

2023 Elwha River Winter Steelhead Escapement Estimate Based on ARIS Multi-Beam SONAR Data

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Executive Summary

We used an ARIS 1800 multi-beam SONAR unit to monitor winter run steelhead escapement in the Elwha River by estimating daily passage from January 23, 2023, through June 7, 2023. Only one channel, the Old Mainstem or East Channel, was monitored this year as changes to channel morphology precluded significant flow and therefore fish passage up the Hunt Road Channel. We reviewed the imagery data 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 1,926 fish; with a coefficient of variation (CV) of 1.2% (95% CI 1,883 – 1,969). An additional 14 steelhead returned to the hatchery facility downstream of the SONAR site and another 8 steelhead were captured in the river at sites below the SONAR site and brought to the hatchery facility. Adding these 22 fish to our SONAR estimate yields a total escapement estimate of 1,948 steelhead. This is the fourth highest escapement of winter steelhead to the Elwha since the SONAR project began in 2013. This estimate also includes 170 kelts, or downstream migrating post spawn steelhead, which is the most recorded in the history of the project.

The Old Mainstem SONAR was installed on January 23, 2023. Fish were detected migrating past the SONAR site on the first day of operation and three winter steelhead were captured in net sampling in December 2022, six weeks before SONAR installation. Fifty-percent of the recorded steelhead passed the SONAR site by April 6, which was about a week earlier than the average 50% passage date for 2014-2022. Species composition netting in conjunction with additional upstream net and hook and line sampling indicated that 65% of the total run, or 1,268 fish, were of natural-origin (NOR) with the remaining 680 fish originating from the Lower Elwha Klallam native broodstock hatchery program (HOR). Hatchery and natural origin proportions exhibited significant spatial and temporal distribution differences: 96% (24/25) of the fish captured in the middle and upper river were NOR. In the whole lower river, 53% of fish captured (59/102) were NOR, while 65% of the fish captured below the channel split at RKM 1 were NOR. Temporal shifts in NOR:HOR proportions in the lower Elwha ranged from 14% (1/6) natural origin in January to 70% natural origin in April (23/33). The high proportion of HOR steelhead in January was driven by the capture of 5 HOR fish within 25 meters of the LEKT hatchery outfall which exhibited morphology characteristic consistent with resident trout.

Our recommendations for next year are similar to last year: perform net sampling throughout December and January even if the SONARs cannot be installed that early and to search for alternative sources of funding as the National Park Service's ten-year commitment to funding adult enumeration following dam removal expired 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 numerous commercial fisheries in Alaska (Westerman and Willette 2003; Dunbar and Pfisterer 2004; Dunbar 2001, 2003; McKinley 2002), and Canada (Levy et al. 1991, Cronkite et al. 2006). More recently, SONAR technology has greatly improved counting accuracy by incorporating multiple high frequency beams, producing "movie" quality images while also providing detailed data on several other fish characteristics including direction of travel, range, length, and swimming speed (Belcher et al. 2001, 2002). The main unit in use for fisheries applications today is the **D**ual-frequency **I**Dentification **S**ONar (DIDSON) and its newer version, the **A**daptive **R**esolution **I**magining **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 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 covers winter timed steelhead enumeration from late January through early June (see Denton et al., 2010-2022 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 was terminated (2010) and a native captive broodstock program was conducted between 2006-2011 with a goal of providing native steelhead to accelerate the recovery of steelhead following dam removal. Since 2011 the LEKT hatchery steelhead program has converted to a supplementation program producing on station smolt releases using a combination of HOR and NOR adults, although very few NOR adults had been incorporating in the program until 2019.

Additionally, monitoring efforts following dam removal, specifically utilizing snorkel surveys, have identified a growing summer steelhead run with adults being identified in the lower, middle and upper river during the summer months (Duda et al., 2021). 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 in 2005, well before dam removal. Summer steelhead generally migrate through the lower Elwha from June through October, outside the operational period covered in this report.

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. In the summer of 2022, another rockfall was discovered near the top of Rica Canyon (~RKM 27) that may be a seasonal barrier for some species (Conner, 2022).

Annual adult abundance estimates are critical for evaluating the success and rate of recolonization by 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 limited visibility and made the use of traditional enumeration methods (i.e. redd surveys) for specific species and time periods nearly impossible during peak sediment transport (Magirl et al. 2014). In addition, the removal of both dams provided 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. Finally, snowmelt during peak spawning periods can preclude the effectiveness of steelhead spawning ground surveys in the main stem Elwha River. Therefore, SONAR is the best technique for producing basin-wide escapement estimates for anadromous salmon and winter steelhead populations during and after dam removal.

Due to their ESA listing status of “threatened” and chronically low adult abundance prior to and immediately following dam removal, Elwha River steelhead recovery is important to multiple stakeholders including the LEKT and sport fishers, and is also a strong indicator of the health of the ecosystem as a whole (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, was maintaining in-stream infrastructure in a constantly shifting environment during dam removal operations. While sediment levels are now back to background levels (Ritchie et al. 2018), maintenance still routinely occurs on the SONAR. Second, due to highly variable streamflows during the steelhead migration, the SONAR sites require constant attention, 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). However, in 2023, due to multiple factors including stream channel changes and the effects of multiple engineered logjams (ELJ's), only one channel on the east side of the valley was hydrologically active during the steelhead migration season. The objectives of this study are to: 1) provide an estimate of winter run steelhead escapement to the Elwha River; 2) provide run timing distribution information; 3) incorporate and describe various sources of error in the winter steelhead 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), the Hunt Road Channel (HRC) and the Old Mainstem (OM), in the lower Elwha River have necessitated two separate SONAR installations to accurately detect steelhead passage up until 2022 (Fig. 1). However, in 2023, stream channel changes and the effects of numerous ELJ's consolidated almost all of the flow in the east channel or Old Mainstem (OM). Therefore, SONAR monitoring only occurred in the Old Mainstem in 2023. Flow data collected during the 2023 steelhead season between 1,500 cfs and 3,300 cfs, indicated that only ~4% of the total river flow was transported down the HRC. An ARIS 1800 (Sound Metrics, Bellevue, WA) was used to monitor the OM during the course of this study (1.1/1.8 Mhz, provided by the National Park Service – Olympic National Park). The SONAR was powered by a 24-volt, 200-amp hour battery bank that was continually charged by an array of solar panels.

SONAR 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; 4) fish movement was primarily directed upstream with little milling in the location of the SONAR; and 5) site bathymetry would deter fish from migrating within 3 meters of the SONAR head. Depending on stream flow, the OM site was 30-36 meters wide and 2.2 meters deep in the thalweg.

The 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 water surface with a downward angle of approximately 4-6° (Fig. 2). The goal of this placement was to ensonify the bottom of the river across the entire width of the channel in addition to clearly identifying

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

In previous years we have utilized a picket weir to move fish far enough in front of the SONAR units to accurately ensonify them. The new OM site has a shallow gravel bar gently sloping across to the thalweg on the far bank so the picket weir was deemed unnecessary. Data review also revealed no “fish shadows” moving close by the SONAR head indicating that fish were not moving too close to the SONAR to accurately detect.

Winter steelhead passage was recorded from January 23 through June 7, 2023. There was one data gap during this time period totaling 3 days (Fig 3). There were also several other short (< 8 hour) data gaps due to electrical issues at the site.

The SONAR was also in operation after June 7, 2023 to record Chinook and coho salmon passage. Data, analysis and an estimate of Chinook and coho passage for this time period are available in the project’s Chinook and coho reports (Denton et al., in prep). It should be noted that most summer steelhead migrate through the lower Elwha from June through October and this report does not attempt to enumerate that run timing of steelhead. See the projects Chinook report for more details on summer steelhead, whose run timing overlaps with Chinook (Denton et al., in prep)

Species Composition

We conducted twenty-six tangle net surveys between January 4 and June 12, 2023, 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, determine the end of the steelhead run, and to estimate hatchery:natural proportions (or pHOS, the percentage of hatchery origin spawners). Captured fish were measured to 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 snares fish from the jaw and not the gills in order to reduce negative encounter effects, and 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 salmon and SONAR measured fish (Fig 4). 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 and to describe spatial and temporal variability in pHOS. PHOS has been shown to vary significantly both temporally and spatially, with natural origin fish returning over a longer temporal period and also utilizing a larger portion of the watershed. 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. Additional sampling occurred in former Lake Mills and former Lake Aldwell on 8 different dates using both tangle nets and angling to better characterize variability in pHOS, and to provide a more accurate measure of the percentage of natural origin fish. Not all sites were sampled on all days. See Peters et al. 2022 for

methods, data, and analysis of this portion of the project.

Data Analysis

Post Processing

All ARIS data was processed using ARISfish proprietary software (V1.5). There were 24 one-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.

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 (cm) 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 were 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 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 137 steelhead captured during the study revealed that steelhead measured between 420 mm and 965 mm (the largest steelhead ever sampled by the project) (Fig. 4). Twenty-two bull trout were captured at the species composition sampling sites and measured between 420 mm and 540 mm, leading to overlap between the smallest steelhead and the largest bull trout. Based on this data, only SONAR targets recorded as 510 mm or greater were included in the final escapement analysis. This cutoff theoretically included ~97% of all steelhead sized SONAR targets (only 5 of 137 steelhead measured less than 510 mm and two of these were hatchery fish caught at the outlet of the hatchery in January that exhibited morphological characteristics of resident trout (see discussion for more info on these fish) while only including 30% (6/22) of the sampled bull trout. We only used passage events of observer confidence level 1 in the final escapement analysis. Less than one percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (3/3,271). Five percent of all downstream passage events were recorded as observer confidence level 2 (83/1,501).

Net sampling in 2023 indicated the presence of spawned out steelhead migrating back out to the ocean, known as kelts. In 2023, 40% (28/70) of categorized steelhead sampled during the run from the species composition sites were categorized as “spawned”, with the first one being sampled on February 22. This does not include five abnormal hatchery fish that were captured at the hatchery outflow on January 31 and were categorized as spawned out and exhibiting morphological characteristics consistent with resident trout. It is important to note that not all steelhead categorized as “spawned” were necessarily kelts, they could simply have been caught near their spawning site in a condition that would not be conducive to a successful migration back to sea. If we only consider fish sampled below the split (which is below the lowest steelhead spawning area), 30% (6 of 20) sampled fish were kelts. To account for downstream migrating steelhead that had already spawned we did not subtract downstream moving targets for any 24-hour period after February 22 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) 171 fish (~9% of the total run size) to the final escapement estimate.

Raw targets meeting the above criteria were then aggregated into 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 estimate. 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). We initialized the values in each cell (552 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 completed and then the 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 three 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 2023 winter steelhead escapement included SONAR targets recorded through June 7 based on findings of the species composition sampling. No “new” or “holding” winter steelhead were captured in our sampling after May 31. Seven additional steelhead were captured at the species composition sites after May 31 but before June 13, four on June 5, two on June 7 and one on June 12. All were spawned out and 5 of 7 were natural origin. One of the six steelhead sampled on May 31 was designated as “new” condition. Therefore, it was assumed that new entry of steelhead likely occurred beyond May 31 but also ended by June 13. To account for this, SONAR data was counted through June 7. Extending the end of the steelhead season an extra week past the capture of the last “new” steelhead sampled added 41 additional steelhead to the total passage estimate, 28 of which were added as a result of the kelt correction. One “new” Chinook was captured on June 7 and another one was sampled on June 13 indicating that most large bodied salmonids migrating passed the SONAR sites after June 7 were 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. We simulated the proportion of steelhead for a given iteration and day as:

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

where i represents the iteration (1 – 10,000) and j indexes the 6-hour chunk (1 – 552). The total number of fish, $N_{i,j}^{\text{total}}$, and total number of steelhead, $N_{i,j}^{\text{steelhead}}$, 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:

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

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 10 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. 5). A trend line was fit to the data with an intercept of 0 and then a vector of observer error residuals was generated. Each cell of the 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, after initial deployment, there was one data gap of three days and several of less than 8 hours. 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 23 and June 7, 2023, 3,096 hours (129 days) were recorded, which represented 98% of the total possible hours in this year’s steelhead run. During this time, 4,774 fish passage events were recorded and analyzed. The best estimate for steelhead passage upstream of the SONAR sites was 1,926 fish with a coefficient of variation (CV) of 1.2% (95% CI 1,883 – 1,969) (Tables 2 and 3). When the hatchery returns and broodstock removals below the SONAR sites of 22 fish were added to the SONAR estimate, the escapement estimate for the Elwha River in 2023 was 1,948 fish. In order of decreasing variance, the largest sources of error were (1) the observer error correction (0.9%), (2) uncertainty associated with species composition (0.8%), and (3) filling in data for missing time periods (0.2%) (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 passed the site on the first day of deployment. We initiated species composition sampling on January 4 but did not capture any steelhead until the third sampling event on January 31, although three “new” steelhead were captured during net sampling which occurred in December. Weekly species composition sampling through June indicated that winter steelhead ceased migrating past the SONAR sites on about June 7. Twenty-five, 50 and 75% of the run had passed the SONAR sites on March 5, April 6, and April 28, respectively (Figs. 7 and 8).

In general, daily passage seemed to be independent of flow (Fig. 9). The hydrograph was variable over the course of the study, reaching an instantaneous high of 4,330 cfs on May 17 but generally remaining below 2,000 cfs for the majority of the season with all of the high flow events except one occurring from snowmelt in May.

Sampling at the species composition sites and additional upstream sites captured 137 (7.1% of total run size) unique (non-recaps) winter run steelhead. Fifty-four of these fish were adipose clipped (hatchery origin) while the other 83 were natural origin. There were significant differences in 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 47%, 53/112) compared to sampling the middle and upper river (pHOS 4%, 1/25). There were fewer sites in the lower river in 2023 among which to compare spatially variability in pHOS because of the lack of water and therefore fish in the HRC. Nevertheless, pHOS below the split was lower (35% 9/26) as compared to all the samples in the lower river (46% 53/112). pHOS also varied by month with a low of 30% (3/10) in June to a high of ~85% in both January and May. Aside from January’s relatively high pHOS, the trend of more NOR fish early in the season with pHOS slowly increasing until May is consistent with previous years (Table 4b). Using only fish captured downstream of the channel split, the best estimate for pHOS for the entire run was 35%. Assuming this represents an unbiased sample of the total run, approximately 1,268 of the 1,948 total returning steelhead were natural-origin recruits (NOR), while the remaining 680 were hatchery-origin recruits (HOR).

Net sampling from lower river sites indicated a male:female sex ratio of approximately 1:1.5 (46 male, 67 female). The sex ratio of the middle and upper river sites was heavily skewed towards females at 1:2.4 (7 male, 17 female). Additionally, the sex ratio of NOR fish was dominated by females at 1:2.1 (26 male, 56 female) while it was equal for HOR fish (27 male, 27 female).

Discussion

Our estimate of 1,948 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 23 based on the observance of fish passage on the first day of recording at both sites and the capture of three steelhead in early December, daily passage at the beginning of the run was relatively small for the first week of operation (~50 fish). Additionally, the first

two net sampling events (January 3 and 23) did not encounter any steelhead. 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 stakeholders reliable information upon which to base management decisions. This uncertainty comes from three main sources, (1) the observer error correction (0.9%) (2) uncertainty associated with species composition (0.8%) and (3) filling in data for missing time periods (0.2%) (Table 3).

The highest source of uncertainty was the observer error correction (CV 0.9%). The regression coefficient indicated a 1:1 relationship between technician and expert counts and the r^2 (0.93) indicated a good fit of the regression. The project has employed the same technician for several years, resulting in reliable and accurate data review and consistently low CV's associated with this correction. While it is possible that some portions of the SONAR imagery at certain flows allow fish to pass through the site undetected by both observers, the observers agree closely on observable fish passage events.

The second source of uncertainty was associated with the species composition adjustment (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. Twenty-two bull trout were captured during netting operations throughout the steelhead run but 16 of them were smaller than the length cutoff of 510 mm. Of the six bull trout that were above 510 mm, three were captured in late May when few steelhead were migrating upstream thereby lowering the uncertainty associated with assigning SONAR targets to species during that time period (Table 1). The other three bull trout that measured over the length cutoff were spread throughout the steelhead run. The first Chinook salmon was sampled on June 7, the last day of the steelhead run. Therefore, in 2023, there was no overlap in the steelhead and Chinook runs.

The final and smallest source of uncertainty (CV 0.3%) was associated with filling the data gaps that occurred over the course of the study. Once the SONAR was installed there was only one data gap (3 days) and passage on both sides of it was similar which limits the uncertainty around filling those gaps. A relatively mild late winter/early spring storm season in 2023 enabled us to keep the SONAR in the water and recording for almost the entire run. Additionally, the new OM site enables SONAR installation in a very protected location just downstream of a large, engineered log jam, allowing for operations during higher flows than the old site. It is important to note that since 2019 fish passage has been detected on the first day of installation, 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 50 steelhead passed by the SONAR during the first week of operation, it is plausible that more than 100 steelhead passed by before installation that were not part of our 1,948 fish estimate. To add further context, net sampling occurred on two days in December of 2022 even though the SONAR was not yet installed. Three “new” steelhead were captured during these events indicating that fresh steelhead were entering the system in December, at least 6 weeks before SONAR installation. However, one of these three steelhead was radio tagged and this fish was detected leaving the system one week after capture, indicating that at least some of these

December fish were simply “dip-ins” on their way to other watersheds in Puget Sound. 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). These observations are further supported by sport catch records from 1961 to 1966 (a period of time prior to any hatchery releases) which indicate that ~42% of the run had entered the river by the end of January (PNPTC, WDFW, Makah, 1999). While it is unknown if 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 2023, the SONAR was installed roughly one week earlier than the average install date of the project (January 28).

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 2023 season. McHenry et al. (2023) observed 268 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 482 fish. When the hatchery collection of 22 fish is added (including 8 fish taken for broodstock from below the SONAR site) the total of 504 fish only amounts to about 29% 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 2023 as in most other years. Secondly, survey effort was opportunistic, not all areas were surveyed, and some surveyed areas were not visited consistently, particularly the mainstem. Taken together, there is a high likelihood that numerous redds were uncaptured during these surveys. Finally, spawning may be occurring in areas upstream of Geyser Valley which are seldom surveyed. This large area was surveyed by helicopter twice in 2023, with zero redds recorded on both flights. However, ground-based surveys in the former Mills reservoir that coincided with the second flight recorded numerous redds that were missed by the flight surveys (McHenry et al. 2023). So, a lack of observable redds from the helicopter flights should be used with caution.

We also put this year’s steelhead escapement estimate in context with the last ten years’ SONAR derived estimates (Denton et al. 2013 through 2022). In previous years, the escapement estimate has varied from a low of 385 (2013) to a high of 2,519 (2022) 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 estimates pre-2019 should be used with caution because the majority of sampled fish were captured within 1KM of the LEKT hatchery facility (Table 5). Our escapement estimate of 1,948 steelhead this year marks the fourth highest return of steelhead to the Elwha since the start of the SONAR project in 2013. The estimate of NOR steelhead in 2023, 1,268 is the third highest on record.

Similar to 2019 through 2022, extensive effort was made this year to produce an unbiased estimate of the proportion of hatchery fish (pHOS). 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 (December through June). In 2023, 137 steelhead were captured (an additional 6 fish were recaptured) ranging from RKM 1 to ~RKM 16. 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 2019-2022 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 2019-2023 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 in the lower river (47%) and lowest at sites in the middle and upper river (4%). For the first time since increased longitudinal sampling began in 2019, an HOR fish was captured in the middle river. It was a spawned out female captured in former lake Aldwell on March 29. Temporal variability was also apparent in pHOS but temporal trends were not as apparent as in previous years. In all previous years the early part of the run was dominated by NOR fish and then the proportion moved closer to 50:50 by May (Denton et al. 2022). In 2023, the month with the highest pHOS was January (86%, 6 of 7) and the lowest was March (30%, 10 of 33). The high pHOS in January was driven by five HOR fish that were captured within 25 meters of the of the LEKT hatchery outfall that produces steelhead. They were in spawning condition and resembled resident trout more than steelhead, with spots well below their lateral lines (Fig. 10a and 10b). It is not clear if these fish could have been escapees or releases from the captive brood program housed in the LEKT hatchery or if they had actually been to the ocean. These fish notwithstanding, it is important to note that two of the three “new” steelhead sampled in December were HOR and one HOR “new” steelhead was sampled on January 31. These samples would seem to indicate that in 2023, HOR steelhead were more temporally protracted than in previous years.

Male to female ratios followed a similar pattern to previous years whereas a higher proportion of the NOR fish (1:2.1) were female as compared to an even split for the HOR fish (1:1). In 2023 NOR fish showed a higher proportion of females in previous years although it has always been higher than 1:1.5. It is possible that some of this trend is driven by the likelihood that we are sampling some summer run steelhead, particularly in the upper watershed. Based on snorkel surveys in the upper river in September, the sex ratio of the summer run steelhead population is heavily skewed towards females.

The date at which 50% of the run had passed the SONAR sites in 2023, April 6, was earlier than all but three years 2019, 2017 and 2013 (Fig. 8). 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 2014-2018 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. It is interesting to note the approximate 50% entry date from the 1961-1964 catch record data was early February, two full months earlier than the current run timing (PNPTC, WDFW, Makah, 1999). 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 generally concentrated later than NOR fish although that trend seems weaker in 2023 (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 7) very similar to the 2014-2022 average of June 10. Net sampling occurred throughout June in conjunction with the Chinook project and seven additional steelhead were captured after June 7. All of them were spawned out except one which was deemed to be a summer steelhead.

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 was similar to 2019 through 2022 with passage evident soon after installation (Fig 7). If this trend continues, we may have to consider installing the SONAR earlier in January or even December, although high flows during that time of year would make it difficult and inconsistent on a year-to-year basis. Historically the most abundant portion of the run was thought to enter the river in December and January (Dick Goin, pers. comm. 7/16/05). Net sampling in December of 2022 revealed the presence of newly entered steelhead, confirming the passage of steelhead well before the installation of the SONAR. 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, or additional biological sampling, such as scale analysis to assess repeat spawner rates. The current method of removing all downstream migrants from any day with net negative passage accounted for 171 kelts this year, which amounts to ~9% of the total run size. Considering that the first kelt was detected during species composition sampling on February 24 (not counting the January HOR fish sampled within 25 meters of the LEKT hatchery outfall) and that 30% of the steelhead sampled below the split were categorized as "spawning" it seems likely that more than 171 kelts outmigrated passed the SONAR sites this year. This would lead to an underestimate of the final steelhead estimate since those kelts should not have been subtracted from the final estimate. Also, some portion of those 171 kelts were likely summer run fish, particularly in the early (February) downstream migrants, adding further uncertainty to their tabulation. In conclusion, it is important for managers to note that while our current escapement estimation techniques and official number are based on the best available data, there are compelling reasons to consider this estimate to be conservatively low based on the high probability that fish are migrating passed the SONARs before installation and some number of post-spawn downstream migrating kelts are being subtracted from the final estimate.

Recommendations

We are pleased to report that last year's recommendation of performing some net sampling in December and early January was accomplished and yielded important information. We recommend that this early season sampling continues.

The year 2023 marked the first year of operation after long term funding from the Park Service expired. While the Lower Elwha tribe was able to fund the project this year, a long-term funding need remains. It is clear that redd surveys are not a viable proxy for run size and that existing redd surveys mostly 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, Chinook and bull trout captured by date at ten species composition sites during in-river netting operations.

Date	Steelhead	Chinook	Bulltrout	% Steelhead
1/4/2023	0	0	0	NA
1/23/2023	0	0	0	NA
1/31/2023	2	0	1	NA
2/7/2023	2	0	0	100%
2/9/2023	2	0	0	100%
2/13/2023	3	0	0	100%
2/22/2023	3	0	0	100%
2/24/2023	3	0	0	100%
2/27/2023	6	0	0	NA
3/7/2023	6	0	1	86%
3/13/2023	1	0	0	100%
3/20/2023	1	0	0	100%
3/27/2023	1	0	0	100%
3/4/2023	3	0	0	100%
4/10/2023	0	0	0	NA
4/12/2023	4	0	0	100%
4/17/2023	3	0	0	100%
4/24/2023	1	0	1	50%
5/8/2023	0	0	0	NA
5/22/2023	0	0	0	NA
5/25/2023	1	0	1	50%
5/30/2023	1	0	1	50%
5/31/2023	1	0	1	50%
6/5/2023	0	0	0	NA
6/7/2023	0	1	1	0%
6/12/2023	0	1	0	0%

Table 2. Total estimates of steelhead passage on the Elwha River in 2023. Each step is an adjustment of the previous step, they are not stand-alone estimates. The number of kelts were estimated based on procedures described in the text and added to the gap filling estimate, plus the hatchery take, to arrive at a total run estimate.

Type of Count (Adjustment)	Estimate
Raw Passage	1,872
Species Composition	1,765
Observer Error	1,661
Gap Fill	1,755
Kelts	171
Hatchery Take	22
Total Escapement	1,948

Table 3. 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	CV
Species Comp	0.8%
Observer Error	0.9%
Gap Fill	0.2%
Total	1.2%

Table 4a. Number and proportion of natural and hatchery origin steelhead in different sampling areas of the Elwha River in 2023. 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 (HRC), except for a small overflow channel that connects the two. Lower River includes an additional 42 steelhead that were captured above the river split but below the former Elwha Dam. 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	83	54	39%
Below Split	17	9	35%
Lower River	59	53	47%
Middle and Upper River	24	1	4%

Table 4b. Number and proportion of natural and hatchery origin winter run steelhead caught by month in the lower Elwha River in 2022 and 2023. This table includes all fish from table 4a except for the 25 fish captured in the middle and upper river sites.

Month	Natural	Hatchery	% Hatchery
December (2022)	1	2	67%
January	1	6	86%
February	14	8	36%
March	23	10	30%
April	11	15	58%
May	2	10	83%
June	7	3	30%

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 through 2022 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	58% - 91%
2021	2,293	2,074 - 2,523	803 - 1,560	733 - 1,490	35 - 68%
2022	2,519	2,409 - 2,639	1,500 - 2,230	199 - 1,029	59 - 93%
2023	1,948	1,905 - 1,991	1,268	680	65%

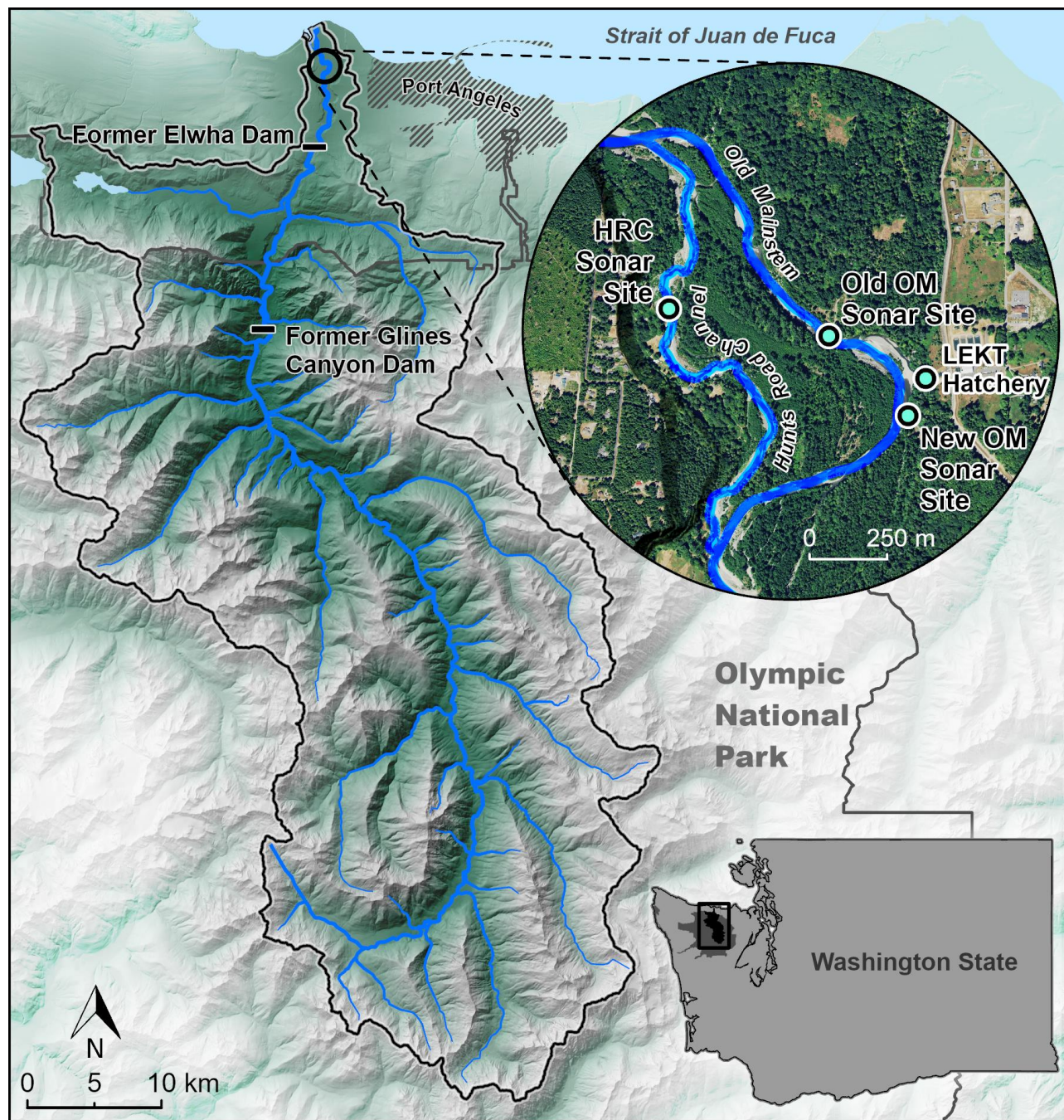


Figure 1. Map of the Elwha River, depicting the former dam sites, SONAR sites, Elwha Tribal Hatchery, and the two distinct migratory pathways that existed prior to 2022. Only the New OM SONAR site was operated in 2023.



Figure 2. Old Mainstem SONAR site looking upstream. The SONAR itself is attached to the pole mount which is in turn attached to the ladder. The solar panels and top side box are just out of sight on the logjam in the upper left hand corner of the picture.

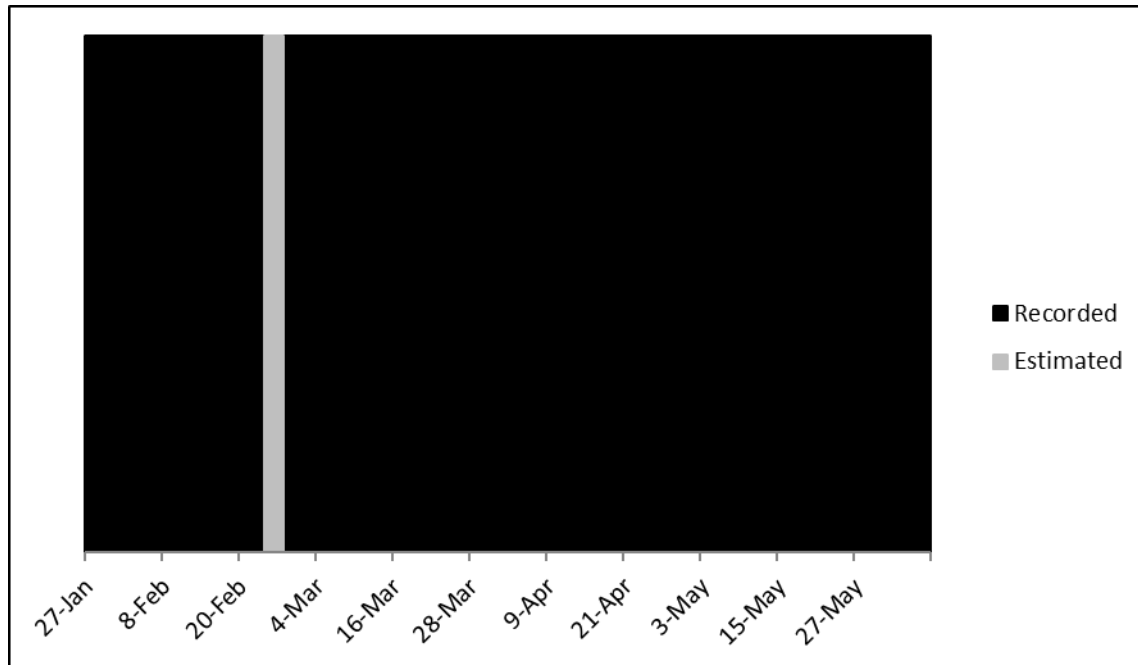


Figure 3. Dates which had data recorded, black bars, or estimated, grey bars, for the Old Mainstem of the Elwha River in 2023.

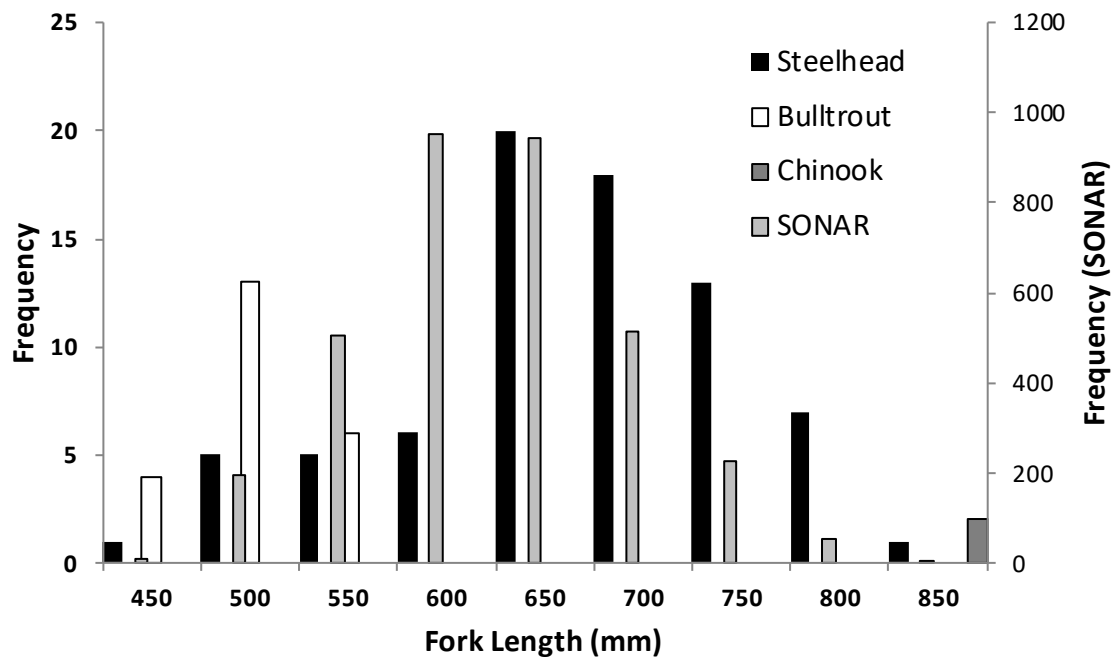


Figure 4. Length frequency histogram of all fish captured during netting operations at 10 locations in the Elwha River between January 31 and June 12, 2023 (left hand y-axis). Length frequency histogram of all SONAR measured targets of observer quality 1 counted during the same time span (right hand y-axis).

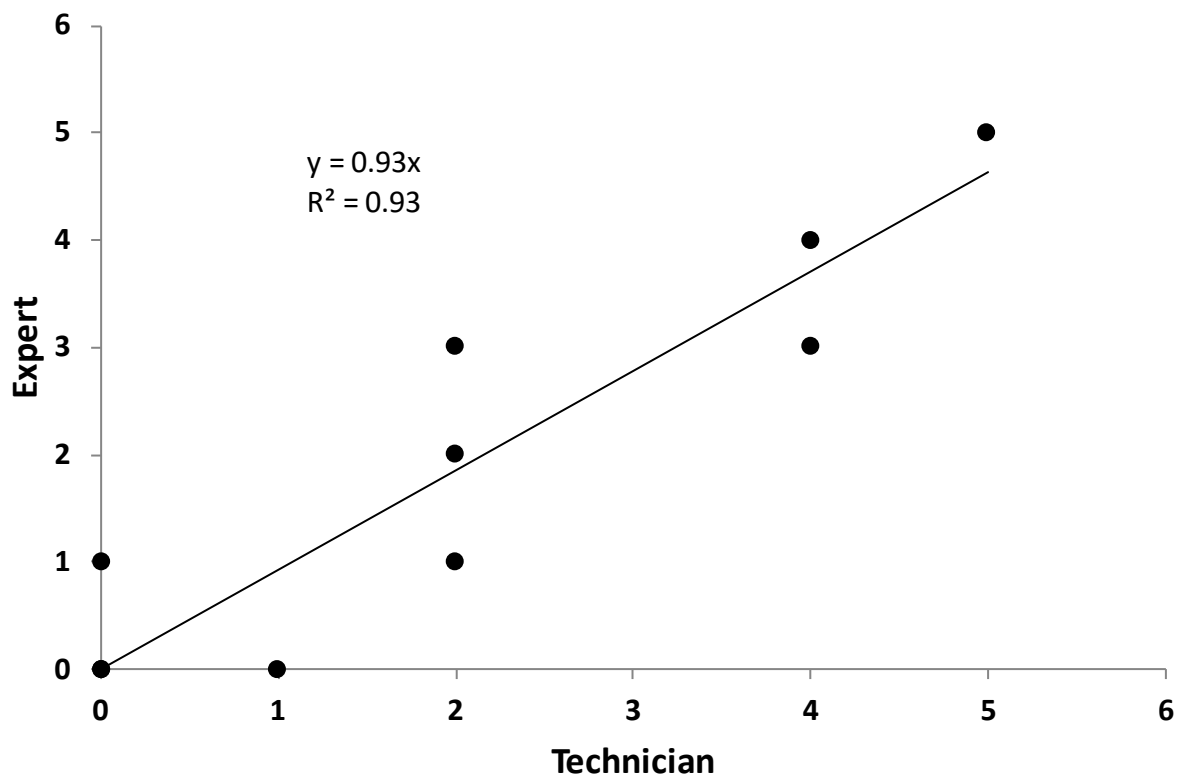


Figure 5. Total upstream passage counted by a technician and an expert for 10 six-hour chunks. Point (0,0) has two data points.

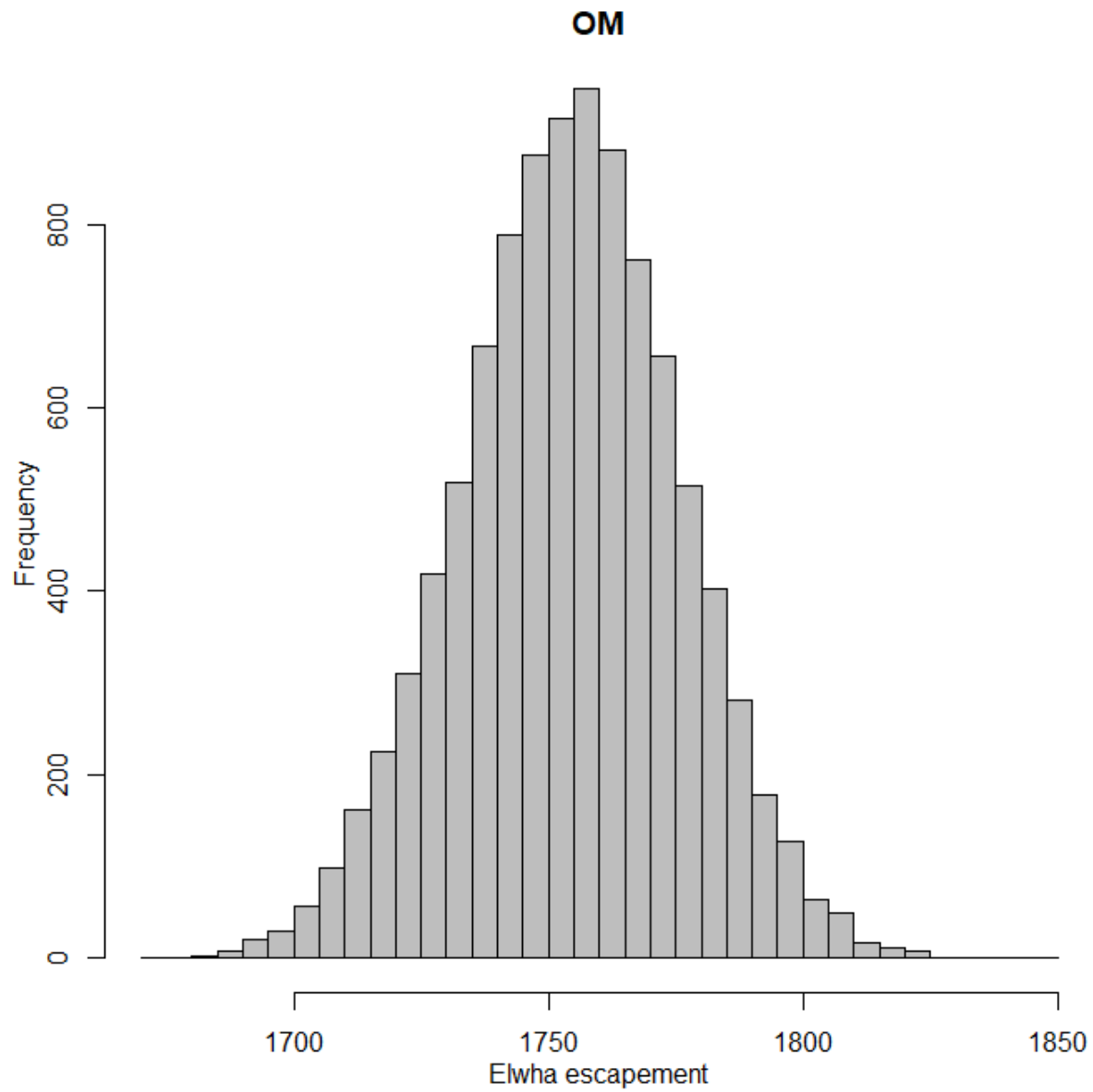


Figure 6. Run size frequency histogram for steelhead escapement to the Elwha River in 2023 based on 10,000 model runs. These model outputs do not include the estimated 170 kelts or 22 fish that were removed from the river for hatchery operations. These fish were subsequently added to produce the final escapement estimate of 1,948 fish.

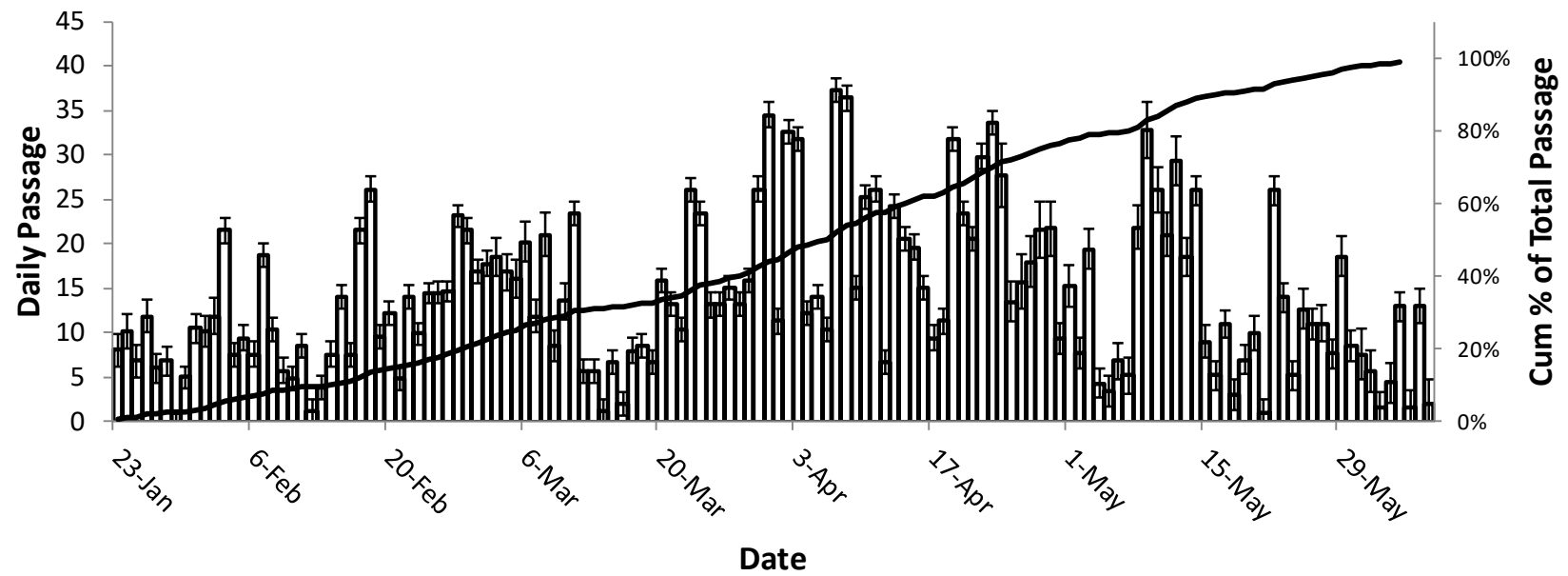


Figure 7. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Elwha River in 2022. The total escapement estimate was 1,948 steelhead which includes an additional 22 fish that returned to the hatchery or were removed for broodstock downstream of the SONAR site.

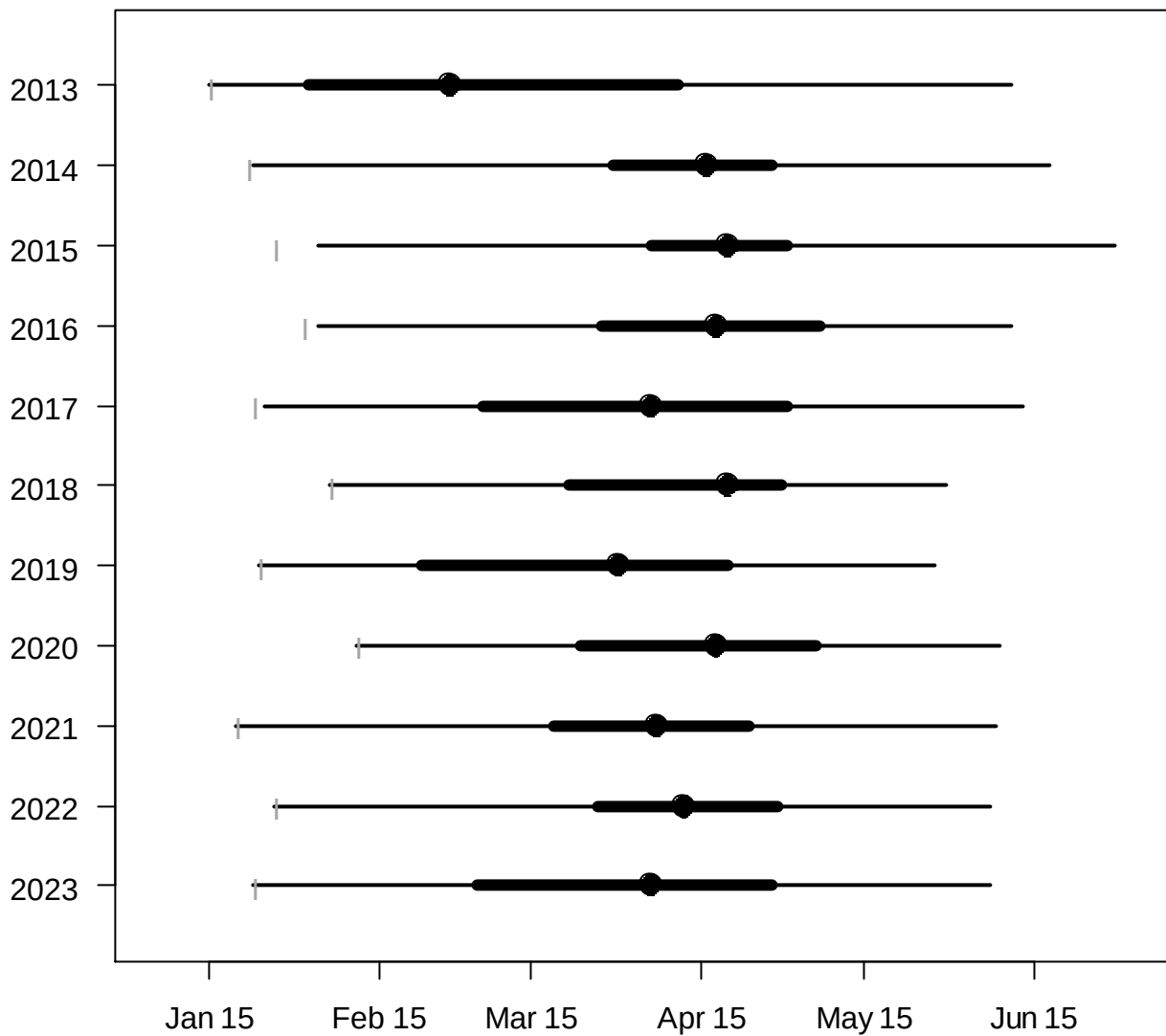


Figure 8. Run timing of steelhead in the Elwha River from 2013 to 2023. For each year the small vertical gray line shows the install date, the long thin black line encompasses the first fish detection until the end of the run. The thick black line shows the time period during which 25% to 75% of the run passed the SONAR sites. The black dot shows when 50% of the run had passed.

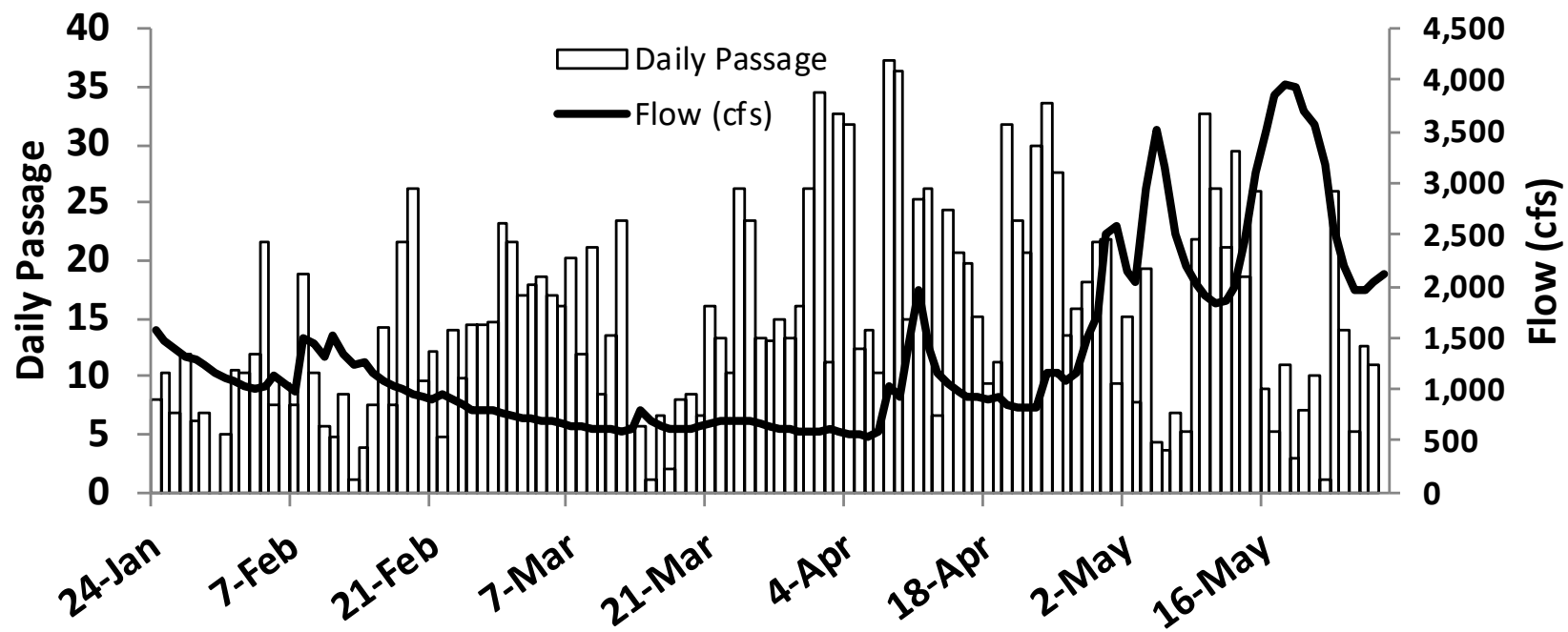


Figure 9. Daily passage of steelhead and mean daily flow (cfs) in the Elwha River in 2023.



Figure 10a. Female steelhead (FL = 470 mm) in spawning condition captured within 25 meters of the LEKT hatchery outfall on January 31, 2023.



Figure 10b. Male steelhead (FL = 580 mm) in spawning condition captured within 25 meters of the LEKT hatchery outfall on January 31, 2023.

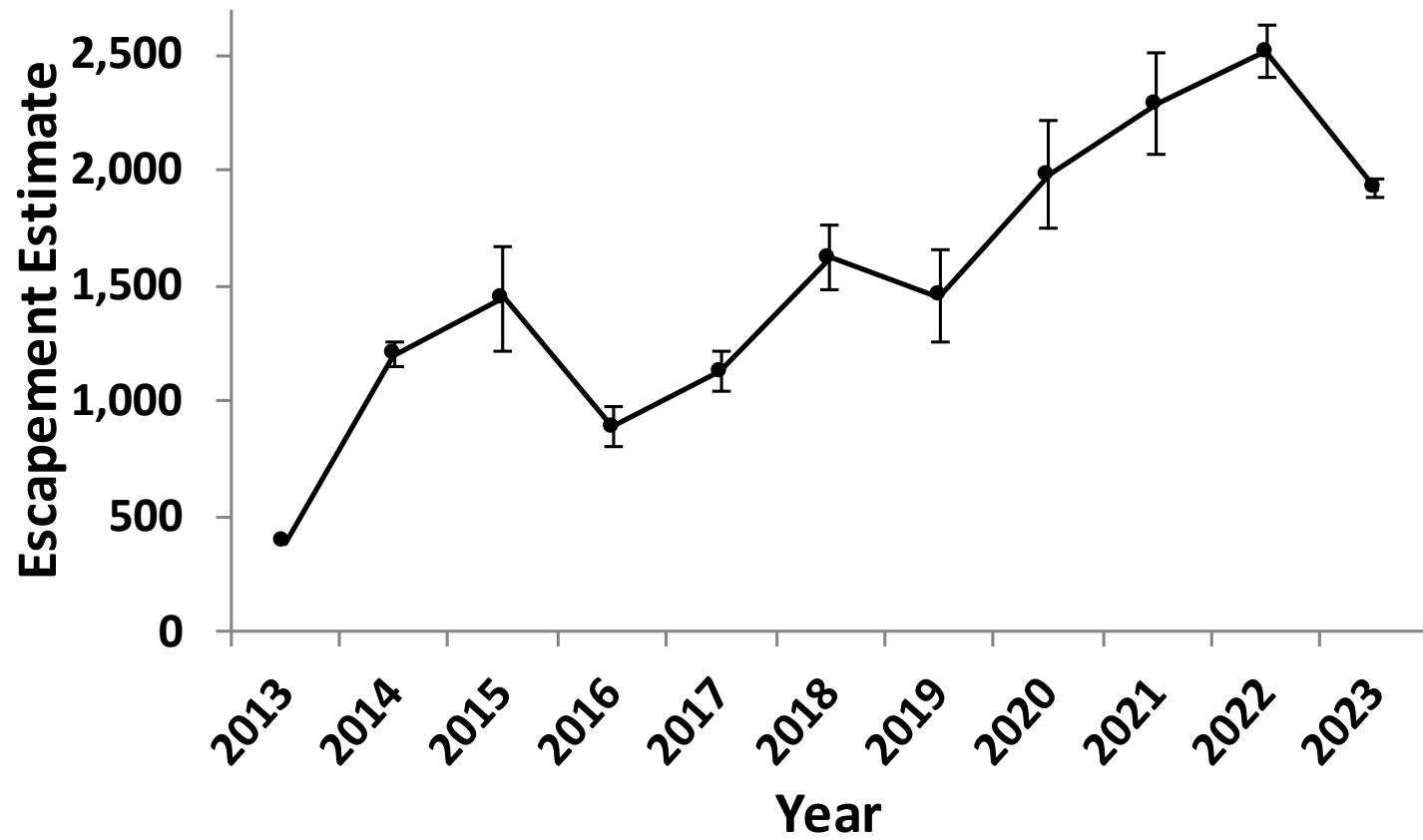


Figure 11. Yearly escapement estimates and 95% confidence intervals for steelhead in the Elwha River from 2013 through 2022. No confidence interval was calculated for 2013.