

2016 Elwha River 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 steelhead escapement in the Elwha River on a daily basis from February 1st, 2016 through June 10th, 2016. We reviewed each hour long file in its entirety then we adjusted these raw counts for species composition, observer error, and filling in data gaps. This process yielded a steelhead escapement estimate above the SONAR sites of 890 fish; with a coefficient of variation of 3.8% (95% CI 810 - 976).

We also provide channel specific estimates of passage for the Hunt Road Channel (HRC), 405 (6.2% CV, 95% CI 358 - 455) and the Old Mainstem (OM) 487 (4.6% CV, 95% CI 443 - 531). In addition to overall coefficients of variation (CV), we estimated individual CV's for all three sources of uncertainty: gap filling (3.2%), observer error (2.4%), and species composition (1.5%).

Fifty percent of the steelhead had passed the SONAR sites by April 15th, which was similar to the April 20th and April 16th dates in 2015 and 2014, respectively. Species composition netting indicated that approximately 36% of the total run, or 320 fish, were of natural origin with the remaining 570 originating from the Lower Elwha Klallam native broodstock program.

We improved our estimate over last year, as evidenced by the lower CV, by reducing data gaps and avoiding the need to subsample May and June data. Our major recommendation for next year is to determine whether to modify/add to the species composition protocol to produce a more unbiased estimate of the natural origin:hatchery origin ratio of the run.

Introduction

One of the most important pieces of information for salmon fisheries managers is an accurate count of adults returning to spawn in a river system, hereafter referred to as escapement. Multiple methods have been used to estimate escapements of adults, including aerial surveys, counting towers, weirs, redd surveys, mark recapture, and SONAR technology (reviewed by Cousens et al., 1982). Over the years, the technology and techniques involved has remained basically static for most of these methods except SONAR, whose technology and application to escapement estimation has rapidly evolved over the last few decades (Maxwell 2008).

Single beam SONAR systems have been used to enumerate fish migration in rivers since the early 1960's. Similar technology is still being used to measure escapement in a number of commercial fisheries in Alaska (Westerman and Willette 2003; Dunbar and Pfisterer 2004; Dunbar 2001, 2003; McKinley 2002), and Canada (Levy et al. 1991, Cronkite et al. 2006). More recently, sonar technology has greatly improved counting accuracy by incorporating multiple high frequency beams, producing "movie" quality images while also providing detailed data on several other fish characteristics including direction of travel, range, length, and swimming speed (Belcher et al. 2001, 2002). The main unit in use for fisheries applications today is the **D**ual-frequency **I**Dentification **S**ONar (DIDSON) and its newer version, the **A**daptive **R**esolution **I**maging **S**onar (ARIS).

Several studies have compared sonar counts of adult salmon derived from DIDSON imaging systems to other enumeration methods such as weir passage (Holmes et al. 2006), visual counts (Enzenhofer et al. 1998), and mark-recapture (Cronkite et al. 2006, Holmes et al. 2006). These studies have shown that SONAR counts were more accurate (insignificant error calculations) when compared to more traditional methods. It is important to note, however, that almost all of the fisheries applications of SONAR have been focused on large salmon runs that transpire over the course of only a few short weeks, which requires large technical staffs and operating budgets (eg. Lilja et al. 2008, Enzenhofer et al. 2010). In this study, we attempt to enumerate a small, protracted run of steelhead using multi-beam imaging SONAR.

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

with adults being identified in both the lower, middle and upper river during the summer months (Denton, unpublished data). This study does not attempt to enumerate that population.

The Elwha River, located on the north Olympic Peninsula in Washington State, provides a unique opportunity for fish enumeration using a multi-beam sonar system. Two dams had blocked fish passage to nearly 146 KM of main stem and tributary habitat since 1911, but removal of both dams began in September 2011 (Elwha River Fisheries and Ecosystem Restoration Act, 1992). The lower dam (Elwha) was completely removed by the spring of 2012. Large scale removal operations were completed at the upper dam (Glines) in August of 2014, but a subsequent rockfall in the fall of 2014 has continued to impede passage at that site although passage conditions appear to be improving.

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

Due to their ESA listing status of “threatened” and chronically low adult abundance, Elwha River steelhead are of great concern (Brenkman et al. 2008). Estimating adult steelhead returns on the Elwha River presents both a unique and common set of challenges. First, and unique to the Elwha River, is maintaining in-stream infrastructure in a constantly shifting environment due to the extreme sediment loads created by dam removal operations. Second, and applicable to many streams in the Pacific Northwest, is that due to highly variable streamflows during the steelhead migration upstream, the SONAR sites require constant maintenance, including removal and re-installation to avoid loss or damage to the equipment. Lastly, like other rivers in the PNW, the Elwha River mainstem is anastomosing, displaying a forested island morphology and providing 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 two different SONAR devices. The sediment loads and dynamic, multiple channels provide a unique opportunity to evaluate the performance of SONAR to estimate adult escapements and run timing, examine sources of estimation error, and increase our understanding of SONAR in future monitoring efforts. To that end, the objectives of this study are to: 1) provide an estimate of 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 2016 (Fig. 1). The primary enumeration site was located in the Old Mainstem (OM) while a secondary site was located in the Hunt Road Channel (HRC). Both sites were located at approximately RKM 0.8. While current data does not exist on the proportion of flow down each channel, at most flow levels approximately 30% of the flow is transported down the HRC, with the remaining 70% traveling down the OM (Personal communication, Mike McHenry 2016). These flow proportions are roughly the opposite of what they were in previous years due mostly to changing wood loads associated with a series of engineered log jams at the head of the channel split. 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 18 and 22 m across and 1.3 meters in the thalweg, while the OM site was 18-25 meters wide and 2 meters in the thalweg.

Each SONAR was attached to a pole mount (Enzenhofer and Cronkite 2005) that was mounted on a reinforced ladder. The SONAR and ladder were positioned just under the surface of the water with a downward angle of approximately 4-6° (Fig. 2). The goal of this placement was to ensonify the bottom of the river across the entire width of the channel in addition to clearly identify the far bank (see Enzenhofer 2010 for details on aiming the beam).

We constructed a weir approximately three meters downstream of the DIDSON that extended from the bank to 5 m beyond the SONAR (Fig. 3). This weir directed fish to an area of the channel more effectively covered by the sonar beams, producing greatly improved imagery and minimizing the possibility of fish passing directly underneath the beam and avoiding detection.

The HRC site was connected to line power, which ensured a constant power supply. The OM site was powered by a 24-volt, 200 amp hour battery bank that was continually charged by an array of solar panels. A weir was also constructed at the OM site to direct upstream passage of adult fish (Fig 4).

Steelhead passage was recorded at the OM site from February 1st through June 10th, 2016. There were three data gaps during this time period: February 13th to February 21st, March 1st to March 7th, and March 11th to March 13th. (Fig 5a). Steelhead passage was recorded at the HRC site from February 9th through June 10th. There were six gaps during this time period: February 13th through

February 21st, February 27th to February 28th, March 4th to March 13th, March 19th to March 20th, May 13th to May 15th, and May 28th through May 30th (Fig 5b).

The SONARs were also in operation after June 10th, 2016 to record Chinook salmon passage. Data, analysis, and an estimate of Chinook passage for this time period is available in the project's Chinook report (Denton et al., in prep.)

Species Composition

We conducted fourteen tangle net surveys between February 10th and June 10th to capture live adult salmonids at nine different sites in the lower five kilometers of the river. We did this to differentiate species of salmonids over the course of the run timing and to determine the end of the steelhead run. Captured fish were measured for fork length and qualitatively categorized as “new” if they appeared to have entered the river within the previous 2 weeks, “holding” if they appeared to have been in the river for more than 2 weeks, or “spawned out” if they appeared to have already spawned. In previous year's we only included “new” and “holding” fish in the species composition analysis. Due to much lower numbers of captured fish in 2016 as compared to previous years, we were forced to also include “spawned out” fish this year (Table 1). Nine of 27 (33%) of the steelhead captured during species composition analysis were classified as spawned out. The tangle-net was designed to snare fish from the jaw not the gills in order to reduce encounter effects. The net was approximately 30 m long and 2 m deep with loosely hung, variable mesh sizes from 15 cm to 19 cm.

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 and bull trout (Fig. 6). Additionally, species composition data was used to determine the sex ratio of steelhead.

Finally, we categorized captured steelhead as hatchery or natural origin by checking for coded wire tags (CWT), the presence or absence of an adipose fin, and the condition of their dorsal and pectoral fins. During the course of this study, concurrent tangle net sampling was performed by Olympic National Park staff upstream of the species composition sampling sites. Data from this sampling was used to inform natural/hatchery origin proportions and sex ratio, but was not used for species composition adjustments.

Data Analysis

Post Processing

All DIDSON data was processed using DIDSON proprietary software (V5.25.26). The entire hour of each file was reviewed. Raw data was transformed in a four step process that enabled empty periods of time to be efficiently reviewed, while still highlighting fish passage events for closer inspection. Files were background subtracted, using the default parameters, to remove rocks and make it easier to discern moving objects, such as migrating fish. Subsequently, each file was transformed into an echogram using the default parameters, with the exception that all 96 beams were included rather than

only the center beam. This dramatically increases the probability that any fish entering the ensonified area will be detected in the echogram.

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

The procedure for processing ARIS data was the same (background subtraction, echogram formation, manual review of likely targets), except ARIS data is processed with its own software, ARISFish (v.1.5).

After determining that a pattern on the echogram was indeed a fish, we noted several variables, including the date, time, direction (upstream or downstream), distance from SONAR head, length (mm) and observer confidence. Length was measured in centimeters using software specific procedures. The final characteristic was a qualitative value. The reviewer recorded a 1 if they were extremely confident that the target was indeed a fish passing in the specified direction or a 2 if they are somewhat confident that the target was a fish passing in the specified direction.

Escapement Estimation and Uncertainty Tabulation

Basic fish passage is tabulated by simply subtracting downstream passage events from upstream passage events (Xie et al. 2005):

$$N = U - D$$

Where N is the net upstream movement of fish for a given period of time, U is the sum of upstream fish for that time period and D is the sum of downstream moving fish for that time period.

In order to sum the upstream and downstream passage events for each hour long file, we first had to determine which passage events to include in our analysis, namely the minimum length threshold and which observer confidence categories. A length frequency histogram of the in-stream netting data revealed that steelhead were between 500 mm and 920 mm (Fig. 5). However, only 3.6% of measured steelhead (1/28) were smaller than 550 mm and only 9.5% of bulltrout (2/21) were larger than 550 mm. Therefore, only fish recorded as 550 mm or greater were included in the final escapement analysis. We only used passage events of observer confidence level 1 in the final escapement analysis. One percent of all upstream passage events that met the length criteria were recorded as observer confidence level 2 (25/1,836). Thirteen percent of all downstream passage events were recorded as observer confidence level 2 (148/1,104).

Raw targets meeting the above criteria were then aggregated into channel specific six-hour chunks, four per day. Each channel specific six hour chunk was then pushed through a three step adjustment simulation to determine the final escapement. This simulation used collected data to correct raw counts for the three major adjustments that make up the total escapement estimate: 1) down weighting the raw counts to reflect the proportion of SONAR targets that were steelhead; 2) adjusting the steelhead counts to account for observer error; and 3) filling in passage data for gaps in the corrected steelhead data.

We used a simulation based approach and replicated this simulation procedure a large number of times (10,000) for each channel individually. We initialized the values in each cell (532 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 2016 steelhead escapement only included SONAR targets recorded through June 10th based on findings of the species composition sampling. No steelhead, spawned out or otherwise, were captured in the watershed after June 10th. In addition, one fresh Chinook salmon was captured on June 14th and an additional four were captured during the June 22nd sampling event, indicating that most, if not all, of the large bodied salmon migrating past the SONAR sites after June 10th 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:

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

where i represents the iteration (1 – 10,000), j indexes the 6-hour chunk (1 – 628) and k indexes the channel. The total number of fish, $N_{i,j,k}^{\text{total}}$, and total number of steelhead $N_{i,j,k}^{\text{steelhead}}$ were available on a daily basis, so the four six-hour chunks from each day were assumed to have the same species composition.

We then adjusted each of the raw counts for the proportion that were steelhead as a random draw from a Binomial distribution:

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

where X is the number of steelhead and total number of fish for each six-hour chunk.

The CV for escapement for this step was calculated by performing the correction directly on the net passage data as opposed to the expanded data used by the simulation. Then the counts of all 6-hour chunks were summed for each iteration, yielding 10,000 estimates. Finally, the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates.

Observer Error

It is generally recommended to account for the possibility of observer error in SONAR counts (Holmes et al. 2006). We quantified observation error by comparing counts for 13 six hour chunks between the primary technician and a more experienced, “expert” counter. Six hour total passage counts by the expert counter were considered to be a measure of “actual” passage and were compared to the technicians “predicted” counts (Fig. 7). A trend line was fitted to the data with an intercept of 0 and then a vector of observer error residuals was generated. Each cell of the steelhead matrix was then adjusted by multiplying it by the coefficient from the regression trend line and adding a random residual.

The CV for escapement for this step was calculated by performing the correction directly on the net passage data as opposed to the expanded data used by the simulation. Then the counts of each 6-hour chunks were summed for each iteration, yielding 10,000 estimates. Then the standard deviation of all 10,000 estimates was divided by the mean of all 10,000 estimates.

Filling Data Gaps

As stated above, there were three data gaps, totaling 19 days, in the OM during the course of this study. In addition, there were six data gaps in the HRC during the course of the study. The period of time from when the OM was initially installed (February 1st) to when the HRC was installed (February 9th) is also considered a data gap that required estimating passage. Therefore, there were a total of 36 missing days of data for the HRC during the course of this study.

A number of different approaches could be used to fill in missing counts, including borrowing data from the neighboring channel or assuming return timing to follow some distribution (normal, double half-normal, etc). We used a generalized additive modeling (GAM) approach to fill in missing values, because this approach also allowed us to include uncertainty estimates (gam in the ‘mgcv’ package in R). We fit a spline over time (days), which allowed both a flexible shape of return timing, and uncertainty to increase as the spline became further away from data. For each iteration of the simulation, we first fit the GAM to fill in the data gaps, then for each day drew a random number from a normal distribution centered on the fitted value estimated from the GAM, with corresponding standard

error. This approach ignores autocorrelation in missing values, but also represents upper bounds of uncertainty estimates.

Results

Between February 1st and June 10th 2016, 2,055 hours (86 days) of data were recorded on the HRC, and 2,543 hours (106 days) were recorded on the OM which represented 73% of the total possible hours (6,288) in this year's steelhead run. At least one of the channels was monitored for 2,760 hours out of a total of 3,144 hours, or 88% of the total possible hours. During this time period 2,769 fish passage events were recorded and analyzed. The best estimate for the steelhead escapement to the Elwha River in 2016 is 820 fish with a coefficient of variation (CV) of 3.5% (95% CI 748 –890) (Tables 2 and 3). A total of 367 or 45% (CV 4.4%, 95% CI 325 - 409) steelhead went up the HRC, while the remaining 453 or 55% (CV 5.9%, 95% CI 416 – 489) steelhead went up the OM (Figure 8). In order of decreasing variance, the largest sources of error were (1) filling in data for missing time periods (3.0%), (2) the observer error correction (2.0%), and (3) uncertainty associated with species composition (1.5%) (Table 3).

The nature of the SONAR data in combination with in-stream species composition netting provides detailed information on run timing. We initiated species composition sampling on February 10th, but did not capture a steelhead until four sampling events later, March 23rd. Weekly species composition sampling through June indicated that steelhead ceased migrating past the SONAR sites by June 10th. Twenty five, 50 and 75% of the run had passed the SONAR sites on March 27th, April 15th, and May 6th, respectively (Figs. 10 and 12). Twenty five, 50, and 75% of the run had passed the HRC by March 28th, April 16th, and May 8th, respectively, and by March 27th, April 19th, and May 5th for the OM, respectively (Figs. 9 and 10).

Daily passage was also plotted against flow and turbidity (Figs. 13 and 14). The hydrograph was variable over the course of the study reaching a high of 5,890 cfs on February 16th and a low of 1,570 cfs on the May 25th. In general, daily passage seemed to be independent of flow or turbidity, although a relative spike in flow on April 21st seemed to coincide with an increase in passage rate to its highest rate of the entire study over the following week. It should be noted that the hydrograph in 2016 was relatively flat, as the typically spring runoff of late-May through June never materialized.

Finally, species composition netting revealed that 36% of captured fish were of natural origin (10/28). Assuming this represents an unbiased sample of the total run (although see discussion on this point), approximately 320 of the 890 total returning steelhead were natural origin recruits (NOR), while the remaining 570 were hatchery origin recruits (HOR). Additionally, differences in the proportion of natural to hatchery origin fish were seen depending on where they were captured in the watershed. Twenty-nine percent of the fish captured below the LEKT hatchery were of natural origin, 50% of the fish captured between the LEKT hatchery and the former Elwha dam site were of natural origin, and 100% of the fish captured in the middle river were of natural origin, although only one fish was captured upstream of the former Elwha dam site (Table 4). Additionally, species composition sampling indicated a male:female sex ratio of 0.86:1.0 (12 male, 14 female, sex could not be determined on one fish).

Discussion

Our estimate of 890 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. While it is likely some steelhead moved past the SONAR sites before installation on February 1st, few fish were recorded immediately after installation suggesting that few fish went uncounted. Species composition netting throughout the month of 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 four main sources, (1) filling in gaps for missing time periods (CV, 3.0%), (2) observer error (CV 2.0%), and (3) correcting for species composition (CV 1.5%).

The largest source of uncertainty (CV 3.0%) was associated with filling the multiple data gaps that occurred during the course of the study. This is due to the need to estimate 27% of the total possible hours during the course of the run. Fortunately, most of the passage gaps occurred almost entirely in March when there was minimal steelhead passage and only added 146 fish or 16% to the total passage estimate (Table 2). We were also able to reduce the CV associated with the portion of the estimate from last year by installing the HRC site within a week of installing the OM site, thereby reducing the need to fill in a large one sided data gap. Unfortunately, collecting passage data with relatively fragile and expensive in-stream equipment in a Pacific Northwest river during late winter through spring will inevitably require removing the equipment during periods of high flow in order to protect the long term viability of the project. This situation is exacerbated in the Elwha River as it responds to recent dam removal activities with increased woody debris and sediment loads. Thus, data gaps, sometimes lengthy, during steelhead season are inevitable. That being said, we had far fewer data gaps than in previous years (Denton et al. 2013, 2014, 2015).

The second highest source of uncertainty was the observer error correction (CV 2.0%). The regression coefficient (.95) was only marginally different from a 1:1 relationship between technician and expert counts and the r^2 (.75) indicated a good fit of the regression. The project has employed the same technician for several years, resulting in reliable and accurate data review.

The final, and smallest source of uncertainty was associated with the species composition (CV 1.5%). The low level of uncertainty associated with this source can largely be attributed to the continued implementation of 2014's recommendation to sample for species composition at least bi-weekly throughout the season and weekly during periods when multiple species are known to be in the river. The low level of uncertainty can also be attributed to high proportion (90%) of steelhead caught (27/30) which greatly reduced the uncertainty of the binomial draw. However, it should be noted that far fewer fish were captured this year (30) as compared to last year (253) or even 2014 (54). This resulted in some periods of the species composition correction model only inputting one total fish and one total steelhead (Table 1). Capturing just one bull trout during one of these periods would have had a relatively large impact on both the species composition correction and the uncertainty associated with it.

Although there is no other independent estimate of steelhead escapement on the Elwha, our estimate can be put into context with redd surveys conducted in several tributaries in the middle river as well as the mainstem during the 2016 season. McMillan et al. (2016) observed a total of 152 steelhead redds from the river mouth up to the former Lake Mills reservoir. Using redd to fish multiplier of 1.8, gives a redd based estimate of 274 fish, or about one third of the SONAR base escapement. This disagreement is not unexpected for multiple main reasons. First, due to visibility issues, only one main stem survey was conducted and not until late May, potentially missing redds from early in the season. Secondly, while survey effort was extensive, not all areas were surveyed and some surveyed areas were not visited frequently. Third, 43% of the recorded redds were located within 2 km of the LEKT hatchery. This dense cluster of redds was likely difficult to accurately count and contained high levels of superimposition where early redds were disguised under redds constructed later in the season. Fourth, it appears as though passage has become relatively easier at the former Glines Canyon Dam as compared to previous years, based on a lack of redd clusters at the base of the former dam. This highlights the possibility that steelhead may now be spawning in the upper ~60 km of river that is not surveyed. Finally, 42 adult steelhead returned to the LEKT hatchery 35 of which were transplanted elsewhere in the watershed. All of these fish would have been counted by the OM SONAR, which operated approximately 500 meters downstream of the hatchery outfall. Thirty three of these fish were relocated upstream of the beaver pond in the upper reaches of Indian Creek, but no redds were observed in that portion of the creek (McMillan et al. 2016). Presumably, some portion of these fish did not successfully create redds, and therefore were not enumerated with redd counts (Table 5).

This year's steelhead escapement estimate can also be put in context of the last three years' SONAR derived estimate (Denton et al. 2013, 2014, and 2015). The best estimate for steelhead escapement in the Elwha for 2013, 2014, and 2015 was 385, 1,200, and 1,440 fish respectively. 2014 was the first year of hatchery returns from the LEKT native broodstock program so the 2013 estimate would not include any of those fish. Assuming all of the 2013 fish were of natural origin, and using natural/hatchery ratios from the species composition sampling, the four year population trend for natural origin fish would be 385, 400, 190, and 320 fish for 2013, 2014, 2015, and 2016 respectively. The hatchery origin population trend would be 0, 800, 1,260, and 570 fish for 2013, 2014, 2015, and 2016 respectively (Table 6).

It is important to note that the species composition sampling protocol was not designed to provide an unbiased sample of natural vs. hatchery origin ratios, so these numbers should be used with caution (see recommendations below). That being said, overall catch rates were more similar between channels this year than last year, indicating that the species composition sampling was not as biased for HOR fish as it was in 2015. In 2016, ten steelhead were caught in the HRC and eleven steelhead were caught in the OM. By contrast, in 2015, 17 steelhead were caught in the HRC and 154 were captured in the OM.

The date at which 50% of the run had passed the SONAR sites in 2016, April 17th, was similar to the estimates from 2014 and 2015 of April 16th and April 20th, respectively, but a full month and a half later than the 2013 estimate of February 27th. The dates at which 50% of the run had passed up the OM and HRC in 2016 were similar, April 19th and April 16th, respectively. This differs from the last year,

where the HRC channel reached its 50% passage date 2.5 weeks earlier than the OM. One possible explanation for this difference is it's correlation with the difference in ratio of NOR:HOR steelhead in the system in 2016 (36%) vs. 2015 (13%).

Recommendations

We did not have to implement 2015's recommendation to move the OM site downstream to avoid milling fish in late April and May. Due to this year's lower return numbers, particularly for HOR steelhead homing to the nearby LEKT hatchery, milling fish in front of the OM SONAR was never a problem. This also made analyzing the data much more efficient and accurate as we did not have to contend with multiple fish in the ensonified area simultaneously and did not have to subsample files.

Our major recommendation for next year is to suggest that additional work is undertaken to produce a sampling protocol that will result in an unbiased estimate of the HOR:NOR ratio of the steelhead return. As previously mentioned, the current sampling design was developed to accurately sample the species composition of fish migrating past the SONAR sites. It does not necessarily focus on capturing an equal number of fish from each channel and certainly does not focus on capturing fish from throughout the watershed. While in some years (2016) it may do an adequate job at producing an unbiased estimate, in others (2015) the estimate is surely skewed.

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Table 1. Total number of “new” and “holding” steelhead and other salmonids which measured at least 55 cm captured by date at 9 sites during in-river netting operations.

Date	Steelhead	Bulltrout	% Steelhead
2/10/2016	0	0	NA
2/24/2016	0	0	NA
3/16/2016	0	0	NA
3/23/2016	1	0	100%
3/30/2016	1	0	100%
4/6/2016	2	1	67%
4/13/2016	4	0	100%
4/27/2016	9	0	100%
5/4/2016	2	1	67%
5/11/2016	4	1	80%
5/19/2016	0	0	NA
5/25/2016	2	0	100%
6/1/2016	1	0	100%
6/10/2016	1	0	100%

Table 2. Channel specific and total estimates of steelhead passage on the Elwha River in 2015. 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	353	473	826
Species Composition	307	429	736
Observer Error	313	433	746
Gap Fill (Final)	405	485	890

Table 3. Channel and source specific coefficients of variation (CV) for the four sources of uncertainty. 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	2.7%	1.7%	1.5%
Observer Error	3.8%	3.1%	2.4%
Gap Fill	5.4%	3.8%	3.2%
Total	6.2%	4.6%	3.8%

Table 4. Number and proportions of natural and hatchery origin steelhead captured during species composition and radio telemetry sampling. The one steelhead caught in the middle river was not used for species composition analysis because it was captured too far away from the SOANR sites.

Location	# of Steelhead	# Natural Origin	# Hatchery Origin	Prop. Natural Origin
Downstream of hatchery	21	6	15	29%
Lower river, upstream of hatchery	6	3	3	50%
Middle river	1	1	0	100%
Whole river (total)	28	10	18	36%

Table 5. Number and source of different steelhead estimates/encounters in the Elwha for 2016. Redd survey estimate is based on a ratio of 1.8 adults per red.

Year	Source		
	SONAR	Redd	Hatchery Returns
2016	890	274	42

Table 6. Yearly escapement estimates for Elwha River steelhead with 95% confidence intervals and number of natural origin recruits (NOR) and hatchery origin recruits (HOR) based on species composition sampling.

Year	Estimate	95% CI	NOR	HOR	% NOR
2013	385	NA	385	0	100%
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%

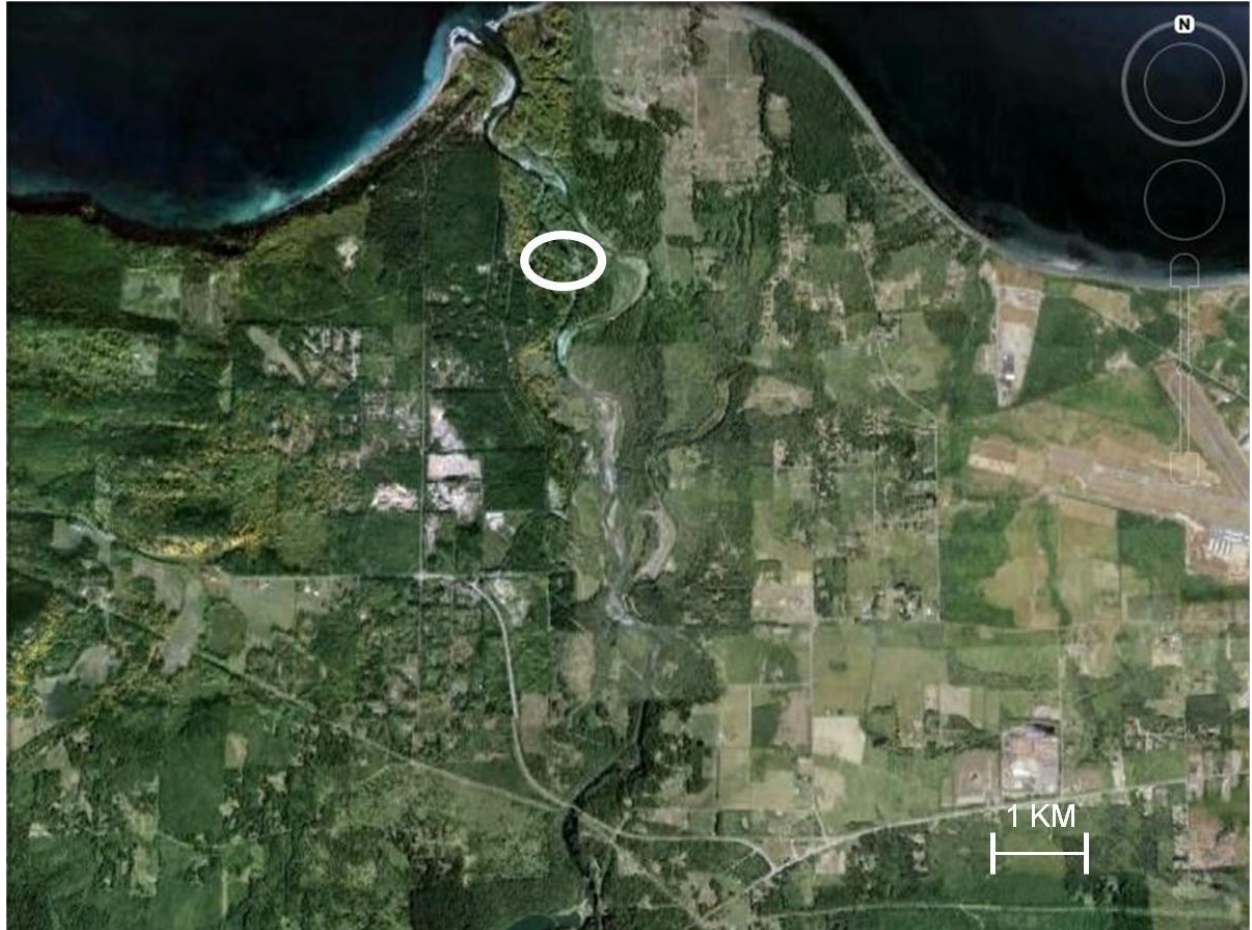


Figure 1. Map of the lower Elwha. Former Elwha dam site is located at the bottom of the figure, with the Strait of Juan de Fuca at the top. White oval depicts the location of the Hunt Road Side Channel DIDSON site. The Old Mainstem site is located approximately adjacent to the upper right hand portion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



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



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



Figure 4. Old Mainstem SONAR site. The SONAR itself is attached to the pole mount which is in turn attached to the ladder. The PVC picket weir immediately downstream from the ladder directs fish away from the bank so they pass at least 5 m from the SONAR head.

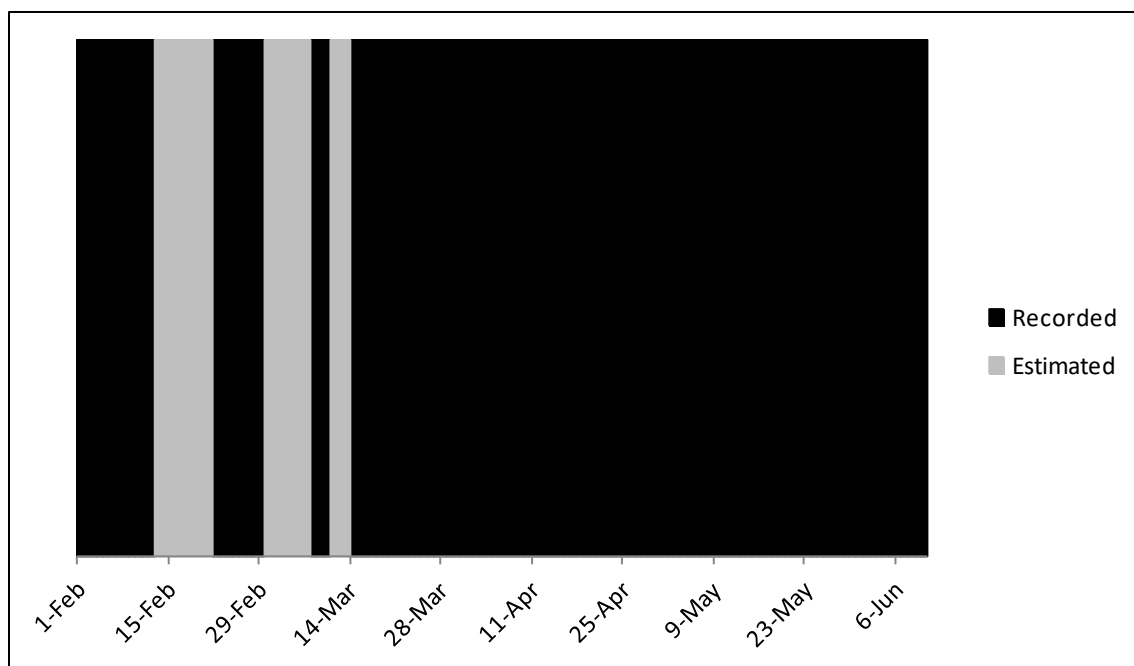


Figure 5a. Dates which had data recorded, black bars, or estimated, grey bars, for the Old Mainstem of the Elwha River in 2016.

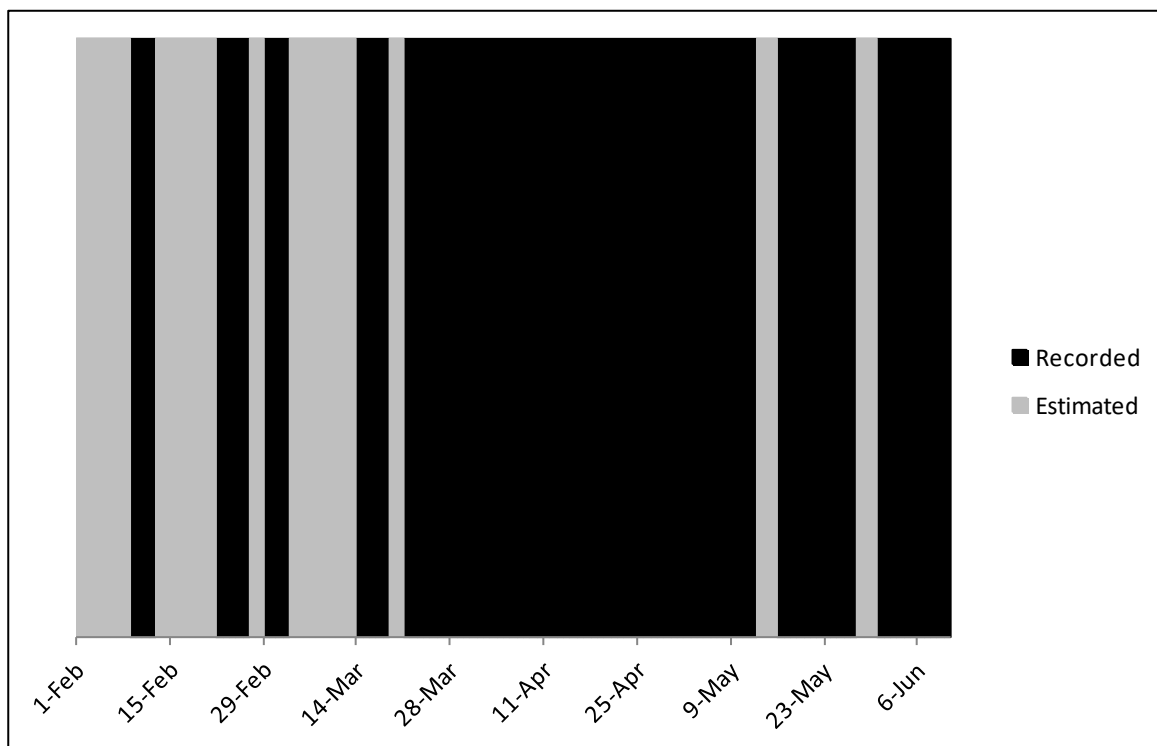


Figure 5b. Dates which had data recorded, black bars, or estimated, grey bars, for the Hunt Road Channel of the Elwha River in 2016.

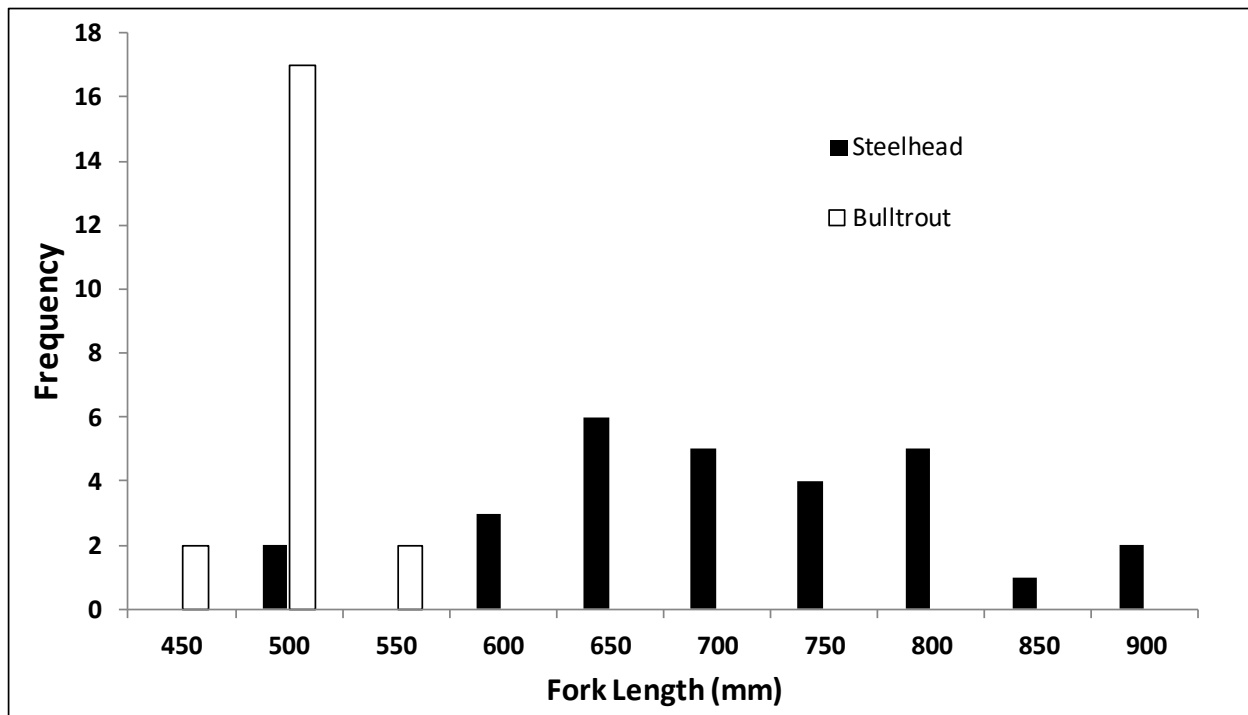


Figure 6. Length frequency histogram of all steelhead and bull trout captured during in river netting operations between March 23rd and June 10th, 2016.

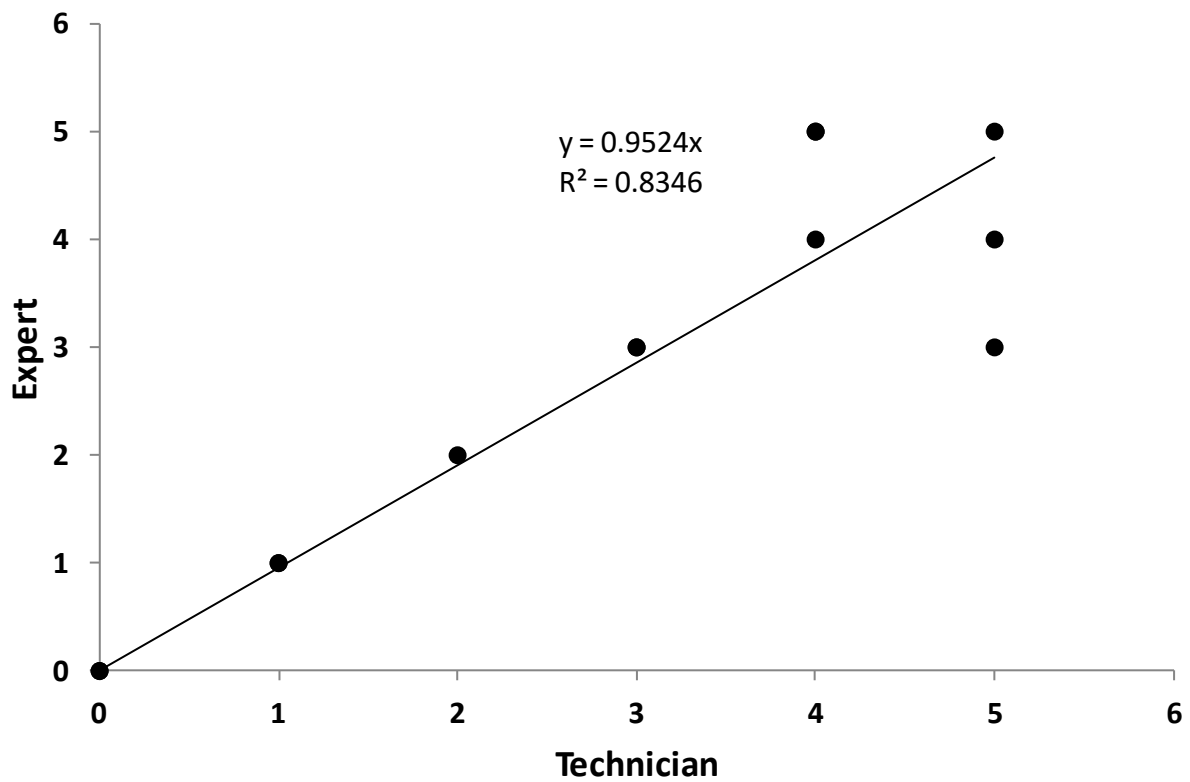


Figure 7. Total upstream passage counted by a technician and an expert for 13 six hour chunks. Points 0,0; 1,1; 3,3 and 4,5 each have two data points.

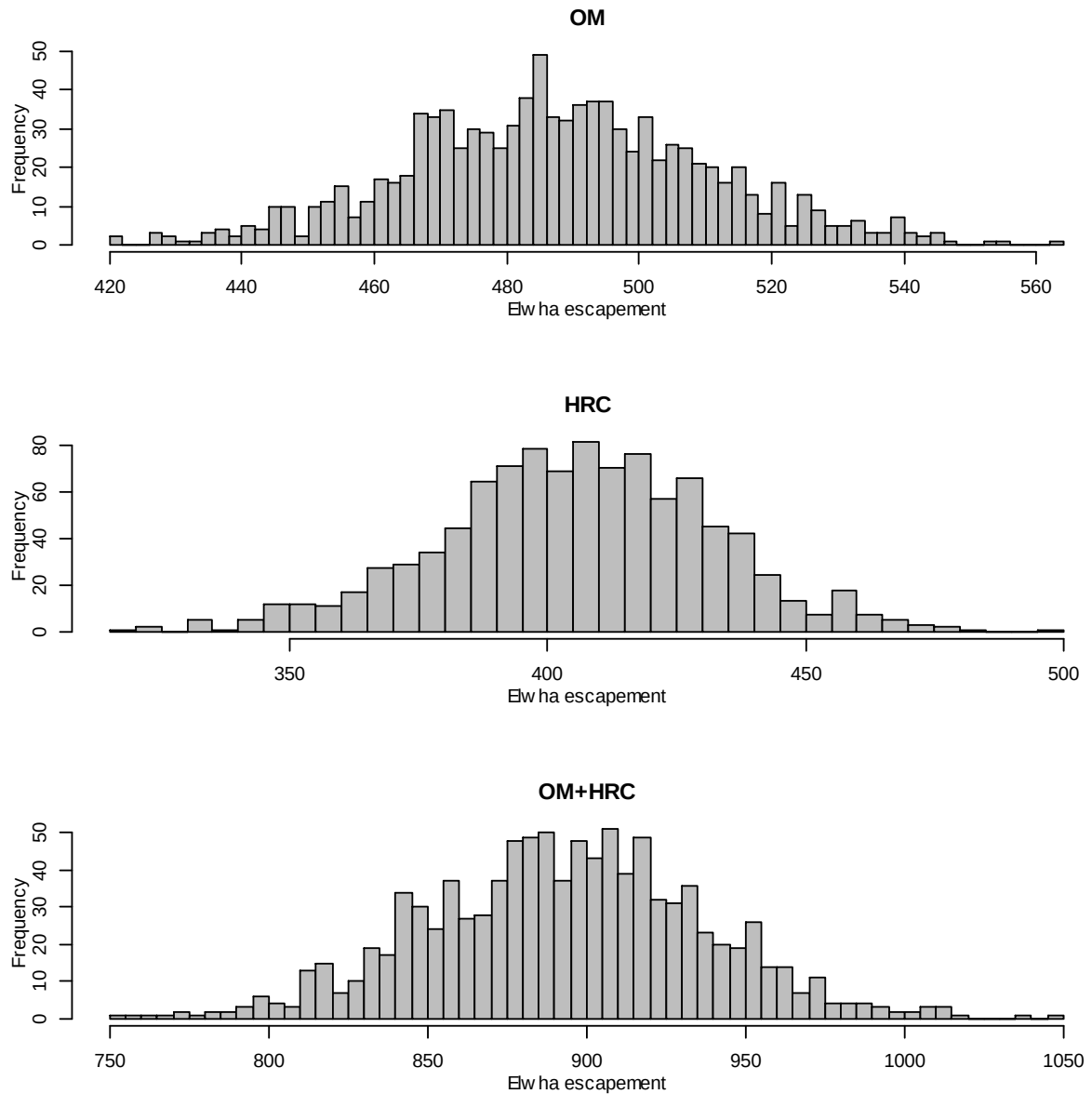


Figure 8. Run size frequency histograms for the steelhead in the Old Mainstem (OM), Hunt Road Channel (HRC) and combined run (OM + HRC) for the Elwha River in 2016.

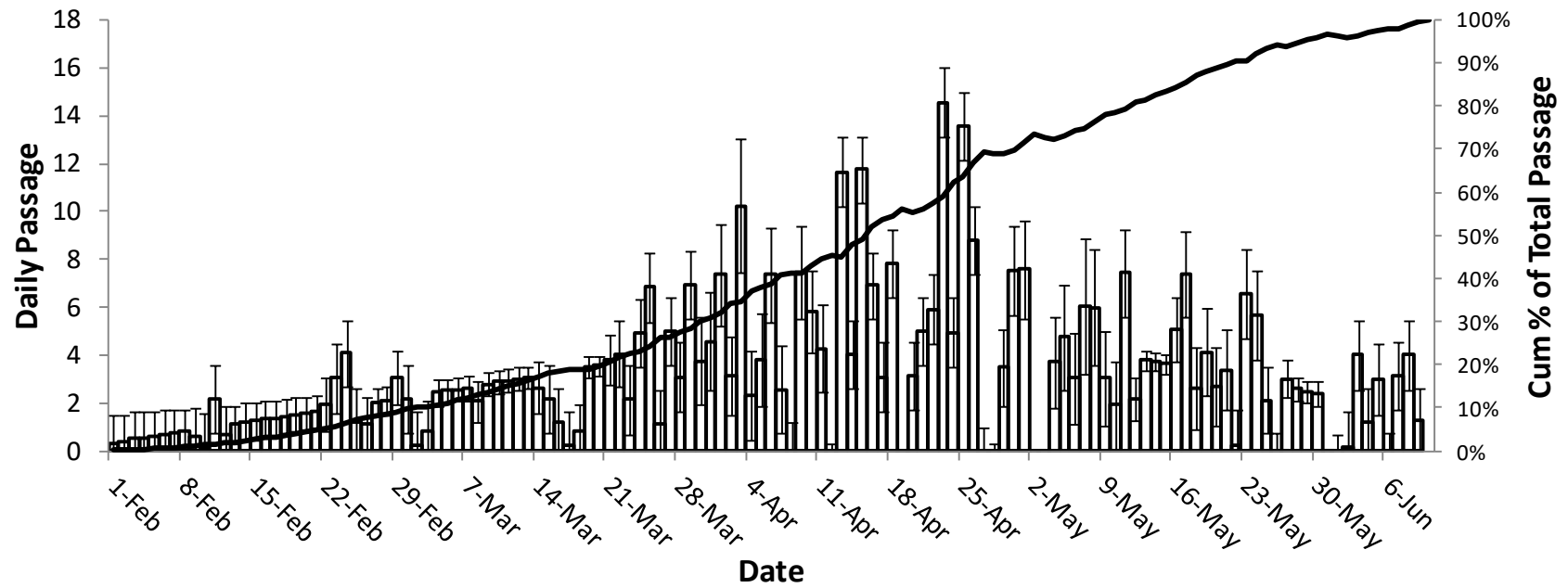


Figure 9. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Hunt Road Channel of the Elwha River in 2016. Total passage for this channel was 405 fish.

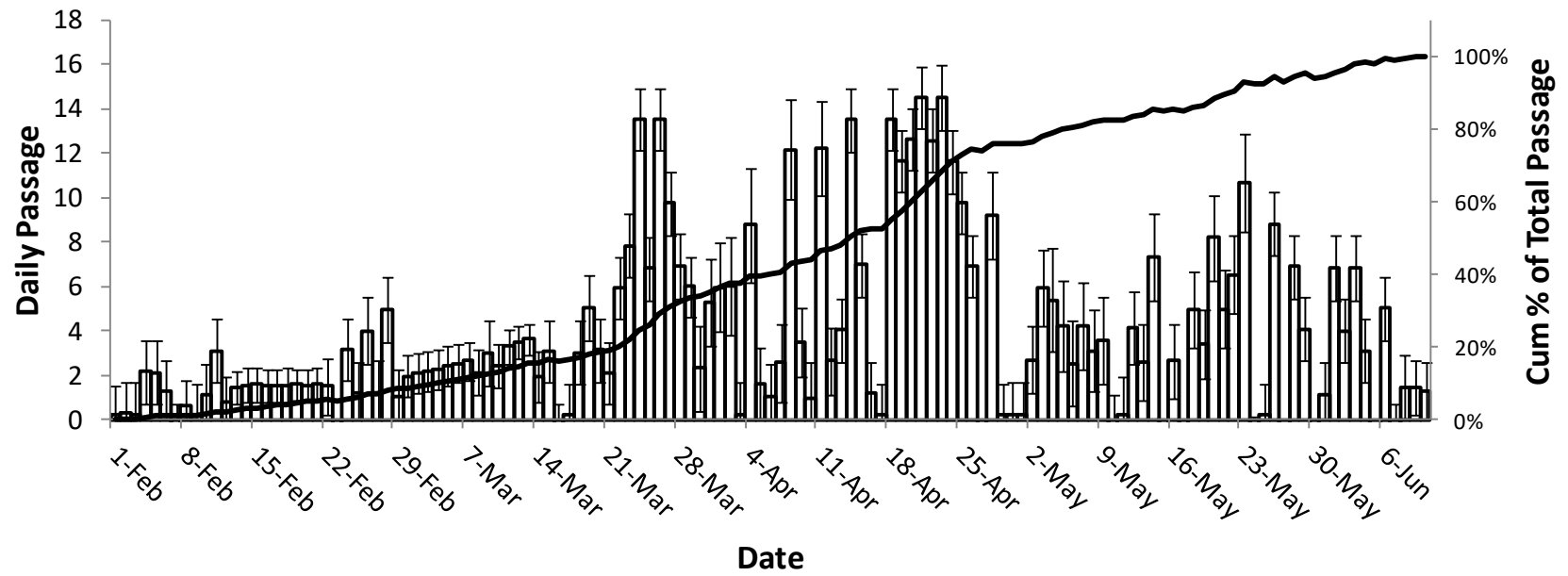


Figure 10. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Old Mainstem of the Elwha River in 2016. Total passage for this channel was 487 fish.

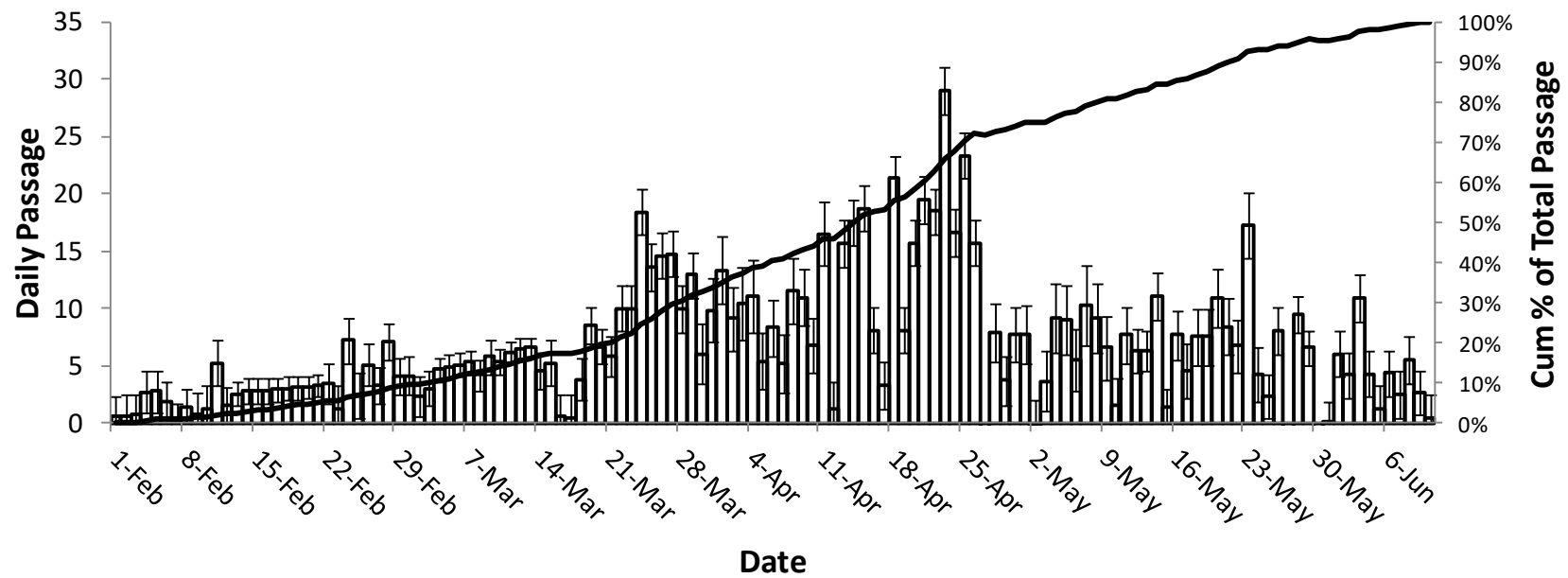


Figure 11. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for both channels the Elwha River in 2016. Total passage estimate was 890 fish.

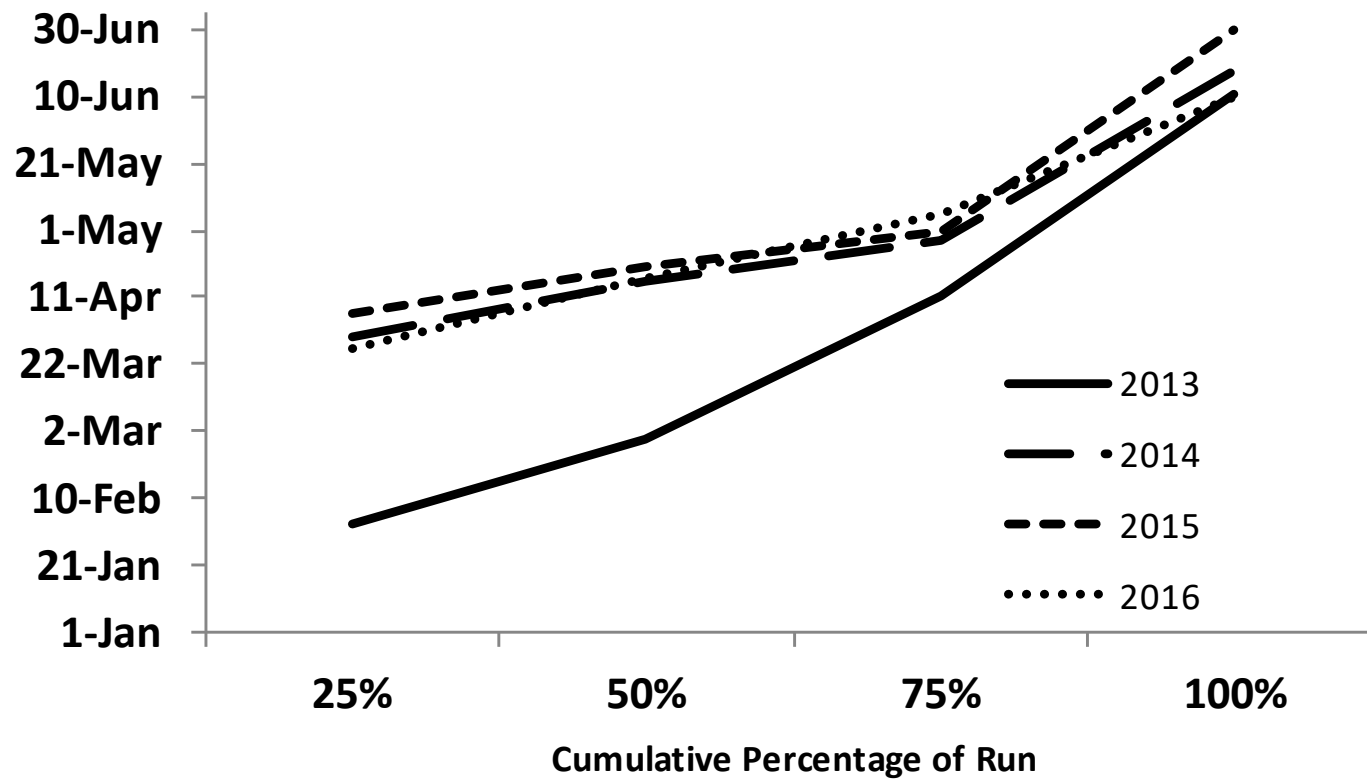


Figure 12. Run timing of steelhead in the Elwha River depicting the date at which 25, 50, 75, and 100% of the run had passed the SONAR sites.

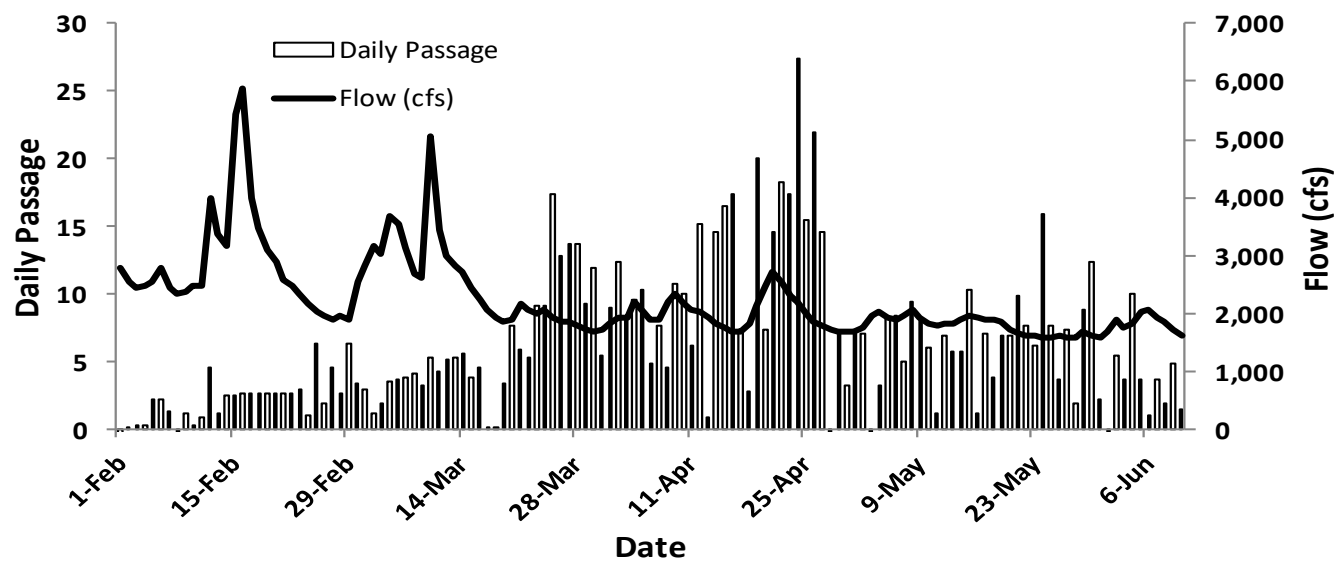


Figure 13. Daily passage of steelhead and flow (cfs) in the Elwha River in 2016.

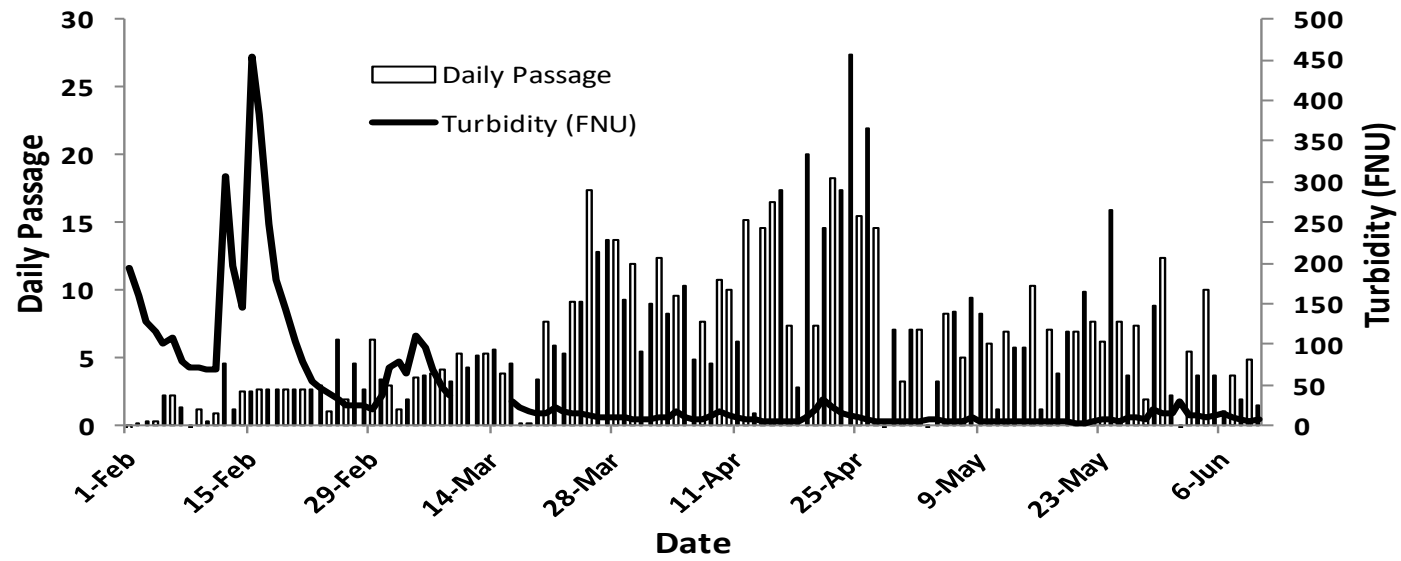


Figure 14. Daily passage of steelhead and turbidity (FNUs) for the Elwha River in 2016.