

2015 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 January 27th, 2015 through June 30th, 2015. We reviewed each hour long file in its entirety for January through April and 20 minutes of each hour for the May and June data. Then we adjusted these raw counts for expansion of the 20 minute counts, species composition, observer error, and filling in data gaps. This process yielded a steelhead escapement estimate above the SONAR sites of 1,450 fish; with a coefficient of variation of 7.5% (95% CI 1,220 – 1,675).

We also provide channel specific estimates of passage for the Hunt Road Channel (HRC), 365 (18.7% CV, 95% CI 205-408) and the Old Mainstem (OM) 1,085 (7.3% CV, 95% CI 910 -1,255). In addition to overall coefficients of variation (CV), we estimated individual CV's for all four sources of uncertainty: gap filling (6.7%), 20 minute expansion (4.5%), observer error (3.1%), and species composition (1.4%).

Fifty percent of the steelhead had passed the SONAR sites by April 20th, which was similar to the April 16th date in 2014. Species composition netting indicated that approximately 13% of the total run, or 190 fish, were of natural origin with the remaining 1,260 originating from the Lower Elwha Klallam native broodstock program.

This year's estimate is an improvement on last year's because we expanded the species composition netting program to occur weekly throughout the course of the run. We also incorporated a more accurate procedure to estimate passage during data gaps which also provides a comparable CV.

Looking towards improving our estimate for next year, we will investigate moving the OM site downstream several hundred meters for the latter portion of the season (April and May) in an effort to avoid milling native broodstock steelhead congregating near the LEKT hatchery. Additionally, as the effects of dam removal subside, reduced sediment and woody debris transport will facilitate leaving in-stream infrastructure in place during high water events, reducing data gaps.

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).

Several studies 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 early October. This report only covers steelhead enumeration from mid-January through mid-June (see Denton et al., 2010, 2012, 2013, 2014). It should be noted that historically the Elwha River had different life histories of steelhead that entered the river nearly year around (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.

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.

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 2015 (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 70% of the flow is transported down the HRC, with the remaining 30% traveling down the OM (Personal communication, Mike McHenry 2015). Therefore, an additional site was established to monitor fish passage in the OM, which is located on “river” right of the valley floor. 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 20 and 30 m across and 1.3 meters in the thalweg, while the OM site was 15-20 meters wide and 1 meter in the thalweg.

The 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 January 27th through June 30th, 2015. There were nine data gaps during this time period: January 30th to February 3rd, February 6th through February 16th, February 21st and 22nd, March 17th and 18th, March 21st through 23rd, March 27th through March 30th, April 4th and 5th, April 13th through April 15th, and June 3rd through June 28th (Fig 5a). Steelhead passage was recorded at the HRC site from March 2nd through June 30th. There were three

gaps during this time period: April 7th through April 12th, May 2nd and 3rd, and May 16th through May 18th.

The SONARs were also in operation after June 30th, 2015 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 weekly tangle net surveys between January 24th and June 30th to capture live adult salmonids at 12 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 an effort to not count spawned out fish and possibly double count the fish, only “new” and “holding” fish were included in the species composition analysis (Table 1). 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 non-steelhead salmonids, mostly resident bull trout and a few early Chinook salmon (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 except for files from May and June when only the first 20 minutes was reviewed. This subsampling regime for the May and June portion of the run was necessary because the large numbers of hatchery origin steelhead milling in the OM SONAR reach, located ~400 meters downstream from the LEKT hatchery, made the accurate counting of fish passage extremely time consuming. Uncertainty derived from this subsampling regime was captured through the procedure

described in the next section. Subsampling twenty minutes on the hour is well within accepted subsampling proportions (Lilja et al.2008).

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 millimeters 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 430 mm and 900 mm (Fig. 5). However, only 3.4% of measured steelhead (7/203) were smaller than 550 mm and only 19.6% of bulltrout (10/51) 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 (44/3,080). Eighteen percent of all downstream passage events were recorded as observer confidence level 2 (395/2,226).

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 four step adjustment simulation to determine the final escapement. This simulation used collected data to correct raw counts for the four major adjustments that make up the total escapement estimate: 1) Expanding the 20-minute counts from May and June; 2) down weighting the expanded counts to reflect the proportion of SONAR targets that were non-steelhead; 3) adjusting the expanded steelhead counts to account for observer error; and 3) filling in passage data for gaps in the corrected, expanded 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 (628 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 five 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.

Expansion

In order to expand the twenty minute counts from May and June, we used a binomial sampling procedure, using a large number of iterations (10,000) to expand 20-minute counts to 60-minute counts and also incorporate uncertainty. We assumed the 20-minute counts to be representative of the respective 60-minute periods, in which case the observed 20-minute counts can be seen as being drawn from a binomial distribution, $X_{20} \sim \text{Binomial}(N_{60}, p = 1/3)$. In this framework, the observed counts (X_{20}) and proportion of time (p) are known, but the total fish passing by (N_{60}) is an unknown quantity. For each value of X_{20} , we estimated the relative probabilities of N_{60} using the binomial density function (because $p = 1/3$, the expected value of N_{60} is $3 * X_{20}$). We then drew unique values of N_{60} from this distribution for each iteration of the simulation.

Species Composition

Calculation of the 2015 steelhead escapement only included SONAR targets recorded through June 30th based on findings of the species composition sampling. Only one non-spawned out steelhead was captured in the species composition sampling on July 17th. No steelhead, spawned out or fresh, were captured during species composition sampling on June 30th. In addition, two fresh Chinook salmon were captured on June 17th and an additional four were captured during the June 30th sampling event, indicating that most of the large bodied salmon migrating past the SONAR sites after those dates 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 2). Because of the low numbers of “new” and “holding” 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:

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

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

The CV for escapement for this step was calculated by performing the correction directly on the net passage data 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 11 six hour chunks between the primary technician and a more experienced, “expert” counter. Similar to the expansion procedure, 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 nine data gaps in the OM during the course of this study. These gaps totaled 58 days, almost half of which occurred during a large gap in June. In addition, there were three data gaps in the HRC during the course of this study, totaling 11 days. The period of time from when the OM was initially installed (January 27th) to when the HRC was installed (March 2nd) is also considered a data gap that required estimating passage. Therefore, there were a total of 44 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 January 27th and June 30th 2015, 2,424 hours (101 days) of data were recorded on the HRC, and 2,304 hours (96 days) were recorded on the OM which represented 64% of the total possible hours (7,392) in this year's steelhead run. At least one of the channels was monitored for 3,264 hours out of a total of 3,696 hours, or 88% of the total possible hours. During this time period 5,669 fish passage events were recorded and analyzed. The best estimate for the steelhead escapement to the Elwha River in 2014 is 1,450 fish with a coefficient of variation (CV) of 7.5% (95% CI 1,220 – 1,675) (Tables 2 and 3). A total of 365 or 25.2% (CV 18.7%, 95% CI 205 - 480) steelhead went up the HRC, while the remaining 1,085 or 74.8% (CV 7.3%, 95% CI 910 – 1,255) steelhead went up the OM (Figure 8). In order of decreasing variance, the largest sources of error were (1) filling in data for missing time periods (6.7%), (2) expanding the May and June 20 minute counts (4.5%), (3) the observer error correction (3.1%), and (4) uncertainty associated with species composition (1.4%) (Table 3).

The nature of the SONAR data in combination with in-stream species composition netting provides detailed information on run timing. We caught one spawned out Chamber's Creek steelhead

during the first species composition sampling event on January 27th and then captured three non-Chambers Creek steelhead on the subsequent sampling event on February 4th. Weekly species composition sampling through the end of June indicated that fresh steelhead ceased migrating past the SONAR sites by June 30th. Twenty five, 50 and 75% of the run had passed the SONAR sites on April 6th, April 20th, and May 1st, respectively (Fig. 10). Twenty five, 50, and 75% of the run had passed the HRC by March 8th, April 16th, and May 10th, respectively, and by April 10th, April 20th, and May 1st for the OM, respectively (Figs. 9, 10, and 11).

Daily passage was also plotted against flow and turbidity. The hydrograph was highly variable over the course of the study reaching a high of 14,400 cfs on February 6th and a low of 460 cfs on the last day of the study, June 30th. In general, daily passage seemed to be independent of flow or turbidity, although a relative spike in both on March 21st seemed to coincide with a reduction in passage rate for the following three days (Figs 12 and 13).

Finally, species composition netting revealed that 13% of captured fish were of natural origin (26/206). Assuming this represents an unbiased sample of the total run, approximately 190 of the 1,450 total returning steelhead were natural origin recruits (NOR), while the remaining 1,275 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. Eight percent of the fish captured below the LEKT hatchery were of natural origin, 18% of the fish captured between the LEKT hatchery and the former Elwha dam site were of natural origin, and 60% of the fish captured in the middle river were of natural origin (Table 4). Additionally, species composition sampling indicated a male:female sex ratio of almost 1:1 (99 male, 101 female).

Discussion

Our estimate of 1,450 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 January 27th, 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, 6.7%) (2)expanding the 20-minute May and June counts (CV 4.5%), (3) observer error (CV 3.1%), and (4) correcting for species composition (CV 1.4%).

The largest source of uncertainty was associated with filling the multiple data gaps that occurred during the course of the study. This is due to the need to estimate 36% of the total possible hours during the course of the run. Also, a large portion of this gap filling occurred on the HRC before it was installed. This resulted in measured passage on only one side of the gap, which made it difficult for the gap fill procedure to accurately estimate passage during this five week period, as shown by the large error bars

relative to daily passage in the HRC before March 2nd (Fig. 8). Fortunately, most of the passage gaps occurred when there was minimal steelhead passage (HRC in February and OM in June), and only added 280 fish or 19% to the total passage estimate (Table 2). 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.

The second highest source of uncertainty (CV 4.5%), expanding the 20 minute counts from May and June, was an acceptable introduction of error for the review efficiency it facilitated. The OM SONAR site is located approximately 400 meters downstream from the Lower Elwha Hatchery, where the majority of this year's steelhead run homed to. This resulted in hundreds of steelhead spawning and milling around the OM SONAR site during May and June. This phenomenon is further evidenced by McMillan et al. (2015) recording 157 steelhead redds within 2 KM of the LEKT hatchery. This cluster of spawning fish near the OM SONAR site in May and June made accurately counting steelhead passage extremely time consuming, therefore a subsampling regime was incorporated into the data review protocol that would save significant technician review time while providing a reliable measure of uncertainty. Sampling 20 minutes on the hour is well within established subsampling regimes (Lilja 2008), and is the protocol for all of the project's Chinook data (Denton et al. 2012, 2013, 2014).

The third highest source of uncertainty is the observer error correction (CV 3.1%). The regression coefficient (.96) was only marginally different from a 1:1 relationship between technician and expert counts and the r^2 (.94) indicated a very good fit of the regression. The project has employed the same technician for several years, resulting in reliable and accurate data review. It should be noted, however, that most of the data for the observer error analysis was from March and April, with only a few data points representing the period of heavy milling in the OM in May and June. Observer error could be higher during this time period due to the difficulty of counting milling fish. Fortunately, measured passage during this time period was low which would lessen the effect of any increase in observer error.

The final, and smallest source of uncertainty was associated with the species composition (CV 1.4%). The low level of uncertainty associated with this source can largely be attributed to the adoption of last year's recommendation to sample for species composition weekly throughout the season. This not only yielded a temporally complete data set, but many more fish were captured in the species composition this year (253 fish) in comparison to 2014 (54 fish). Finally, a higher proportion of the captured fish in 2015 were steelhead (212/253, 84%) as compared to 2014 (22/54, 40%), which greatly reduced the variability of the binomial draw used in the simulation model.

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 2015 season. McMillan et al. (2015) observed a total of 419 steelhead redds from the river mouth up to the former Glines Canyon Dam. Using redd to fish multiplier

of 1.8, gives a redd based estimate of 754 fish, or about half of the SONAR base escapement. This disagreement is not unexpected for three main reasons. First, mainstem surveys were not initiated until the first week of May, potentially missing redds from early in the season. Secondly, while survey effort was extensive and conditions were generally favorable, not all areas were surveyed and some surveyed areas were not visited frequently. Finally, and perhaps most importantly, 37% of the recorded redds (157/419) were located within 2KM 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.

This year's steelhead escapement estimate can also be put in context of the last two years' SONAR derived estimate (Denton et al. 2013, 2014). The best estimate for steelhead escapement in the Elwha for 2013 and 2014 was 385 and 1,200 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 three year population trend for natural origin fish would be 385, 400, and 190 fish for 2013, 2014, and 2015, respectively. The hatchery origin population trend would be 0, 800, and 1,260 fish for 2013, 2014, and 2015, respectively (Table 5). 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.

The date at which 50% of the run had passed the SONAR sites in 2015, April 20th, was similar to last year's estimate of April 16th, and a full month and a half later than the 2013 estimate of February 27th. Interestingly, the range between the dates at which 25% and 75% of the run had passed up the HRC (March 8th – May 10th, 63 days) was more than 2.5 times the range in the OM (April 6th – May 1st, 25 days). Passage up the OM is likely disproportionately comprised of hatchery origin steelhead returning to the LEKT hatchery indicating this disparity could be a result of a more contracted run timing for the hatchery origin fish as compared to natural origin steelhead.

Redd surveys in previous years has indicated that spawning below the SONAR sites is negligible, however, this year 25 redds were counted below the SONAR sites. This potentially represents 45 additional steelhead that our estimate did not include. Adding these additional fish into our estimate would yield a revised escapement estimate of approximately 1,500 steelhead.

Recommendations

We are pleased to report that we were able to implement all three recommendations from last year's report. Namely, (1) expand the species composition sampling, (2) incorporate an alternative gap filling estimate, and (3) reduce data gaps. All three of these actions have greatly improved our estimate this year.

The main recommendation this year is to explore alternative sites for the OM downstream from its current location if fish milling becomes an issue during late April and May again. Redd spatial data

implies that moving further downstream in the OM ,and therefore farther away from the LEKT hatchery will reduce the number of milling fish in the immediate proximity of the SONAR (McMillan et al. 2015). Assuming large numbers of steelhead spawn in the OM in the future, moving the site downstream will also assist in counting a greater proportion of the escapement into the river as it will potentially be located below additional redds. The OM site runs on solar power, so is theoretically mobile, but several other site attributes will need to exist in order to move the installation.

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Table 1. Total number of “new” and “holding” steelhead and other salmonids which measured captured by date at 12 sites during in-river netting operations.

Date	Steelhead	Other	% Steelhead
1/27/2015	0	0	NA
2/4/2015	3	0	100%
2/25/2015	2	0	100%
3/4/2015	7	0	100%
3/11/2015	7	1	88%
3/18/2015	11	3	79%
3/25/2015	4	0	100%
4/8/2015	6	1	86%
4/15/2015	12	2	86%
4/22/2015	12	0	100%
4/29/2015	17	1	94%
5/7/2015	13	2	87%
5/13/2015	9	0	100%
5/20/2015	4	2	67%
5/27/2015	2	0	100%
6/3/2015	2	5	29%
6/10/2015	1	4	20%
6/17/2015	1	2	33%
6/30/2015	0	4	0%

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	255	910	1,165
Expansion	650	1,175	1,825
Species Composition	260	1,040	1,300
Observer Error	245	925	1,170
Gap Fill (Final)	365	1,085	1,450

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
Expansion	8.0%	4.3%	4.5%
Species Comp	4.7%	1.4%	1.4%
Observer Error	10.0%	2.8%	3.1%
Gap Fill	21.0%	5.4%	6.7%
Total	18.7%	7.3%	7.5%

Table 4. Number and proportions of natural and hatchery origin steelhead captured during species composition and radio telemetry sampling.

Location	# of Steelhead	# Natural Origin	# Hatchery Origin	Prop. Natural Origin
Downstream of hatchery	174	14	160	8%
Lower river, upstream of hatchery	17	3	14	18%
Middle river	15	9	6	60%
Whole river (total)	206	26	180	13%

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.

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%



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.

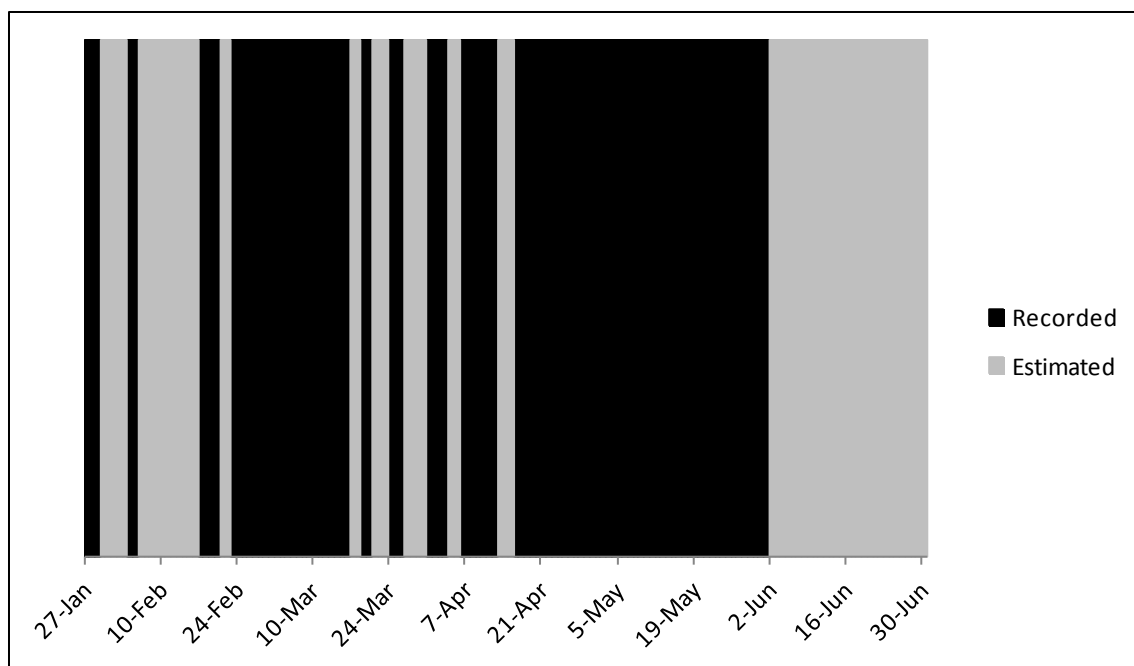


Figure 5a. Dates which had data recorded, black bars, or estimated, grey bars, for the Hunt Road Channel of the Elwha River in 2015.

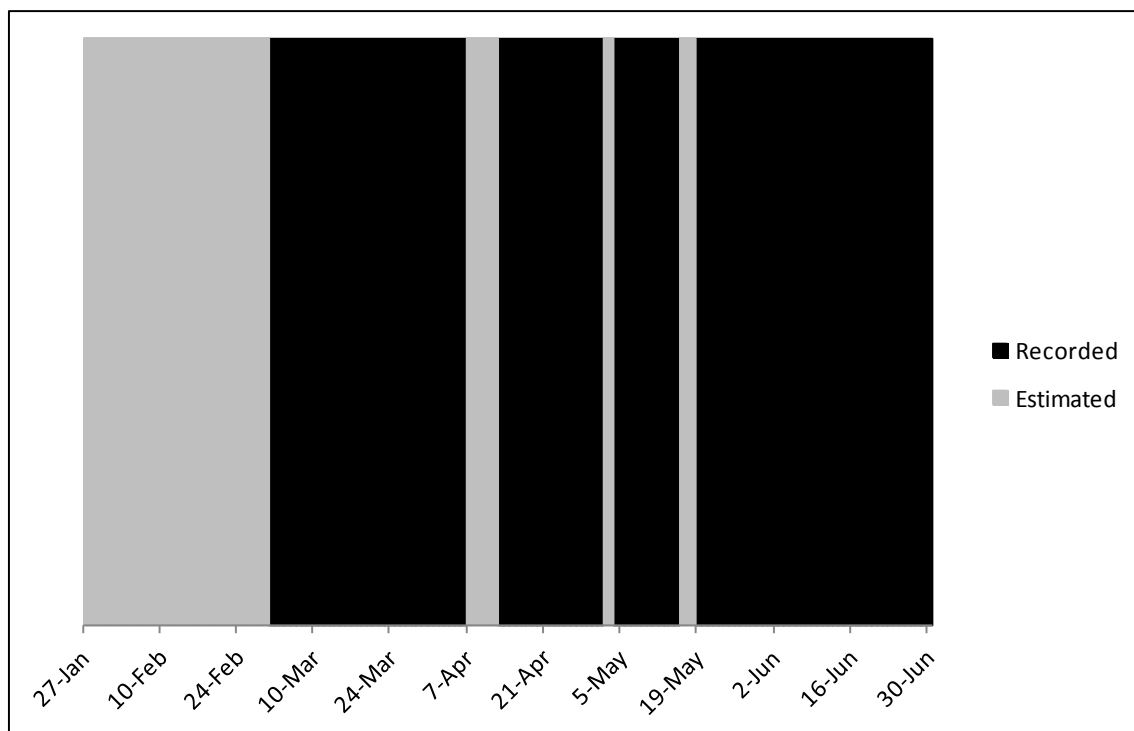


Figure 5b. Dates which had data recorded, black bars, or estimated, grey bars, for the Old Mainstem of the Elwha River in 2015.

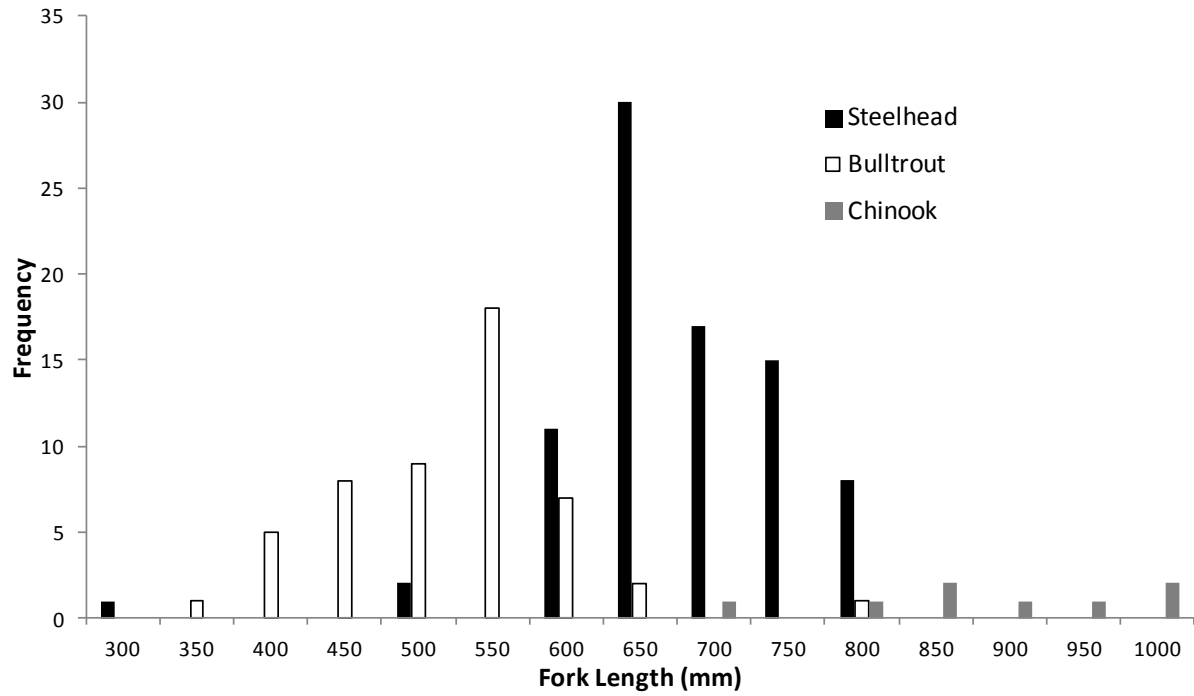


Figure 6. Length frequency histogram of all steelhead and non-steelhead salmonids captured during in river netting operations between January 28th and June 30th, 2015.

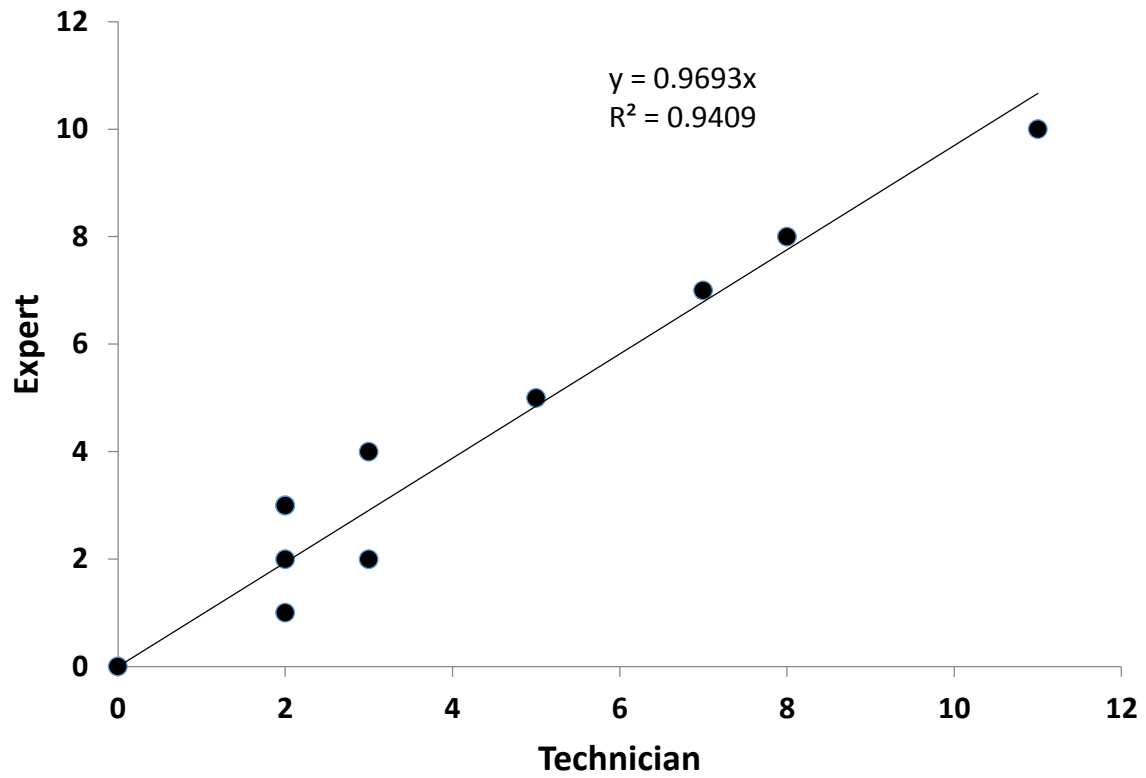


Figure 7. Total upstream passage counted by a technician and an expert for 10 six hour chunks.

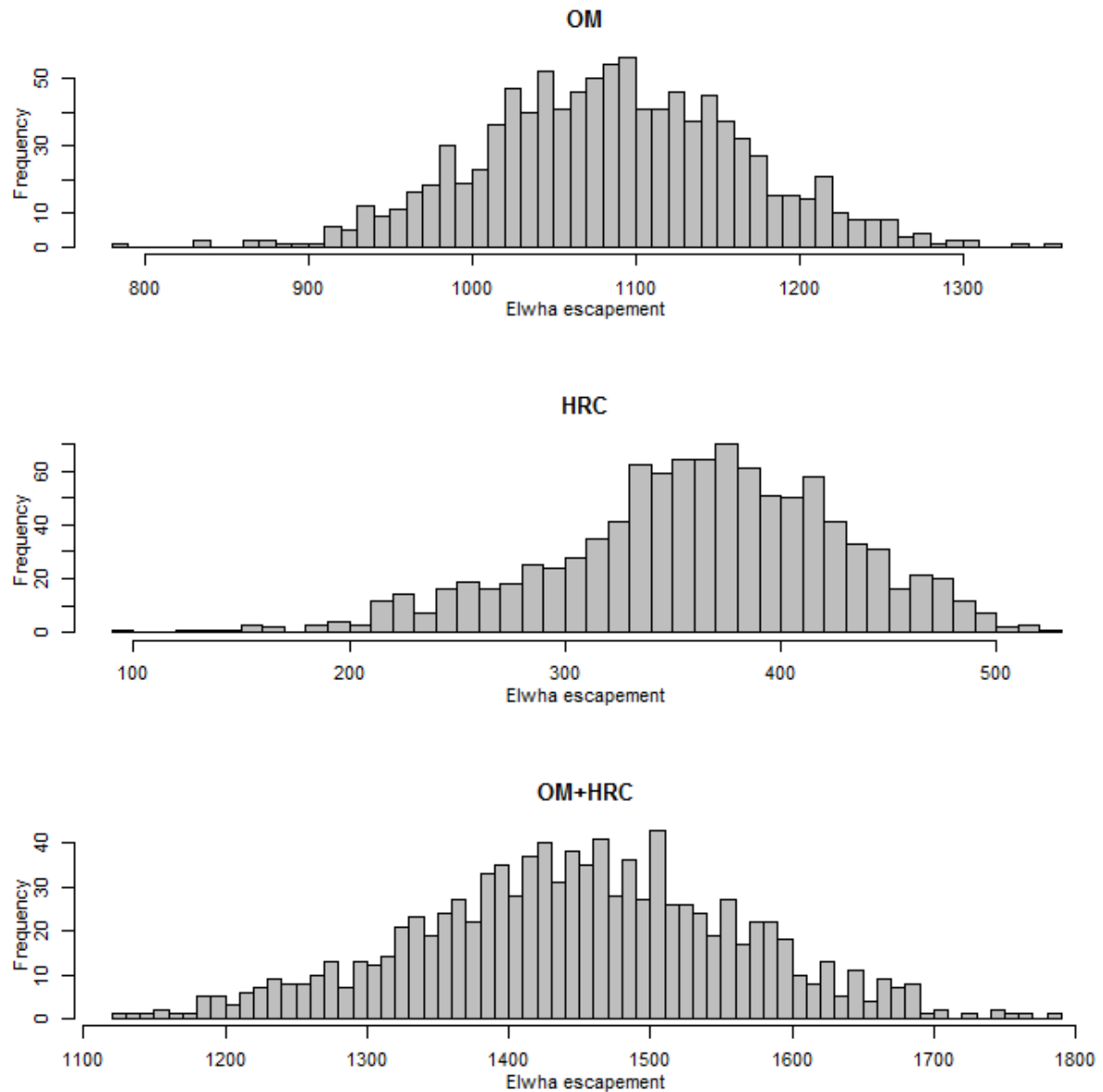


Figure 8. Run size frequency histograms for the steelhead in the Old Mainstem (OM), Hunt Road Channel (HRC) and combined run (OM + HRC) for the Elwha River in 2015.

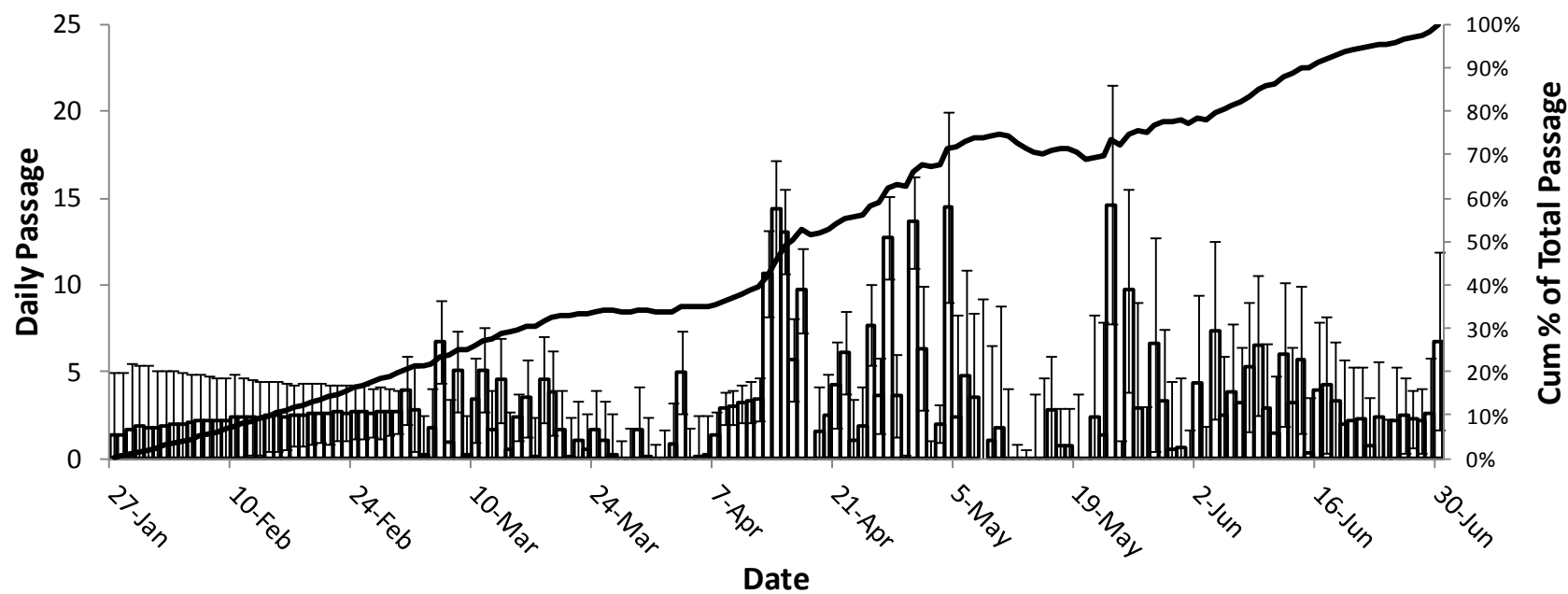


Figure 9. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Hunt Road Channel of the Elwha River in 2015. Total passage for this channel was 365 fish.

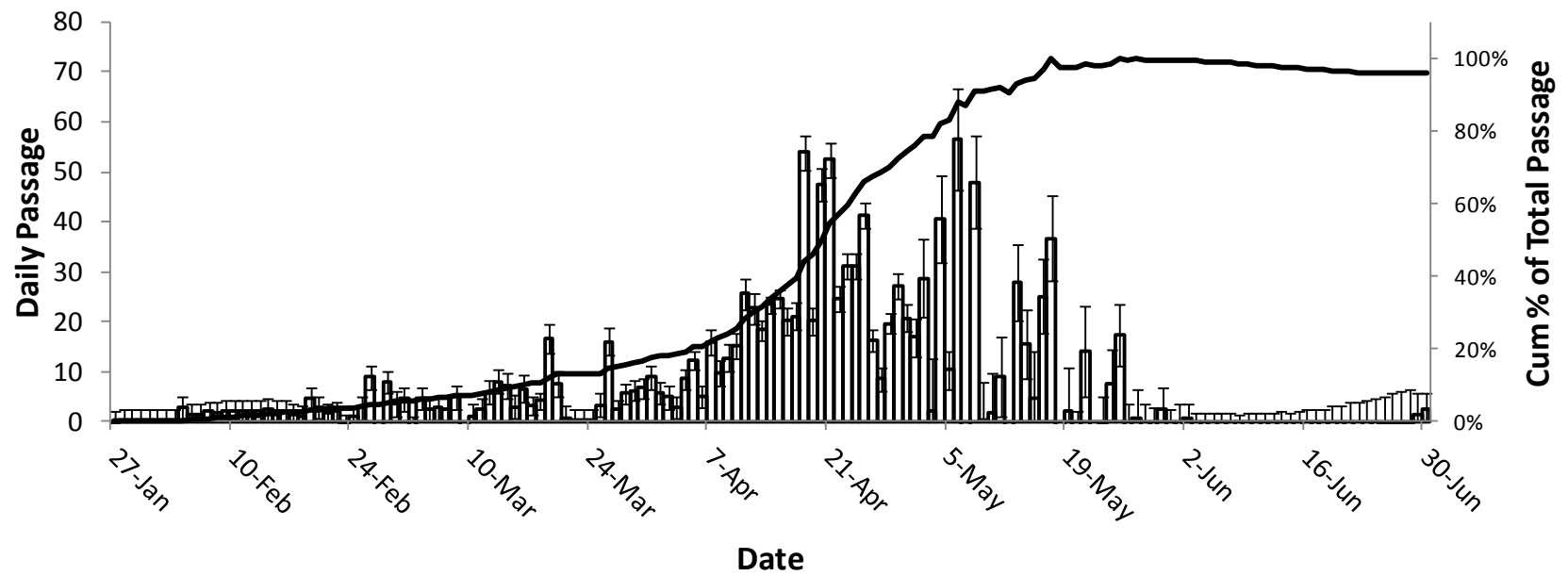


Figure 10. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for the Old Mainstem of the Elwha River in 2015. Total passage for this channel was 1,085 fish.

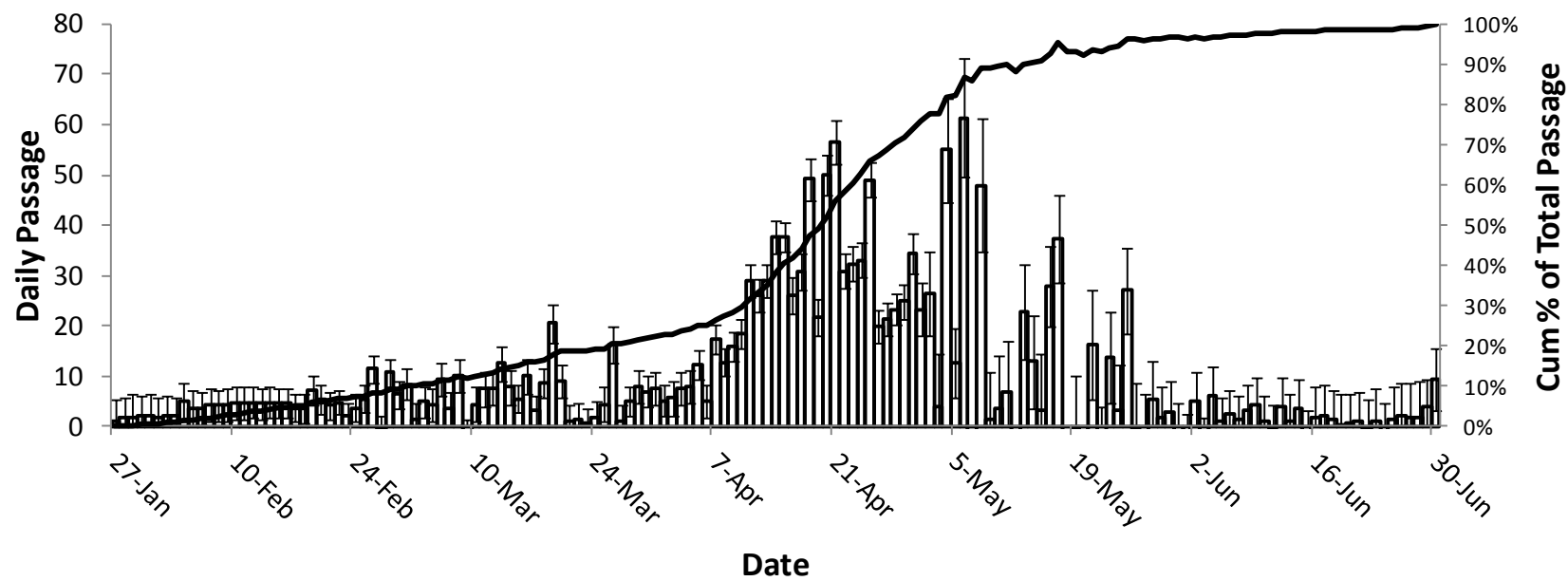


Figure 11. Daily passage estimates for steelhead, with standard deviations, and cumulative percent of run for both channels the Elwha River in 2015. Total passage estimate was 1,450 fish.

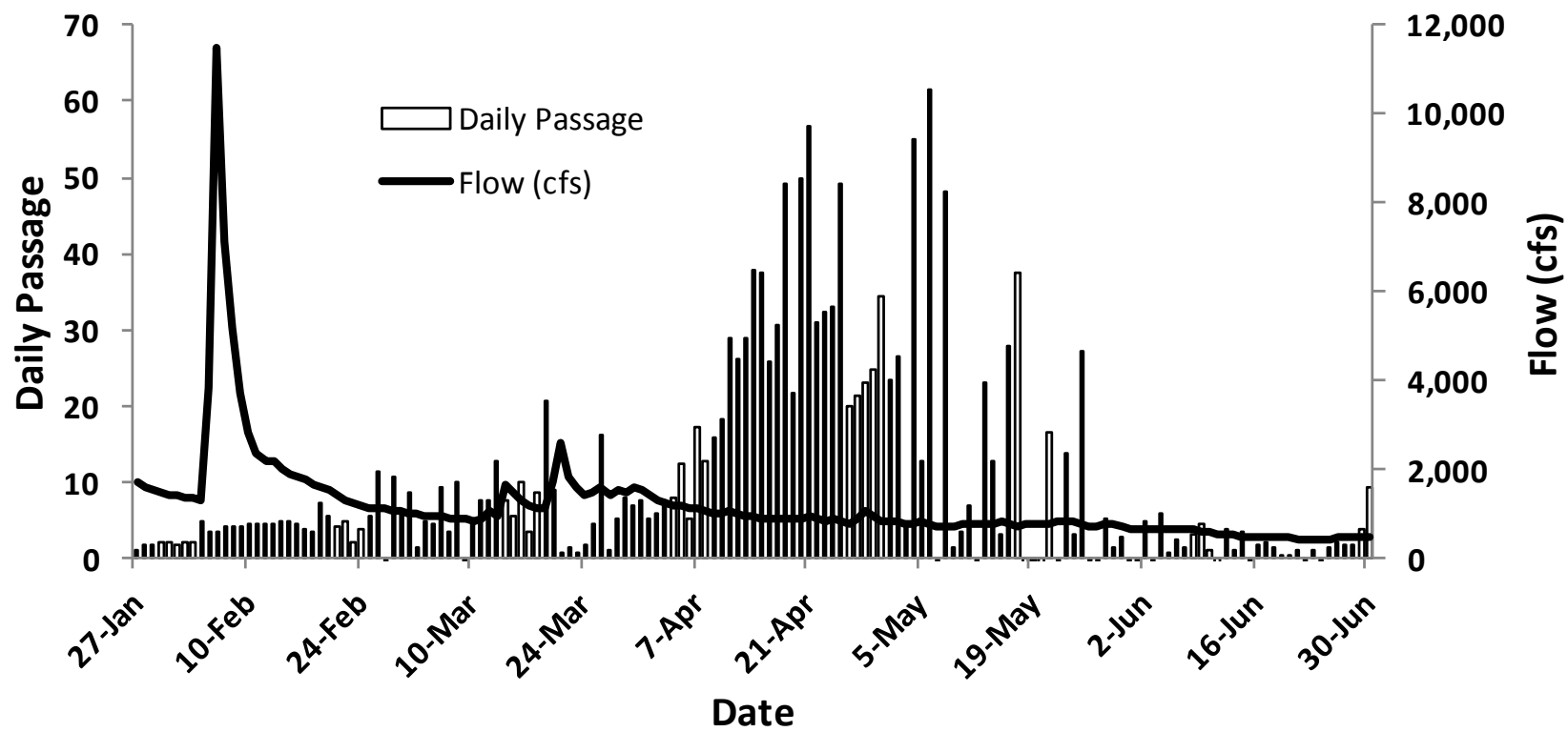


Figure 12. Daily passage of steelhead and flow (cfs) in the Elwha River in 2015.

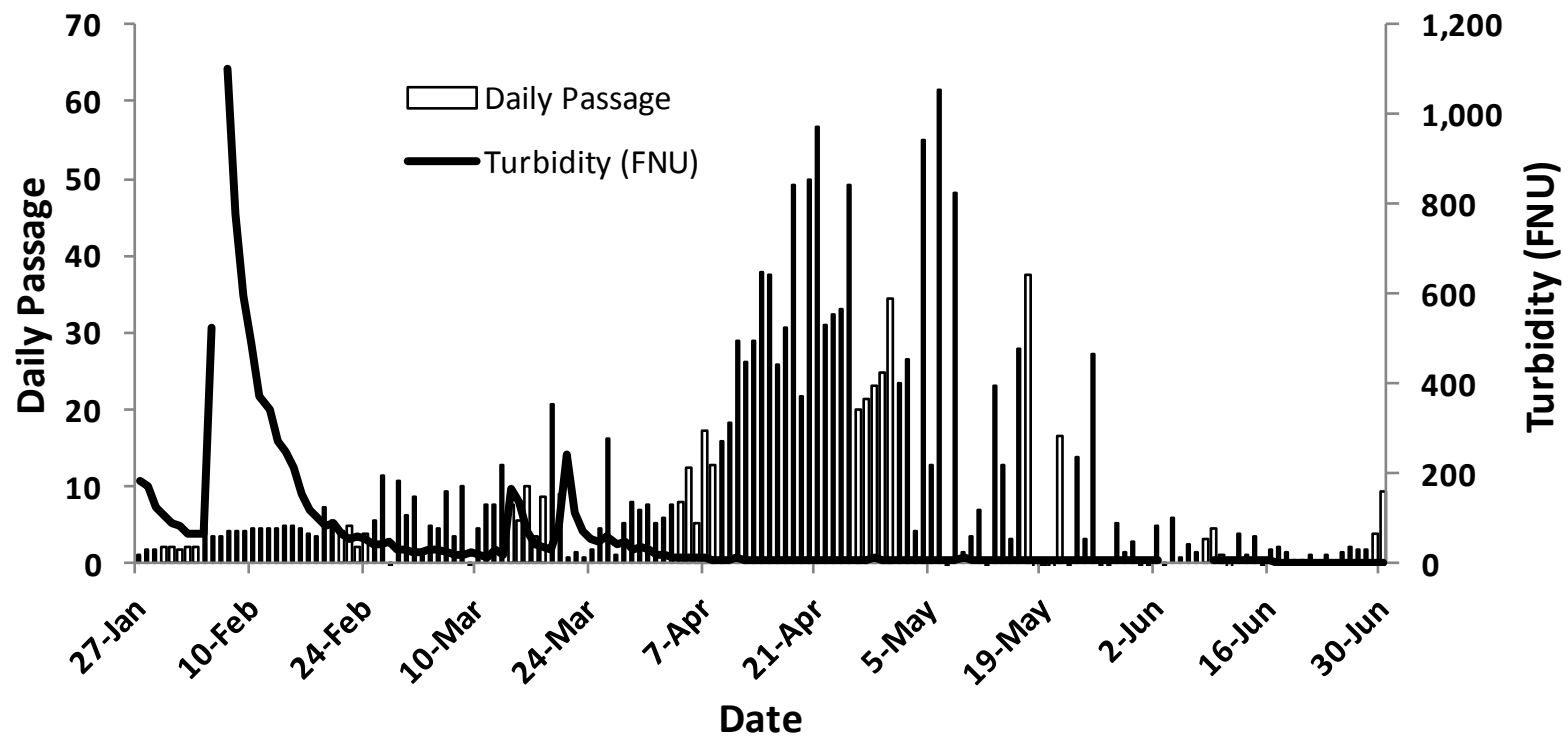


Figure 13. Daily passage of steelhead and turbidity (FNU) for the Elwha River in 2014.