogram of all fish captured during netting operations at 30 locations in the Elwha River between January 19 and June 8, 2021 (left hand y-axis). Length frequency histogram of all SONAR measured targets of observer quality 1 (right hand y-axis). One Chinook was captured June 7 and another one was captured on June 8, 2021.

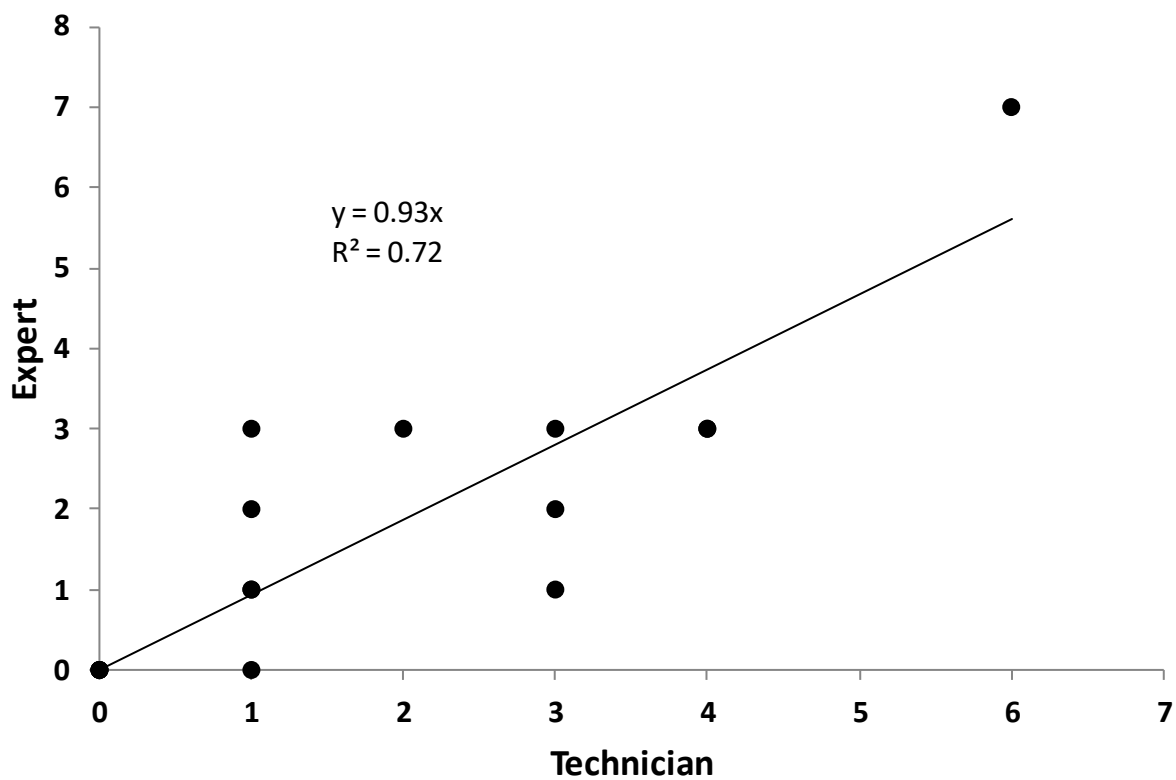


Figure 7. Total upstream passage counted by a technician and an expert for 16 six hour chunks. Point (0,0) has four data points and points (1,1) and (3,4) have two data points.

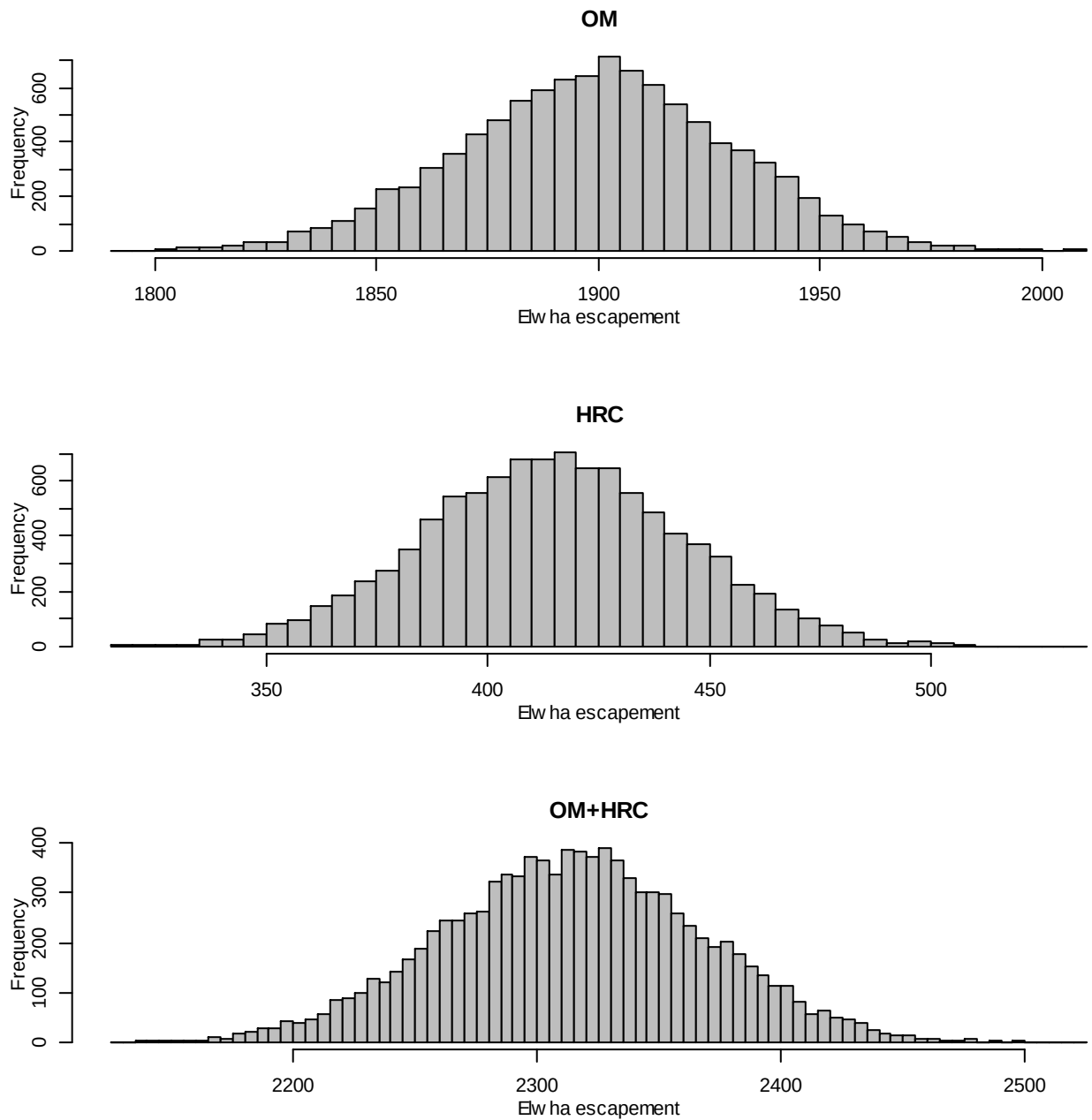


Figure 8. Run size frequency histograms for the steelhead in the Old Mainstem (OM), Hunt Road Channel (HRC) and combined run (OM + HRC) for the Elwha River in 2021.

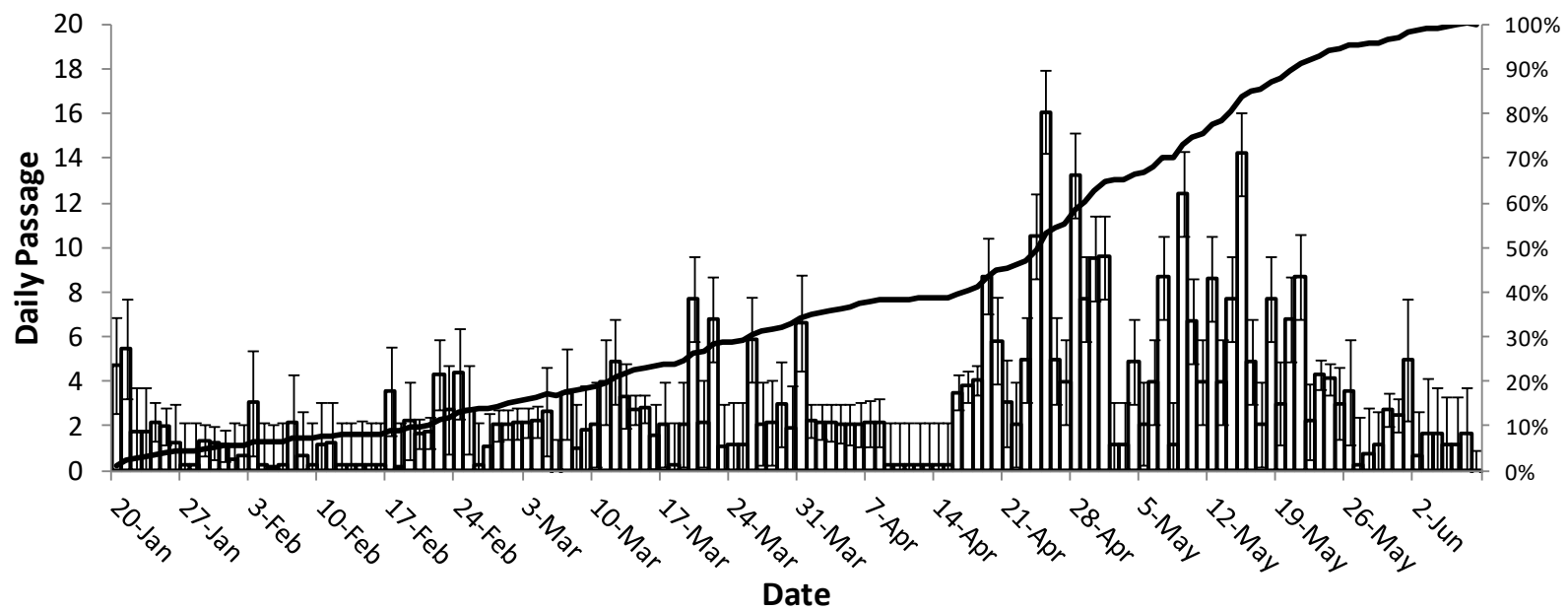


Figure 9. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Hunt Road Channel (or West Channel) of the Elwha River in 2021. Total passage for this channel was 412 steelhead.

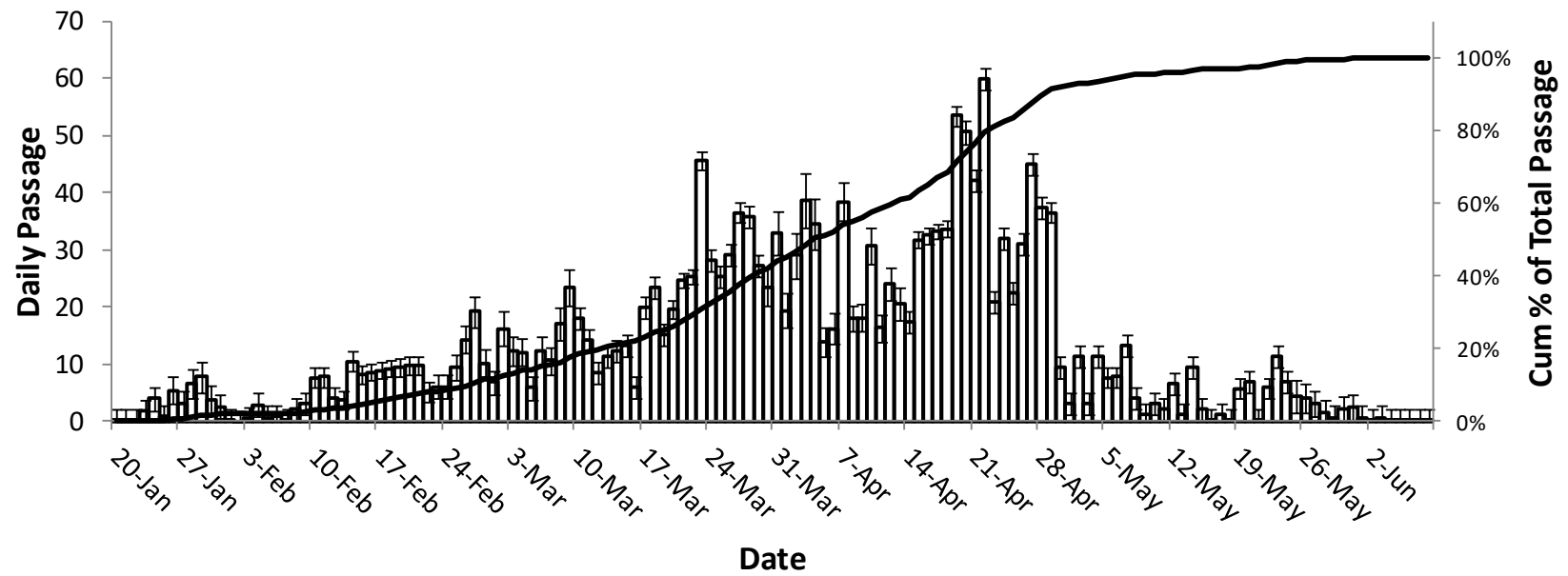


Figure 10. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Old Mainstem (or East Channel) of the Elwha River in 2021. Total passage for this channel was 1,881 steelhead.

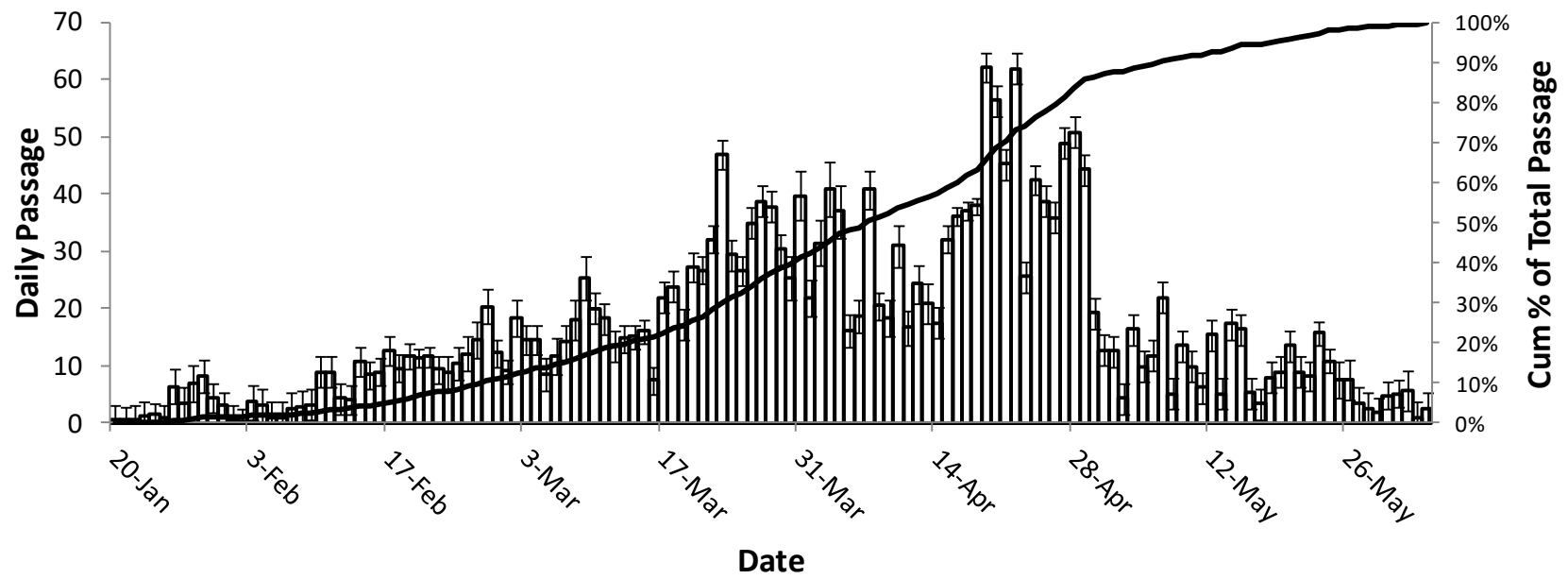


Figure 11. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for both channels the Elwha River in 2020. Total passage estimate was 2,293 steelhead.

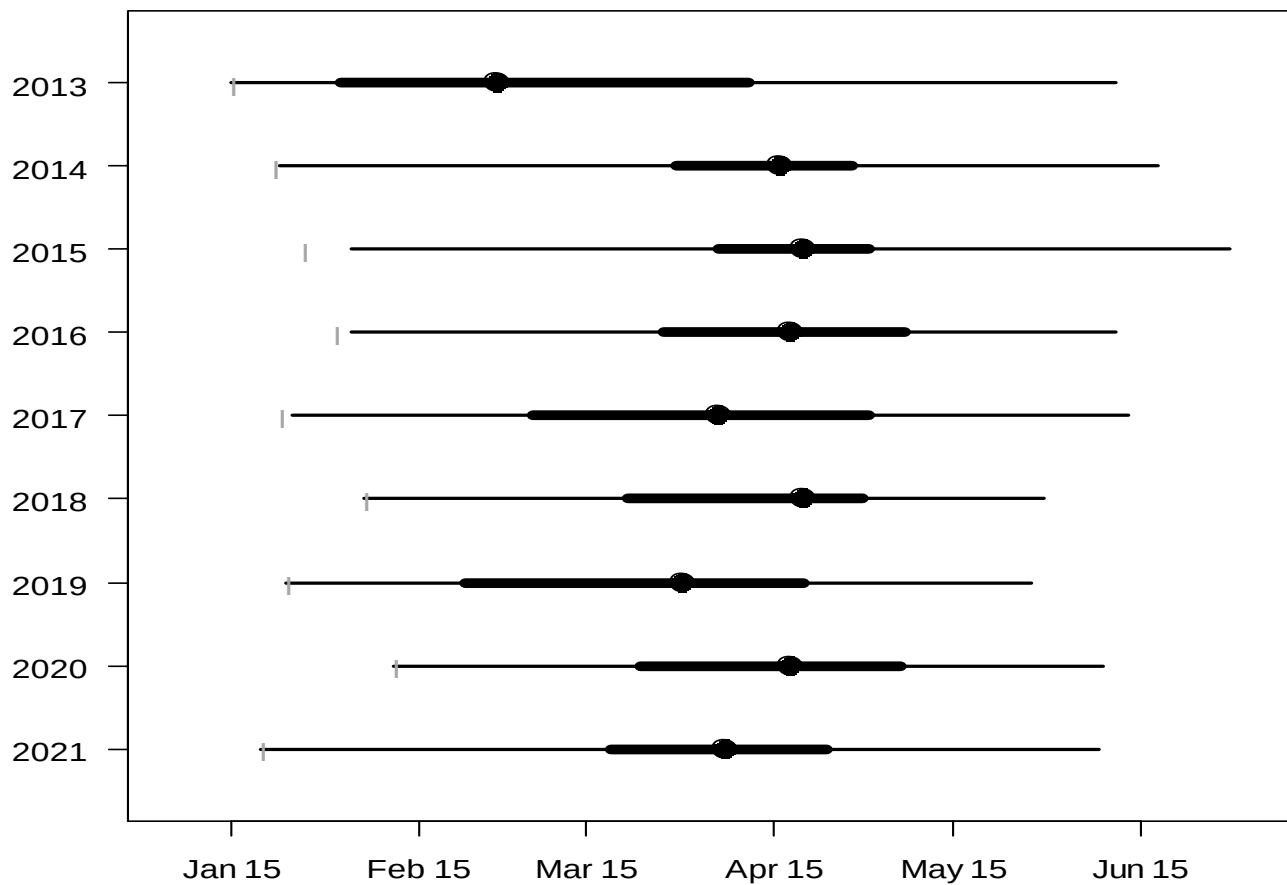


Figure 12. Run timing of steelhead in the Elwha River from 2013 to 2021. For each year the small vertical gray line shows the install date, the long thin black line encompasses the first fish detection until the end of the run. The thick black line shows the time period during which 25% to 75% of the run passed the SONAR sites. The black dot shows when 50% of the run had passed.

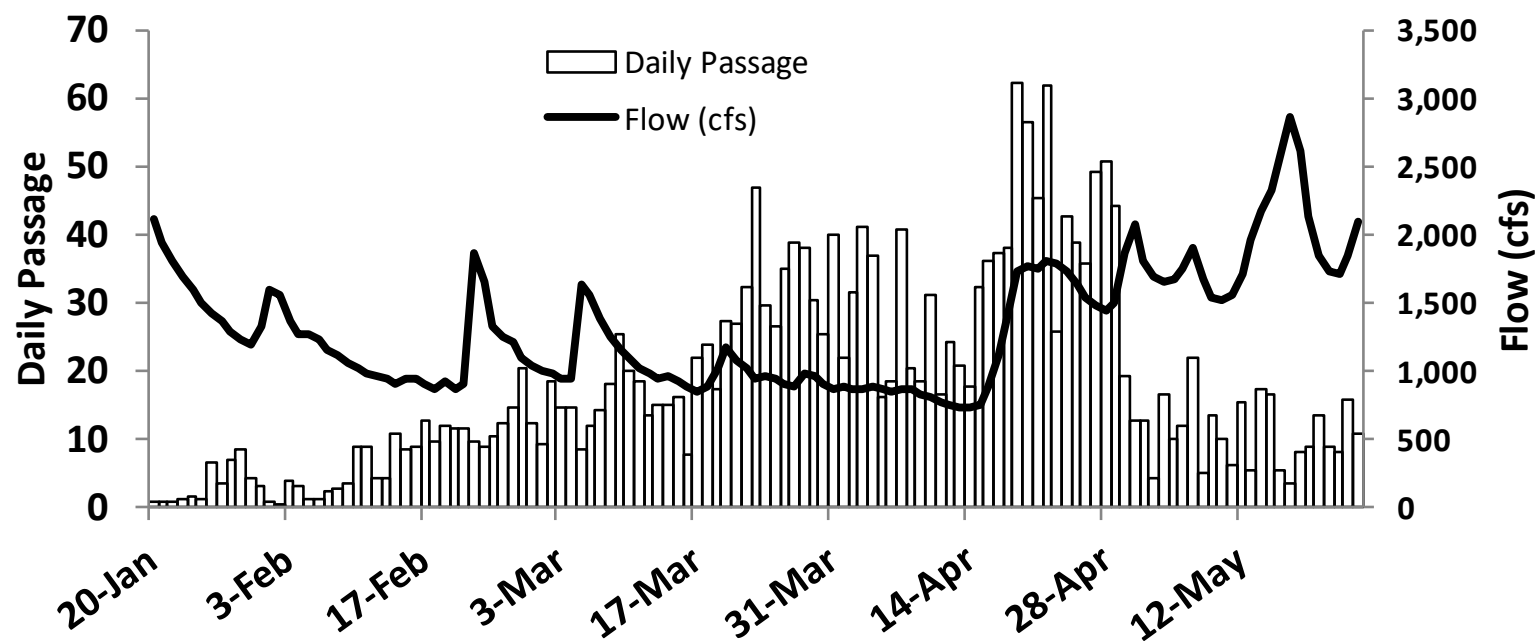


Figure 13. Daily passage of steelhead and flow (cfs) in the Elwha River in 2021.

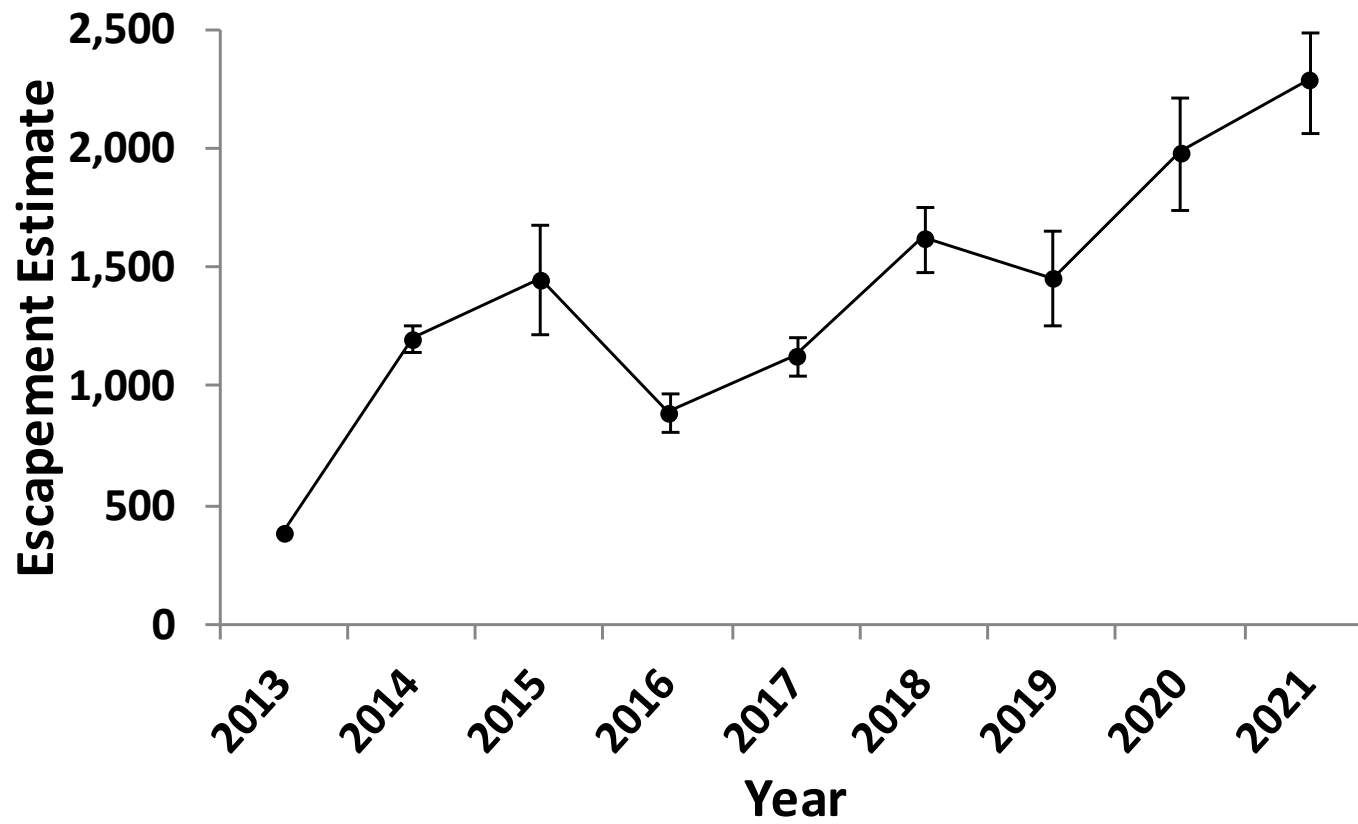


Figure 14. Yearly escapement estimates and 95% confidence intervals for steelhead in the Elwha River from 2013 through 2021. No confidence interval was calculated for 2013.