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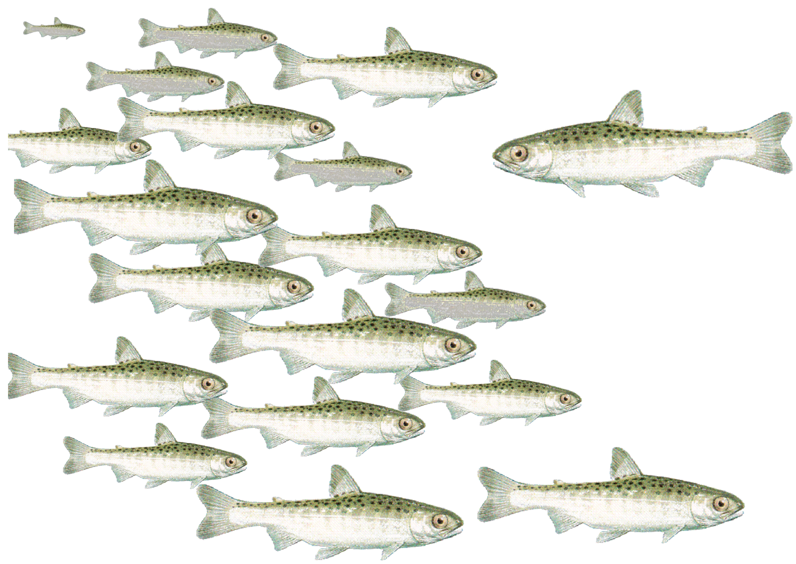
Evaluation of Juvenile Salmon Production in 2016 from the Cedar River and Bear Creek



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Washington Department of Fish and Wildlife
Fish Program
Science Division

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Introduction

This report describes the emigration of five salmonid species from two tributaries in the Lake Washington watershed: Cedar River and Bear Creek. Cedar River flows into the southern end of Lake Washington; Bear Creek flows into the Sammamish River, which flows into the north end of Lake Washington (Figure 1). In each watershed, the abundance of juvenile migrants is the measure of freshwater production upstream from the trapping location.

In 1992, the Washington Department of Fish and Wildlife (WDFW) initiated an evaluation of sockeye fry migrants in the Cedar River to investigate the causes of low adult sockeye returns. In 1999, the Cedar River juvenile monitoring study was expanded in scope in order to include juvenile migrant Chinook salmon. This new scope extended the trapping season to a six month period and, as a consequence, also allowed estimation of coho production, and assessment of steelhead and cutthroat trout movement.

In 1997, WDFW initiated an evaluation of sockeye fry migrants in the Sammamish watershed. In 1997 and 1998, a juvenile trap was operated in the Sammamish River during the downstream sockeye migration. In 1999, this monitoring study was moved to Bear Creek in order to simultaneously evaluate Chinook and sockeye production. Since 1999, the Bear Creek juvenile monitoring study has also provided estimates of coho production and described ancillary data on movement patterns of steelhead and cutthroat trout.

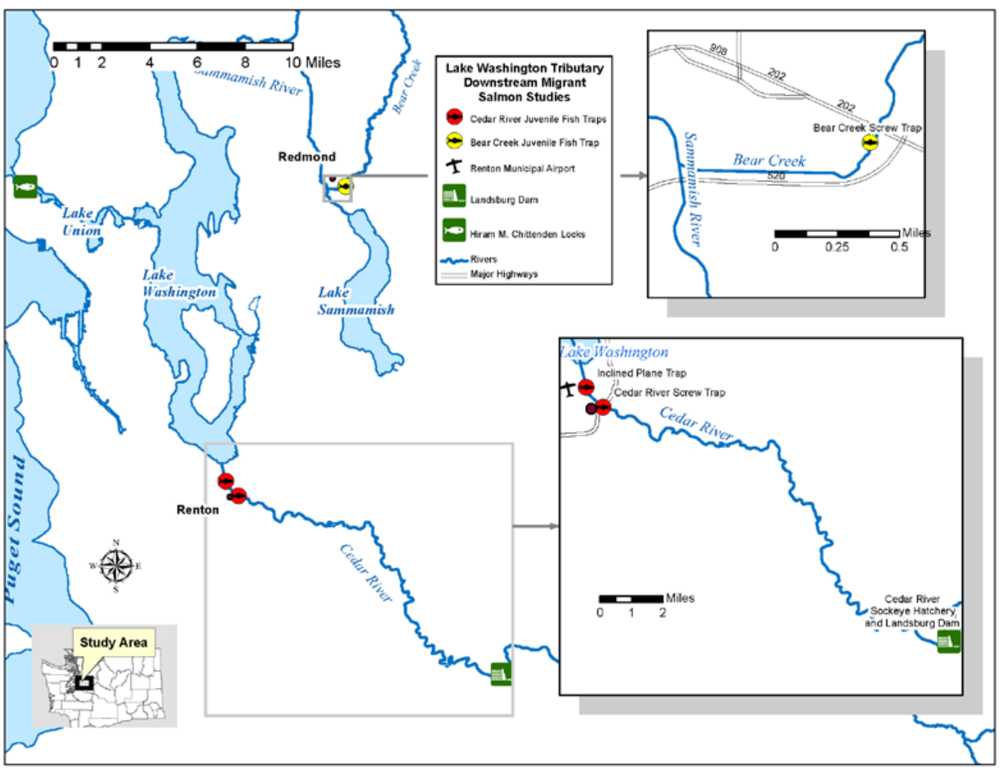

Figure 1. Map of Lake Washington trap sites used to monitor abundance of juvenile migrant salmonids in the Cedar River and Bear Creek, near Renton and Redmond, respectively.

The primary study goal of this program in 2016 was to estimate the number of juvenile sockeye fry, and natural-origin Chinook and coho migrating from the Cedar River and Bear Creek into Lake Washington. This estimate was used to calculate survival of the 2015 brood from egg deposition to lake/river entry and to describe the migration timing of each species. Cutthroat and steelhead movements were assessed through catch totals but no abundance estimates were made. Biological data representing each population are also summarized.

Methods

Fish Collection

Trapping Gear and Operation

Cedar River

Two traps were operated in the lower Cedar River during the late winter/spring out migration period. A small floating inclined-plane trap was operated late winter through spring to trap sockeye and Chinook fry. This trap was designed to minimize predation in the trap by reducing capture of yearling migrants. A floating rotary screw trap was operated early spring through summer to assess migration of larger sub-yearling Chinook as well as coho, steelhead/rainbow, and cutthroat smolts. This trap captured larger migrants that were potential predators of sockeye fry; therefore, the live box was designed to not retain sockeye fry. Together, these traps provided production estimates for each species while minimizing trap-related mortality.

The inclined-plane trap consists of one or two low-angle inclined-plane screen (scoop) traps (3-ft wide by 2-ft deep by 9-ft long) suspended from a 30x13 ft steel pontoon barge. Fish are separated from the water with a perforated aluminum plate (33 - 1/8 in. holes per in^2). The inclined-plane trap resembles larger traps used to capture juvenile salmonids in the Chehalis and Skagit rivers, described by Seiler et al. (1981). Each scoop trap screens a cross-sectional area of 4 ft^2 when lowered to a depth of 16 inches. The screw trap consisted of a 5-ft diameter rotary screw trap supported by a 12-ft wide by 30-ft long steel pontoon barge (Seiler *et al.* 2003).

Over the 25 years that the Cedar River juvenile monitoring study has been conducted, trapping operations have been modified in response to changes in channel morphology and project objectives. In summer 1998, the lower Cedar River was dredged to reduce flooding potential in the City of Renton (USACE 1997). Dredging lowered the streambed, created a wider and deeper channel, and reduced water velocity at the inclined-plane trap location to nearly zero. In response, the inclined-plane trap location was moved upstream in 1999 to river mile 0.8 in order to operate under suitable current velocities.

In 2016, the inclined-plane trap was anchored at RM 0.8, just downstream of the South Boeing Bridge (Figure 1). This trap was positioned off the east bank and repositioned within eight feet of the shoreline in response to changing flows. Both traps fished during the season. One trap consistently fished through the entire season and used for estimating abundance. The second trap was fished sporadically for the sole purpose of collecting additional fish for increasing the number of fish in efficiency trials.

The inclined-plane trap began operating on the night of January 25, 2016 and was operated 55 nights between January 25 and April 21. During each night of operation, trapping began before dusk and continued past dawn. Trapping was also conducted during seven day-light periods between early February and early April. Each hour, captured fish were removed from the trap, identified by species, and counted. Fork lengths were randomly sampled on a weekly basis from all salmonid species, except for sockeye.

The Cedar River Sockeye Hatchery released hatchery reared sockeye fry into the Cedar River above the trap on six nights throughout the season. Fish were released at three separate locations throughout the season and often at two locations on the same night. In total four releases occurred at the lower location (R.M. 2.1) and middle location (R.M. 13.5) and three releases at upper location (R.M. 21.8). A total of 3.2 million fry were released in 2016. To avoid complications estimating hatchery and natural-origin components, the trap was not operated on hatchery release nights. In the past we have assessed that there are residual hatchery sockeye in trap catches following up to three nights after a hatchery release (Kiyohara, 2013). Since hatchery sockeye fry are not externally identifiable as hatchery fish, we are unable to assess the rate of contribution of hatchery fry to natural origin catch and abundance. True abundance and survival of hatchery origin sockeye is likely higher than reported, and natural origin sockeye are likely lower than reported.

In 2016, the screw trap was operated at R.M 1.6, just under the I-405 Bridge (Figure 1) and fished continuously between April 14 and July 14, except for 20 periods when the trap did not operate during daylight periods due to public safety concerns and 10 nights when the trap stopped fishing during the night due to debris. Catches were identified by species and enumerated at dusk and in the early morning in order to discern diel movements. Fork length was measured from a weekly random sample of all Chinook, coho, steelhead/rainbow, and cutthroat smolts.

Bear Creek

A rotary screw trap was operated 100 yards downstream of the Redmond Way Bridge from January 27 to July 14, 2016. The trap was fished for 5 night periods and 6 day periods each week from January 27 to April 8, then fished continuously except for 8 periods when debris stopped the trap.

The screw trap is identical to that employed in the Cedar River and was positioned in the middle of the channel approximately 100 yards downstream of Redmond Way, below the railroad trestle (Figure 1). Catches were identified to species and enumerated at dusk and in the early morning. Fork lengths were randomly sampled on a weekly basis from all Chinook, coho, and cutthroat smolts.

PIT Tagging

During screw trap operation at both sites, a portion of natural-origin Chinook migrants were tagged with passive integrated transponder (PIT) tags. Captured steelhead were tagged as well. Tagging occurred two to three times a week, depending on catches, between April 18 and June 15, 2016. Fish were often held from the previous day to be tagged to increase the total number of fish tagged per day. Fish were released the same day they were tagged. Fish were never held for more than 2 days total. Fish were held in partially-perforated buckets suspended in the river off the stern of the trap or in the live box. Chinook longer than 65 mm that displayed good physical health were considered for tagging. Fork lengths were measured for all PIT tagged fish. Protocols for tagging follow those outlined for the Columbia River basin by the PIT Tag Steering

Committee (2014). Chinook were also tagged at the Landsburg Forebay in the upper Cedar River watershed during the annual cleaning routine. A number of larger Chinook captured during the dewatering process were readily available for tagging and the opportunity was advantageous for increasing the total number of tags in the system.

In 2016, a portion of Issaquah Hatchery Chinook were also tagged and released on three different release dates: May 1, 8, and 18. Survival and detection data are included and compared to that of Bear Creek and Cedar River.

At the Hiram Chittenden Locks facility demarcating the boundary between the Lake Washington watershed from the marine waters of Puget Sound, PIT tag antennae were positioned in the four smolt flumes and the adult fish ladder. In addition, a new antenna was added to one of the large locks filling culverts. Detections from this new location were included in the analysis. Median migration date was the median date of all detected fish at all detection locations at the Hiram Chittenden Locks. Average travel times were calculated using tag date and subsequent detection date at the Hiram Chittenden Locks.

Trap Efficiencies

Cedar River

Inclined-Plane Trap

Trap efficiencies for sockeye in the Cedar River inclined-plane trap were estimated from recaptures of marked natural or hatchery origin sockeye fry released above the trap. Natural origin sockeye captured in the early hours of the same or previous night were used for efficiency trials. Some releases were augmented with hatchery sockeye to create larger release groups. All fry used for efficiency trials were marked in a solution of Bismarck brown dye (14 ppm for 1.5 hours). The health of marked fish was assessed prior to release. Deceased or compromised fish were not included in releases. Fish were transported in buckets with battery operated aerators if needed. At the release location, marked fry were distributed across the middle of the channel using a swinging bucket on a rope. Catches were examined for marked fish and recaptures were noted during each trap check. In 2016, Chinook catches were consistently large enough for regular efficiency trials until March 14, when catches declined and were insufficient for efficiency trials. Following March 14, sockeye trap efficiencies were used for Chinook abundance estimates.

Screw Trap

Trap efficiencies of the Cedar River screw trap were determined for Chinook, coho, and cutthroat from recaptures of marked fish released above the trap. Trap efficiency trials were conducted for each species. Fish were anesthetized in a solution of MS-222 and marked with alternating upper and lower, vertical and horizontal partial-caudal fin clips. Marks were changed on weekly intervals or more frequently when there was a significant change in river discharge. Beginning April 26, Chinook parr larger than 65-mm FL were tagged with PIT tags while smaller Chinook continued to be fin clipped. Similar to fin marks, PIT tags enabled stratified releases and recaptures to be evaluated during data analysis. In addition, individual fish could be identified from the PIT tags, providing information on recapture timing for release groups.

Marked fish were allowed to recover from the anesthetic during the day in perforated buckets suspended in calm river water. In the evening, groups were released at approximately R.M. 2.6 near the Maplewood Roadside Park. Efficiency trial releases were conducted every night or every other night, with frequency determined by the catch of each species. Catches were examined for marks or tags and recaptures were noted during each trap check.

Bear Creek

Similarly to the Cedar River inclined-plane trap, sockeye efficiencies for the Bear Creek screw trap were estimated from recaptures of marked sockeye fry released above the trap, approximately 100 yards upstream of the trap at the Redmond Way Bridge. Fry releases occurred when adequate numbers of fish were available. Fry captured the previous night were marked in a solution of Bismarck brown dye (14 ppm for 1.5 hours). The health of marked fish was assessed prior to release. Deceased or compromised fish were not included in releases. Catches were examined for marks and recaptures were noted during each trap check.

Trap efficiencies of Chinook parr, coho, and cutthroat in Bear Creek screw trap were estimated using the same approach described for similar species at the Cedar River inclined-plane and screw traps. The use of PIT tags to determine Chinook trap efficiency began on April 18, slightly earlier than in the Cedar River. Efficiency trial releases were conducted every night or every other night, with frequency driven by the availability of each species in the day's catch.

Analysis

The abundance of juvenile migrant salmonids was estimated using a mark-recapture approach and a single trap design (Volkhardt et al. 2007). The analysis was stratified by time in order to account for heterogeneity in capture rates throughout the season. The general approach was to estimate (1) missed catch, (2) efficiency strata, (3) abundance for each strata, (4) extrapolated migration prior to and post trapping, and (5) total production.

Missed Catch

Total catch ($\hat{u}_i$) during period i was the actual catch (n) summed with estimated missed catch ($\hat{n}$) during trap outages. Missed catch was estimated using three different approaches depending on what type of trap outage occurred: 1) entire night periods when trap operations were suspended, 2) partial day or night periods when trap operations were suspended, and 3) entire day periods when trap operations were suspended. Three approaches were used because salmonid catch rates differ between the day and night time hours.

Missed Catch for Entire Night Periods

When the trap operations were suspended for entire night periods, missed catch was estimated using a straight-line interpolation between catches on adjacent nights. This approach assumes that abundance of migrating fish during the adjacent nights were similar to the outage period. When the outage occurred on a single night, variance of the estimated catch was the variances of the mean catch on adjacent nights (Equation 1). When the outage occurred on multiple consecutive nights, then one or both adjacent night catches were estimates and Equation 2 was used.

Equation 1

$$Var(\overline{n}_i) = \frac{\sum (n_i - \overline{n}_i)^2}{k(k-1)}$$

Equation 2

$$Var(\overline{n}_i) = \frac{\sum (\hat{n}_i - \overline{n}_i)^2}{k(k-1)} + \frac{\sum Var(\hat{n}_i)}{k}$$

where:

k = number of sample nights used in the interpolation,

n_i = actual night catch of unmarked fish used to estimate the un-fished interval,

$\overline{n}_i$ = interpolated night catch estimate (mean of adjacent night catches), and

$\hat{n}_i$ = missed night catch (estimated) of unmarked fish used to estimate the un-fished interval

When the night catch estimate was interpolated for two or more consecutive nights, variance for each interpolated catch estimate was approximated by scaling the coefficient of variation (*CV*) of mean catch for adjacent night fishing periods by the interpolated catch estimates using:

Equation 3

$$Var(\hat{n}_i) = \left[\hat{n}_i \left(\frac{\sqrt{Var(\overline{n}_i)}}{\overline{n}_i} \right)^2 \right]$$

Missed Catch for Partial Day and Night Periods

When the inclined-plane trap was operated intermittently through the night or the screw trap operated intermittently, missed catch during the un-fished interval ($\hat{n}_i$) was estimated by:

Equation 4

$$\hat{n}_i = T_i * \overline{R}$$

where:

T_i = Hours during non-fishing period *i*

$\overline{R}$ = Mean catch rate (fish/hour) from adjacent fished periods

Variance associated with $\hat{n}_i$ was estimated by:

Equation 5

$$Var(\hat{n}_i) = T_i^{\ 2} * Var(\overline{R})$$

Variance of the mean catch rate ($\overline{R}$) for k adjacent fishing periods was:

Equation 6

$$Var\left(\overline{R}\right) = \frac{\sum_{i=1}^{i=k} (R_i - \overline{R}\ )^2}{k\left(k-1\right)}$$

Missed Catch for Entire Day Periods

Missed day-time catches in the inclined-plane trap were estimated by multiplying the previous night catch by the proportion of the 24-hour catch caught during the day. This proportion (F_d) was estimated as:

Equation 7

$$\hat{F}_d = \frac{T_d}{\overline{Q}^{-1} T_n + T_d}$$

Variance in the day-to-night catch ratio was:

Equation 8

$$Var(\hat{F}_d) = \frac{Var(\overline{Q}) T_n^{\ 2} T_d^{\ 2}}{\overline{Q}^4 \left(\frac{1}{\overline{Q}} T_n + T_d \right)^4}$$

where:

T_n = hours of night during 24 hour period,
T_d = hours of day during 24 hour period, and
$\overline{Q}_d$ = bi-weekly day-to-night catch ratio.

Efficiency Strata

Stratification of the capture and recapture data was necessary to accommodate for changes in trap efficiency over the season. These changes result from a number of factors including river flows, turbidity, and fish sizes. However, when using a mark-recapture approach to estimate abundance, precision of the estimate increases with the number of recaptures. A manufactured drawback of stratification can be a large variance associated with the estimate. Therefore, a *G*-test was used to determine whether to pool or hold separate adjacent efficiency trials (Sokal and Rohlf 1981).

Of the marked fish (*M*) released in each efficiency trial, a portion are recaptured (*m*) and a portion are not seen (*M*-*m*). If the seen:unseen [*m*:(*M*-*m*)] ratio differs between trials, the trial periods were considered as separate strata. However, if the ratio did not differ between trials, the two trials were pooled into a single stratum. A *G*-test determined whether adjacent efficiency trials were statistically different ($\alpha = 0.05$). Trials that did not differ were pooled and the pooled group compared to the next adjacent efficiency trial. Trials that did differ were held separately. Pooling of time-adjacent efficiency trials continued iteratively until the seen:unseen ratio differed between time-adjacent trials. Once a significant difference was identified, the pooled trials were assigned to one strata and the significantly different trial indicated the beginning of the next strata.

Abundance for Each Strata

The abundance of juvenile migrants for a given strata *h* was calculated from maiden catch (actual and missed, $\hat{u}_h$), marked fish released in that strata (M_h), and marked fish recaptured in that strata (m_h). Abundance was estimated using a Bailey estimator appropriate for single trap designs (Carlson et al. 1998, Volkhardt et al 2007):

Equation 9

$$\hat{U}_h = \frac{\hat{u}_h (M_h + 1)}{m_h + 1}$$

Variance associated with the Bailey estimator was modified to account for variance of the estimated catch during trap outages (derivation in Appendix A):

Equation 10

$$V(\hat{U}_h) = V(\hat{u}_h)\left(\frac{(M_h+1)(M_h m_h + 3M_h + 2)}{(m_h+1)^2(m_i+2)}\right) + \left(\frac{(M_h+1)(M_h - m_h)\hat{u}_h(\hat{u}_h + m_h + 1)}{(m_h+1)^2(m_h+2)}\right)$$

Maiden catch ($\hat{u}_h$) was the sum of all actual and estimated catch during strata *h*. Variance of the catch [$V(\hat{u}_h)$] was the sum of all estimated catch variances during strata *h*.

Extrapolate Migration Prior to and Post Trapping

Modality of the trap catches suggested that migration outside the period of trap operation was minimal. Pre- and post-trapping migrations were estimated using linear extrapolation.

Equation 11

$$\hat{N}_e = \frac{\sum_{d=1}^{d=k} \hat{N}_d}{k} * \frac{t}{2}$$

Variance of the extrapolation was estimated as:

Equation 12

$$V(\hat{N}_e) = \frac{\sum_{d=1}^{d=k} (\hat{N}_d - \overline{N})^2}{k(k-1)} * \left(\frac{t}{2}\right)^2$$

where:

$\hat{N}_d$ = Daily migration estimates,

k = Number of daily migration estimates used in calculation, and

t = Number of days between assumed start/end of migration and the first/last day of trapping.

Pre- and post-season migration was based on the first and last five days of measured migration. The assumed migration for sockeye was January 1 to June 30 on the Cedar River and January 1 to April 30 on Bear Creek. The assumed migration for Chinook in both watersheds was January 1 to July 13. Pre- and post-season migration was not estimated for coho or cutthroat.

Total Production

Total production was the sum of the stratified abundance estimates for all *k* strata and the extrapolated migration estimates:

Equation 13

$$\hat{N} = \hat{N}_{before} + \sum_{h=1}^{h=k} \hat{U}_h + \hat{N}_{after}$$

Total variance was the sum of stratified abundance variances and extrapolated migration variances. Confidence intervals and coefficient of variation associated with abundances were calculated from the variance.

Egg-to-Migrant Survival and Productivity

Egg-to-migrant survival estimates are the measured survival between egg deposition and migration of juveniles into Lake Washington. Survival was estimated by dividing the 2016 abundance of natural-origin juvenile migrants by the 2015 potential egg deposition (PED) for each species and watershed. PED was the product of the number of female spawners and their fecundity. Sockeye spawner abundances in the Cedar River and Bear Creek were Area-Under-the-Curve estimates that were calculated in a multi-agency collaborative effort. This estimate assumed an even sex ratio for sockeye. Cedar River sockeye fecundity (3,070 eggs per female) was estimated by the average number of eggs per female during 2015 sockeye broodstock collection for the Cedar River Sockeye Hatchery (Sedgwick, 2016). Fecundity of Bear Creek sockeye was assumed to be the same as the fecundity of Cedar River sockeye.

Productivity for Chinook in both Cedar River and Bear Creek was measured by the number of migrants produced per female spawner that contributed to the outmigrating brood year. Two life-history forms of sub-yearling Chinook salmon are observed in Puget Sound: small fry migrating immediately after emergence and larger parr that spend some time rearing in freshwater. The small fry are defined as fish emigrating between January and early May and larger parr are defined as fish emigrating between early May and July. Because there is an unknown in-river mortality rate during the fry to parr transition, we have chosen to report Chinook freshwater productivity as the number of migrants (both fry and parr combined) per female. We suggest that reporting fry and parr survival separately, as was calculated in previous reports, underestimates the true fry survival because it does not include the fish that migrated as parr (which obviously survived the fry stage). Productivity is further divided into the number of fry and parr per female. The number of female Chinook was based on annual redd counts conducted by state and local agencies and assumed to represent one female per redd (Burton, Craig, & Lantz, 2016). Average fecundity for Cedar River and Bear Creek (4,500 eggs per female) is assumed to be similar to the fecundity of Soos Creek Hatchery Chinook on the Green River.

Cedar River

Sockeye

Production Estimate

Total catch (actual and estimated missed) in the inclined-plane trap was 17,367 sockeye fry. A total of 7,826 natural-origin sockeye fry were caught in the inclined-plane trap during trap operations. We estimated a missed catch of an additional 9,541 sockeye fry for all night trap outages between January 25 and April 21, 2016. Seven day intervals were trapped to evaluate day-time migration: February 8, 16 and 29, and March 7, 22, 29, and April 5. Flows on these days ranged from 555 cfs to 2,882 cfs at the Cedar River USGS gage (#12119000). Day-to-night catch ratios ranged from 4.58% to 211.12%. We estimated a missed catch of 3,893 fry for all day-time trap outages.

Table 1. Abundance of natural-origin sockeye fry entering Lake Washington from the Cedar River in 2016. Table includes; total catch, abundance of fry migrants, 95% confidence intervals (C.I.), and coefficients of variation (CV).

Capture Method	Dates	Total Catch	Fry Abundance	95% C.I. Low	95% C.I. High	*CV*
Pre Trapping	January 1 - 24		68,334	31,698	104,970	27.35%
During Trapping	January 25-April 21	17,367	2,004,802	1,554,927	2,454,677	11.45%
Post Trapping	April 22- June 30		90,707	45,794	135,620	25.26%
	Total		**2,163,843**	**1,710,250**	**2,617,437**	**10.70%**

A total of 12 efficiency trials were conducted in 2016. Low catches limited the number of trials that could be conducted. Efficiency groups of natural origin sockeye were supplemented with hatchery sockeye fry to increase the total number of sockeye released to increase confidence in our estimates. Efficiency data were aggregated into three strata. Capture rates for these strata ranged from 0.65% to 3.54% (Appendix B).

An estimated 2.16 million natural-origin sockeye fry entered Lake Washington from the Cedar River in 2016 (Table 1, Appendix A 1). This estimate includes pre-season and post-season estimates of 159,041 fry total, as well as the estimated abundance of fry during the trapping period of 2.0 million fry. Both pre- and post-season tails each represent less than 4% of the total natural production. Coefficient of variation (*CV*) associated with the natural-origin migration was 10.70%.

Migration began prior to our first day of trapping as noted by sockeye catches on the first night. Migration began moderately with a few notable peaks on February 16 and March 11 of 140,000 and 100,000 sockeye respectively. Migration then declined for the remainder of the season (Figure 2). Due to low catches we were unable to form efficiency trails after April 5 leading to an early conclusion of trapping on April 21. Median migration date for natural-origin sockeye was March 7 (Table 3).

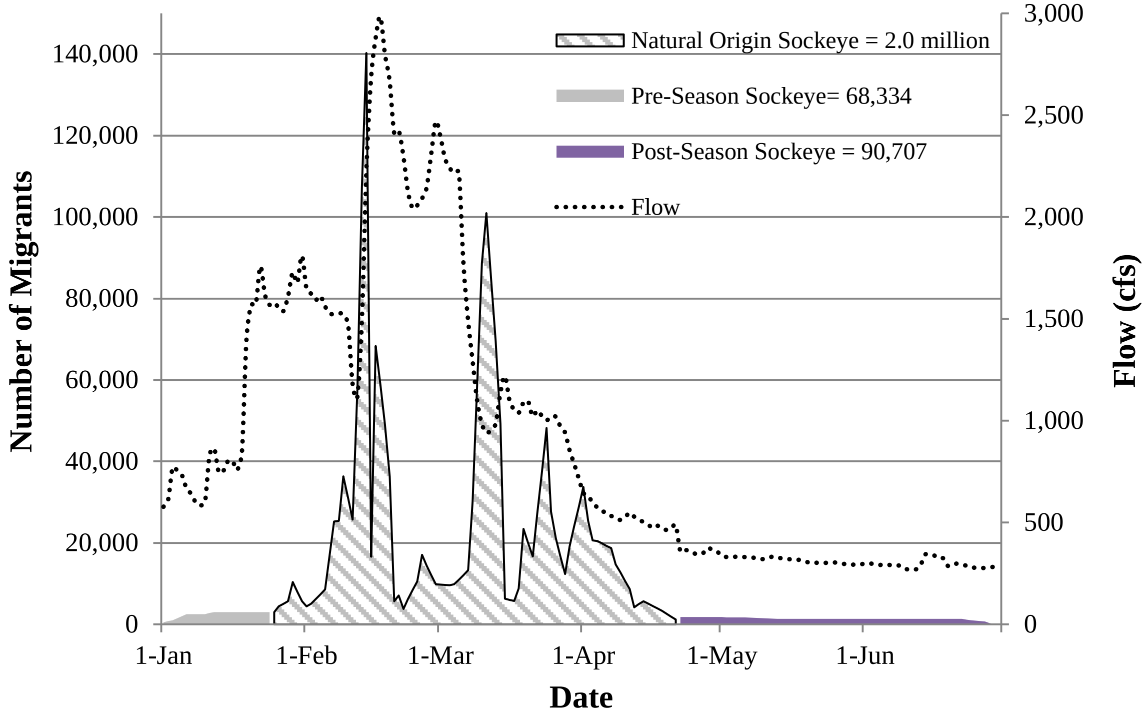

Figure 2. Estimated daily migration of natural-origin sockeye fry migrating from the Cedar River into Lake Washington between January 25 and April 21, 2016. Pre- and post-trapping migration estimates are included. Graph includes daily average flows during this period (USGS Renton gage Station #12119000).

The Cedar River Sockeye Hatchery released sockeye from February 22, 2016 through April 11, 2016. Total sockeye released from the hatchery was 3.26 million. Sockeye were released at three locations above the trap. The trap did not sample any releases in 2016. Hatchery sockeye median migration date was later (seven days) than the median migration date of naturally produced sockeye in 2016 (Table 3).

Table 2. Total number and release locations of hatchery sockeye released from the Cedar River Sockeye Hatchery in 2016.

	Release Location		
Release Date	**Lower**	**Middle**	**Upper**
2/22/2016	228,505		96,811
3/7/2016		670,937	
3/14/2016		289,257	343,040
3/21/2016	429,661	174,400	
3/28/2016	473,648		234,675
4/11/2016	193,537	152,038	
Total	1,325,351	1,286,632	674,526

Table 3. Median migration dates of natural-origin, hatchery, and total (combined) sockeye fry from the Cedar River for brood years 1991 to 2015. Total thermal units for February were measured in degrees Celsius at the USGS Renton gage, Station #12119000. Temperature was not available for the 1991 brood year.

Brood Year	Trap Year	February	Median Migration Date			Difference
i	i+1	Thermal Units	Wild	Hatchery	Combined	(days) W-H
1991	1992		03/18	02/28	03/12	19
1992	1993	156	03/27	03/07	03/25	20
1993	1994	162	03/29	03/21	03/26	8
1994	1995	170	04/05	03/17	03/29	19
1995	1996	153	04/07	02/26	02/28	41
1996	1997	147	04/07	02/20	03/16	46
1997	1998	206	03/11	02/23	03/06	16
1998	1999	187	03/30	03/03	03/15	27
1999	2000	161	03/27	02/23	03/20	32
2000	2001	158	03/10	02/23	03/08	15
2001	2002	186	03/25	03/04	03/19	21
2002	2003	185	03/08	02/24	03/03	12
2003	2004	186	03/21	02/23	03/15	26
2004	2005	193	03/02	02/23	03/01	7
2005	2006	184	03/20	03/06	03/16	14
2006	2007	193	03/23	02/20	02/26	31
2007	2008	170	03/16	03/06	03/15	10
2008	2009	187	03/19	03/06	03/13	13
2009	2010	219	03/07	03/08	03/07	-1
2010	2011	163	03/25	02/18	03/01	35
2011	2012	170	03/22	03/08	03/18	14
2012	2013	184	03/07	03/06	03/07	1
2013	2014	160	03/02	03/11	03/04	-9
2014	2015	222	03/07	03/12	03/07	-5
2015	2016	190	03/07	03/14	03/14	-7
	Average		03/19	03/02	03/11	16

Egg-to-Migrant Survival of Natural-Origin Fry

Egg-to-migrant survival of the 2015 brood Cedar River sockeye was estimated to be 19.6% Table 4). Survival was based on 2.1 million natural-origin fry surviving from a potential 11.0 million eggs deposited by 3,596 females (B. Craig, Washington Department of Fish and Wildlife, personal communication). Average fecundity for the 2015 brood was 3,070 eggs per female sockeye (Sedgwick 2016).

Survival of the 2015 brood was the eighth highest observed since monitoring began. Despite several high flow events peaking as high as 4,661 cfs at the Renton gage during incubation, fry appear to have survived rather well. We have noted higher than expected fry survival in years when high flow events occur in conjunction with low spawner abundance. Fewer spawners may allow for selective use of preferred spawning locations resulting in greater survival of offspring.

Table 4. Egg-to-migrant survival of natural-origin sockeye fry in the Cedar River and peak mean daily flows during egg incubation period for brood years 1991 - 2015. Incubation period is defined from November to February. Flow was measured at the USGS Renton gage, Station #12119000.

Brood Year	Spawners	Females (@50%)	Fecundity	Potential Egg Deposition	Fry Production	Survival Rate	Peak Incubation Flow (cfs)	Date
1991	76,592	38,296	3,282	125,687,226	9,800,000	7.80%	2,060	1/28/1992
1992	99,849	49,924	3,470	173,237,755	27,100,000	15.64%	1,570	1/26/1993
1993	74,677	37,338	3,094	115,524,700	18,100,000	15.67%	927	1/14/1994
1994	107,767	53,883	3,176	171,133,837	8,700,000	5.08%	2,730	12/27/1994
1995	21,443	10,721	3,466	37,160,483	730,000	1.96%	7,310	11/30/1995
1996	228,391	114,196	3,298	376,616,759	24,390,000	6.48%	2,830	1/2/1997
1997	102,581	51,291	3,292	168,848,655	25,350,000	15.01%	1,790	1/23/1998
1998	48,385	24,193	3,176	76,835,676	9,500,000	12.36%	2,720	1/1/1999
1999	21,755	10,877	3,591	39,060,930	8,058,909	20.63%	2,680	12/18/1999
2000	146,060	73,030	3,451	252,025,754	38,447,878	15.26%	627	1/5/2001
2001	117,225	58,613	3,568	209,129,787	31,673,029	15.15%	1,930	11/23/2001
2002	192,395	96,197	3,395	326,590,484	27,859,466	8.53%	1,410	2/4/2003
2003	109,164	54,582	3,412	186,233,926	38,686,899	20.77%	2,039	1/30/2004
2004	114,839	57,419	3,276	188,106,200	37,027,961	19.68%	1,900	1/18/2005
2005	49,846	24,923	3,065	76,388,804	10,861,369	14.22%	3,860	1/11/2006
2006	105,055	52,527	2,910	152,854,370	9,246,243	6.05%	5,411	11/9/2006
2007	45,066	22,533	3,450	77,738,114	25,072,141	32.25%	1,820	12/3/2007
2008	17,300	8,650	3,135	27,118,177	1,630,081	6.01%	9,390	1/8/2009
2009	12,501	6,250	3,540	22,125,910	12,519,260	56.58%	2,000	11/19/2009
2010	59,795	29,898	3,075	91,935,489	4,517,705	4.91%	5,960	1/18/2011
2011	23,655	11,827	3,318	39,243,121	14,763,509	37.62%	2,780	1/30/2012
2012	88,974	44,487	3,515	156,371,805	55,793,120	35.68%	1,513	12/7/2012
2013	140,682	70,341	3,362	236,486,442	37,975,769	16.06%	1,762	11/20/2013
2014	10,450	5,225	3,368	17,597,800	13,878,932	78.87%	2,162	1/8/2015
2015	7,191	3,596	3,070	11,038,185	2,163,843	19.60%	4,661	12/7/2015

Chinook

Production Estimate

Production of natural-origin Chinook was estimated to be 972,641 ± 408,314 (±95% C.I.) sub-yearlings, based on operation of both the inclined-plane and screw traps. Between January 1 and Apri1 13, 2016 941,443 ± 408,028 (±95% C.I.) natural-origin Chinook were estimated to have passed the inclined-plane trap (Table 5, Appendix A 2). This includes an estimate for a pre-trapping period from January 1 to 24 of 181,410 fry and an estimate of 760,033 Chinook fry during the time the inclined-plane trap was operating from January 25 to April 13. This estimate was based on a total catch of 6,787. Chinook efficiency trials were conducted regularly from the start of the season through March 14. Chinook catches declined for the remainder of the period in which the inclined plane trap was operated impacting our ability to conduct further Chinook efficiency trials until the rotary screw trap was deployed (see below). As a result, we relied on sockeye releases to estimate trap efficiency from March 15 to April 13. Although trap efficiencies are not statistically different between sockeye and Chinook, we felt it appropriate to use Chinook trap efficiencies for the period of time we have consistent and reliable data. Trap efficiencies ranged from 0.79% to 3.54%.

Between April 14 and July 14, 2016, 31,198 ± 15,257 (±95% C.I.) natural-origin Chinook parr were estimated to have passed the screw trap (Table 5, Figure 4, Appendix A 3). This estimate is based on a total catch of 1,856 natural-origin juvenile Chinook parr in the screw trap and trap efficiency ranging from 1.3% to 14.9%.

We estimated the abundance of two life-history forms of sub-yearling Chinook salmon observed in Puget Sound: small fry migrating immediately after emergence and larger parr that spend some time rearing and growing in freshwater. The small fry are defined as fish emigrating between January and early April and comprised 97% of all sub-yearlings. The larger parr are defined as fish emigrating between early April and July and comprised 3% of the total migration (Table 8). In 2015, 56% of the fry migration occurred in February which is a month earlier than what is typically observed. Warmer than usual fall and winter temperatures may have contributed to this pattern by increasing incubation rates. Chinook abundance slowly grew over the season to one prominent peak in late February then slowly decreased for the remainder of the season (Figure 3). The parr portion of the migration was much less prominent than the fry component and displayed sporadic movements with one 6-day peak in the end of May that averaged 2,200 Chinook per day (Figure 4).

Table 5. Abundance of natural-origin juvenile migrant Chinook in the Cedar River in 2016. Data are total catch, abundance, 95% confidence intervals (C.I), and coefficient of variation (*CV*).

Capture Method	**Period**	**Total Catch**	**Abundance**	**95% C.I. Low**	**95% C.I. High**	**CV**
Pre-trapping	January 1 - 24		181,410	36,068	326,752	40.88%
Fry Trap	Janunary 25 - April 13	6,787	760,033	378,768	1,141,298	25.59%
Fry Trap subtotal			941,443	533,415	1,349,471	22.11%
Screw Trap	April 14 - July 14	1,856	31,198	15,941	46,454	24.95%
TOTAL		**8,643**	**972,641**	**564,327**	**1,380,954**	**21.42%**

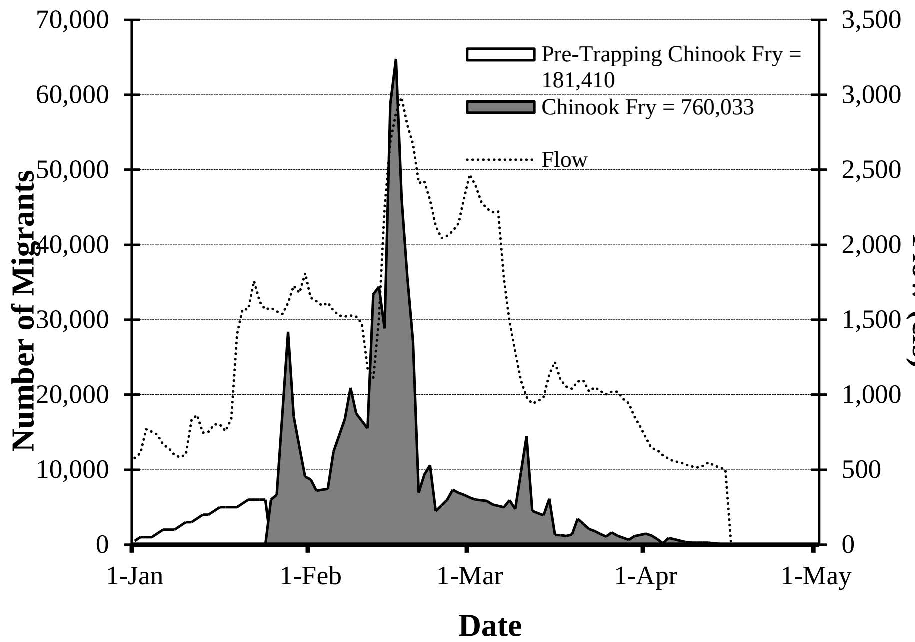

Figure 3. Estimated daily migration of Chinook fry from the Cedar River in 2016 based on inclined-plane trap estimates from January 1 to April 13. Pre-trapping migration estimate included. Graph includes mean daily flows during this time period (USGS Renton gage, Station #12119000) in 2016.

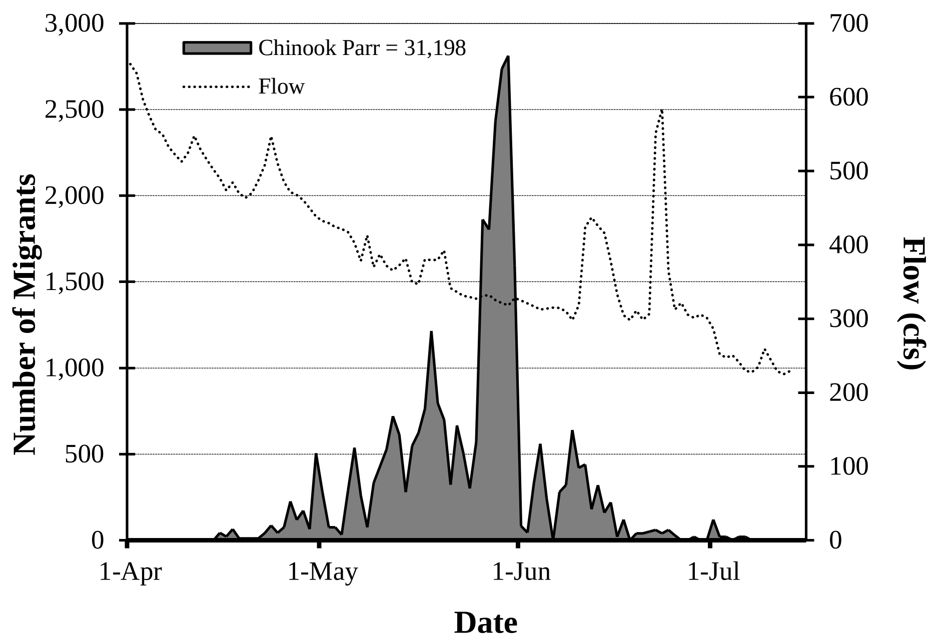

Figure 4. Estimated daily migration of Chinook parr from the Cedar River in 2016 based on screw trap estimates from April 8 to July 13. Graph includes mean daily flows during this time period (USGS Renton gage, Station #12119000) in 2016.

Productivity

The number of juvenile Chinook migrants produced per female spawner was the fifth highest observed from the Cedar River at 1,364 migrants per female (Table 7). The number of fry per female is also the fifth highest (1,320) however the number of parr per female is the sixth lowest since monitoring began. Productivity is higher than what would be expected following two rather dynamic flow events in the Cedar River during incubation. In November flow peaked at 3,600 cfs and in December flows exceeded 4,600 cfs in Renton. Flows during the fry migration period were rather high, averaging 1,600 cfs from January through March, which may have influenced the large number of fry migrants. Productivity was based on 713 female spawners (Burton et al. 2016).

Table 6. Abundance of Chinook fry and parr and productivity (juveniles per female) among brood years. Fry migration estimates were made using inclined-plane trap data. Chinook parr estimates were formed using screw trap data for the remainder of the season. Transition date represents the date which the change from inclined-plane to screw trap data was used to form Chinook estimates. Data are Cedar River broods 1998 to 2015.

Brood	Trapping Dates			Juvenile Abundance			95%	Percent Abundance		Est.	Juveniles/Female			Egg to Migrant
Year	Start	Transition	End	Fry	Parr	Total	CI (±)	Fry	Parr	Fem.	Fry	Parr	Total	Survival
1998	23-Jan	18-Mar	27-Jul	63,702	17,230	80,932	7,732	79%	21%	173	368	100	468	10.4%
1999	20-Jan	27-Apr	13-Jul	46,500	18,223	64,723	5,609	72%	28%	182	255	100	356	7.9%
2000	18-Jan	9-Apr	22-Jul	10,833	21,416	32,249	5,220	34%	66%	53	204	404	608	13.5%
2001	25-Jan	15-Apr	22-Jul	79,799	39,875	119,674	41,349	67%	33%	398	201	100	301	6.7%
2002	21-Jan	21-Apr	12-Jul	194,657	40,740	235,397	51,485	83%	17%	281	693	145	838	18.6%
2003	18-Jan	14-Apr	20-Jul	65,752	55,124	120,876	2,518	54%	46%	337	195	164	359	8.0%
2004	21-Jan	11-Apr	29-Jul	74,292	60,006	134,298	42,912	55%	45%	511	145	117	263	5.8%
2005	20-Jan	1-May	16-Jul	98,967	18,592	117,559	16,233	84%	16%	339	292	55	347	7.7%
2006	18-Jan	18-Apr	20-Jul	110,961	14,225	125,186	16,912	89%	11%	587	189	24	213	4.7%
2007	13-Jan	18-May	19-Jul	705,583	61,379 - 67,037	766,962 - 772,620	76,106	89.5-90.1%	9.9-10.5%	899	785	68-75	853-859	19.0% - 19.1%
2008	1-Feb	22-Apr	18-Jul	127,064	12,388	139,452	38,399	91%	9%	599	212	21	233	5.2%
2009	17-Jan	16-Apr	4-Jul	115,474	36,916	152,390	13,058	76%	24%	285	405	130	535	11.9%
2010	30-Jan	10-May	16-Jul	177,803	10,003	187,806	63,560	95%	5%	266	668	38	706	15.7%
2011	22-Jan	11-May	14-Jul	863,595	38,919	902,514	165,973	96%	4%	324	2,665	120	2,786	61.9%
2012	24-Jan	30-Apr	17-Jul	874,658	19,219	893,877	77,993	98%	2%	433	2,020	44	2,064	45.9%
2013	17-Jan	3-May	16-Jul	1,426,631	32,130	1,458,761	390,039	98%	2%	740	1,928	43	1,971	43.8%
2014	14-Jan	8-Apr	8-Jul	326,901	20,762	347,663	89,751	94%	6%	232	1,409	89	1,499	33.3%
2015	25-Jan	14-Apr	14-Jul	941,443	31,198	972,641	408,313	97%	3%	713	1,320	44	1,364	30.3%

Size

Weekly average lengths of sub-yearling Chinook increased from 40.2 mm fork length (FL) in early February to 100.0 mm FL by July (Figure 5). Chinook caught in the inclined-plane trap ranged from 32 mm FL to 81 mm FL and averaged 41.3 mm FL. Chinook caught in the screw trap increased in size from 53 mm FL to 138 mm FL and averaged 86.6 mm FL.

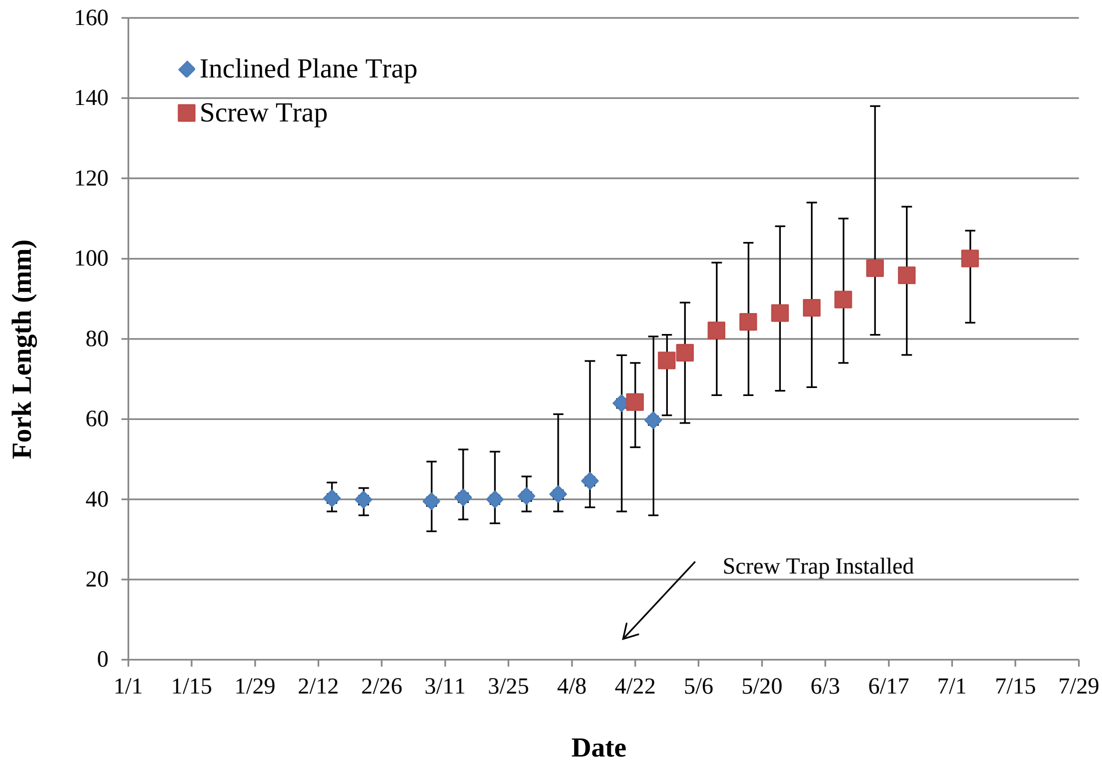

Figure 5. Fork lengths of natural-origin juvenile Chinook sampled from the Cedar River, 2016. Graph shows average, minimum, and maximum lengths by statistical week.

Coho

Production Estimate

During inclined-plane trap operations from January 25 to April 22, 29 coho fry and 35 coho smolts were caught. Catches were insufficient to form efficiency trials and abundance estimates were not made for the period prior to screw trap operations (April 14).

Total catch (actual and missed) of all coho migrants captured in the screw trap was 2,720 coho. This included 2,559 natural-origin coho caught in the screw trap between April 14 and July 14 and an estimated missed catch of 161 coho due to trap outages. Only 29 sub-yearling coho were caught, constituting 1.1% of the total catch.

A total of 17 efficiency trials were conducted. Efficiency trials were aggregated into two strata with trap efficiencies of 2.4% and 5.9% (Appendix A 4). Total coho production was estimated to be 60,621 ± 18,758 (±95% C.I.) migrants for the period the trap was operating with a coefficient of variation of 15.79% (Table 7, Appendix A 4). This estimate includes both yearling and sub-yearlings that moved past the trap during screw trap operations (Figure 6). We observed two life history forms in the Cedar River: typical 1+ yearling coho but also a component that is visually noted as sub-yearling coho, further confirmed by scale analysis. We are unable to determine if these sub-yearling coho exit to marine waters the same year they migrate out of the Cedar River. This abundance estimate represents total abundance of coho exiting the Cedar River into Lake Washington.

Table 7. Abundance of coho migrants from Cedar River in 2016. Table includes abundance of sub-yearling and yearling migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*).

Capture Method	**Dates**	**Total Catch**	**Abundance**	***CV***	**95% C.I.**	
					Low	**High**
Screw Trap	April 14-July 14	2,720	60,621	15.79%	41,862	79,379

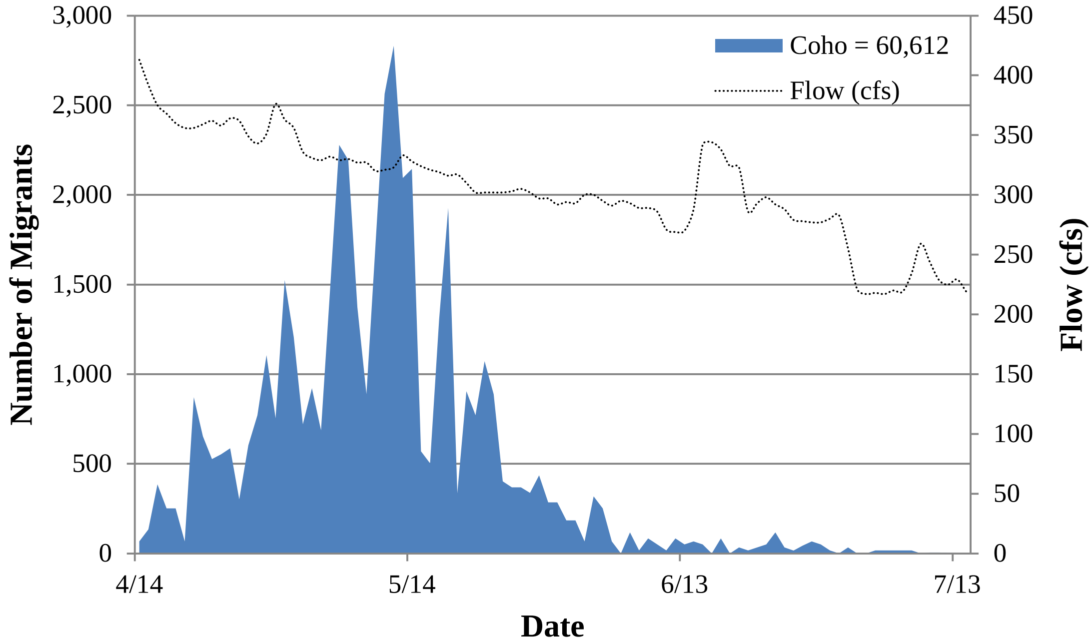

Figure 6. Daily coho migration and daily average flow (USGS Renton gage Station #12119000) at the Cedar River screw trap, 2016. Coho abundance includes both sub-yearling and yearling coho caught in the Cedar River screw trap.

Size

Average fork length of all measured coho migrants, both yearlings and sub-yearlings, was 113.0 mm FL; weekly averages ranged from 93.5 mm to 117.7 mm FL. Individual migrants ranged from 87 mm to 162 mm FL (Figure 7).

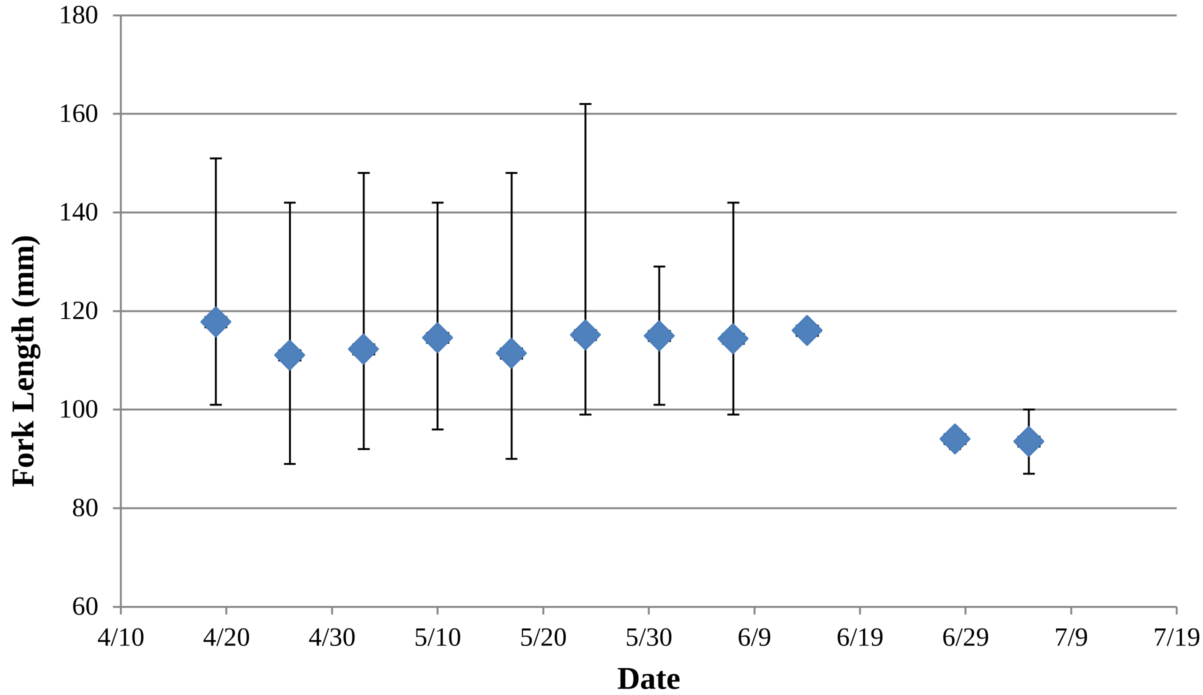

Figure 7. Fork lengths for coho migrants captured in the Cedar River screw trap in 2016. Data are statistical mean, minimum, and maximum lengths.

Trout

Life history strategies used by trout in the Cedar River include anadromous, adfluvial, fluvial, and resident forms. For simplicity, catches and estimates reported herein are for trout that were visually identified as either *Oncorhynchus clarki* (cutthroat trout) or *Oncorhynchus mykiss* (steelhead/rainbow trout) caught in the inclined plane and screw trap. Cutthroat-rainbow hybrids may be included but are difficult to identify in the field. The juvenile anadromous life history strategy, or "smolt," was assigned to *O. mykiss* that had a silver coloration upon capture. Those that did not display smolt-like characteristics were assigned as rainbow trout.

One juvenile cutthroat trout measuring 168 mm was captured in the inclined-plane trap. A total of 3 unidentifiable trout fry, 17 steelhead migrants and 47 juvenile cutthroat trout and 1 adult cutthroat trout were captured in the screw trap. Catches were too few to estimate migrant abundance. Steelhead fork lengths ranged from 158 mm to 251 mm FL and averaged 179.8 mm FL. Juvenile cutthroat fork lengths ranged from 122 mm to 238 mm FL, and averaged 166.2 mm FL.

Incidental Catch

Other salmonid captured in the inclined-plane trap included 1 pink fry and 1 chum fry. Other species caught included three-spine stickleback (*Gasterosteus aculeatus*), unspecified sculpin species (*Cottus* spp.), lamprey (*Lampetra* spp.), speckled dace (*Rhinichthys osculus)*, longfin smelt (*Spirinchus thaleichthys*) and large-scale sucker (*Catostomus macrocheilus*).

Other salmonids caught in the screw trap include 40 ad-marked hatchery Chinook parr, 2 sockeye smolts and 285 sockeye fry. Additional species caught included three-spine stickleback, bluegill (*Lepomis macrochirus*), unspecified sculpin species, large-scale suckers, peamouth (*Mylocheilus caurinus*), lamprey, rock bass (*Ambloplites rupestris*), smallmouth bass (*Micropterus dolomieu*), and warmouth *(Lepomis gulosus).*

Bear Creek

Sockeye

Production Estimate

Total catch (actual and estimated missed) in the Bear Creek screw trap was 5,741 sockeye fry during the trapping period from January 28 to July 14. This included an actual catch of 3,563 sockeye fry and an estimated missed catch of 2,178 sockeye fry. Trap outages included 22 full days early in the season due to staffing constraints and eight periods in which heavy debris prevented the trap from fishing.

Seven efficiency trials using sockeye fry were conducted during the season and aggregated into two final strata, with capture rates ranging from 4.8% to 7.7% (Appendix B1). Catches were initially low and the first efficiency group was not released until February 24. Efficiency releases continued nearly twice or more weekly until March 16 when catches declined near the end of migration.

We estimated a total abundance of 81,125 ± 20,814 (±95% C.I.) sockeye fry emigrating from Bear Creek in 2016 (Table 8, Figure 8). No pre or post trapping abundance was estimated because sockeye were not caught for a week prior to the first sockeye catch nor caught for over a month at the end of the season.

Table 8. Abundance of sockeye fry migrants from Bear Creek in 2016. Table includes abundance of fry migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*).

Capture Method	**Dates**	**Total Catch**	**Fry Abundance**	***CV***	**95% C.I.**	
					Low	**High**
Screw Trap	Jan 28 - July 14	5,741	81,125	13.1%	60,311	101,939

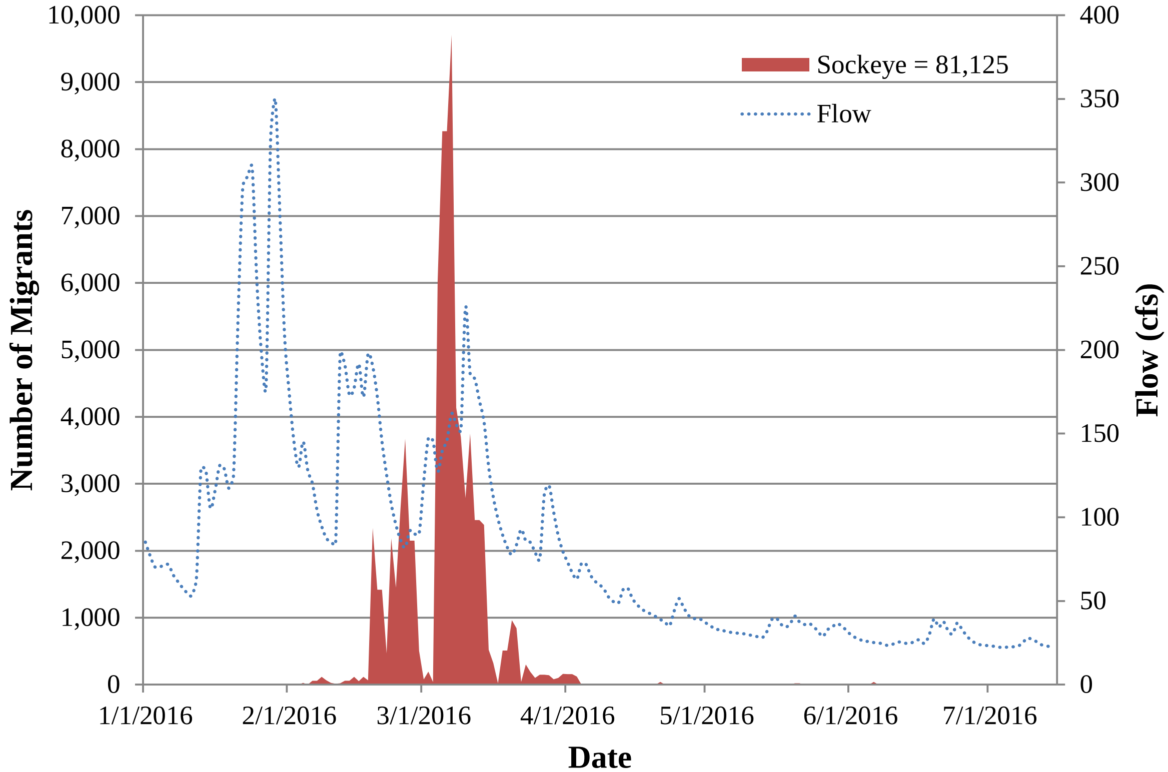

Figure 8. Estimated daily migration of sockeye fry from Bear Creek and daily average flow measured by the King County gage 02a at Union Hill Road in 2016 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2015 brood of Bear Creek sockeye was estimated to be 12.8% (Table 9). Survival was based on 81,125 fry migrants and a PED of 636,490 eggs. PED was estimated based on 207 females in 2015 (B. Craig, Washington Department of Fish and Wildlife, personal communication) and an average fecundity of 3,070 eggs per female based on the data from the Cedar River Sockeye Hatchery from brood year 2015 (Sedgewick 2016). Escapement was the lowest observed since juvenile monitoring began in 1999 and produced the lowest observed fry abundance as well. Regardless of low adult and juvenile abundance, survival is near the average and median of the dataset.

Table 9. Egg-to-migrant survival of Bear Creek sockeye by brood year. Potential egg deposition (PED) was based on fecundity of sockeye broodstock in the Cedar River.

Brood Year	Spawners	Females (@ 50%)	Fecundity	PED	Fry Abundance	Survival Rate	Peak Incubation Flow (cfs)	Peak Incubation Flow Date
1998	8,340	4,170	3,176	13,243,920	1,526,208	11.5%	515	11/26/1998
1999	1,629	815	3,591	2,924,870	189,571	6.5%	458	11/13/1999
2000	43,298	21,649	3,451	74,710,699	2,235,514	3.0%	188	11/27/2000
2001	8,378	4,189	3,568	14,946,352	2,659,782	17.8%	626	11/23/2001
2002	34,700	17,350	3,395	58,903,250	1,995,294	3.4%	222	1/23/2003
2003	1,765	883	3,412	3,011,090	177,801	5.9%	660	1/30/2004
2004	1,449	725	3,276	2,373,462	202,815	8.5%	495	12/12/2004
2005	3,261	1,631	3,065	4,999,015	548,604	11.0%	636	1/31/2005
2006	21,172	10,586	2,910	30,805,260	5,983,651	19.4%	581	12/15/2006
2007	1,080	540	3,450	1,863,000	251,285	13.5%	1,055	12/4/2007
2008	577	289	3,135	904,448	327,225	36.2%	546	1/8/2009
2009	1,568	784	3,540	2,775,360	129,903	4.7%	309	11/27/2009
2010	12,527	6,264	3,075	19,260,263	8,160,976	42.4%	888	12/13/2010
2011	911	455	3,318	1,509,690	266,899	17.7%	348	11/23/2011
2012	4,219	2,110	3,515	7,414,893	1,553,602	21.0%	467	1/10/2013
2013	2,003	1,001	3,362	3,365,362	438,534	13.0%	244	1/12/2014
2014	2,130	1,065	3,368	3,586,920	1,590,812	44.4%	206	2/7/2015
2015	414	207	3,070	635,490	81,125	12.8%	350	1/29/2016

Chinook

Total catch (actual and estimated missed) in the Bear Creek screw trap was 7,121 Chinook during the trapping period of January 28 to July 14. This included actual catch of 5,869 Chinook and an estimated missed catch of 1,252 Chinook during 22 full days, and eight periods when the trap was stopped by debris (Table 10).

Production Estimate

A total of 30 efficiency trials were conducted with Chinook sub-yearlings. Chinook sub-yearling trials were aggregated into three strata; capture rates of these strata ranged from 7.6% to 34.7%. Chinook migration during trap operation was estimated to be 45,946 ± 17,473 (±95% C.I.) (Table 10, Appendix B2). This estimate includes 744 Chinook estimated to have migrated before trap operations began (January 1 to 27) and 45,202 Chinook that migrated during trap operations from January 28 to July 14. The fry migration peaked in early March and the parr component peaked in mid-May (Figure 9).

Table 10. Abundance of natural-origin sub-yearling Chinook emigrating from Bear Creek in 2016. Table includes abundance of juvenile migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*).

Capture Method	Period	Total Catch	Abundance	95% C.I. Low	95% C.I. High	*CV*
Pre-Trapping	January 1 - January 27		744	380	1,108	24.90%
Screw Trap	January 28 - July 14	7,121	45,202	27,733	62,671	19.70%
	Season Totals		45,946	28,473	63,418	19.40%

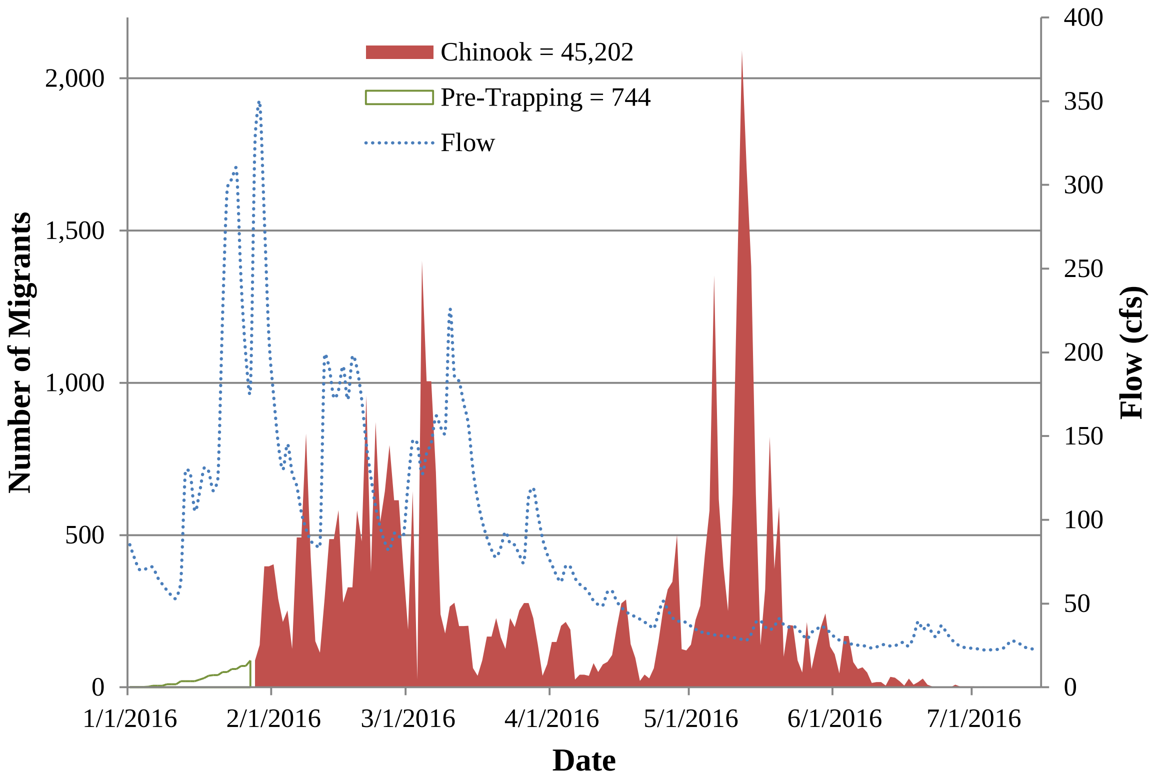

Figure 9. Daily migration of sub-yearling Chinook and daily average flow from Bear Creek, 2016. Daily mean flows were measured at King County gage 02a at Union Hill Road in 2016 (http://green.kingcounty.gov/wlr/waterres/hydrology).

We estimated the abundance of two life-history forms of sub-yearling Chinook salmon observed in Puget Sound: small fry migrating immediately after emergence and larger parr that spend some time rearing and growing in freshwater. Small fry migrants, defined by their emigration between January and April, comprised 53.8% of the total migration (Table 11). Large parr migrants, defined by emigration between May and July, represented 46.2% of total production in Bear Creek during 2016. This was the second year in a row in which the fry component was greater than the parr component. Historically, this result has been rare. Although fry and parr are defined by a timeframe, we do acknowledge that there are some annual variations in size during the defined timeframes. As a result there may be some parr sized fish included in the fry component and fry sized fish in the parr component.

Productivity

The 2015 brood of Bear Creek Chinook produced the third highest fry production and parr per female and the fifth highest egg to migrant survival we have observed since monitoring began in 2001. Survival was estimated at 7.1% (Table 11). Productivity was based on 138 female spawners, which is well above the average return (B. Craig, Washington Department of Fish and Wildlife, personal communication) and a total abundance of 44,124 juvenile Chinook.

Table 11. Abundance and productivity (juveniles per female) of natural-origin Chinook in Bear Creek. Fry are assumed to have migrated between February 1 and April 8. Parr are assumed to have migrated between April 9 and June 30. Data are 2000 to 2015 brood years.

Brood	Juvenile Abundance			% Abundance		Est.	Juveniles/Female			Overall
Year	Fry	Parr	Total	Fry	Parr	Females	Fry	Parr	Total	Survival
2000	419	10,087	10,506	4.0%	96.0%	133	3	76	79	1.8%
2001	5,427	15,891	21,318	25.5%	74.5%	138	39	115	154	3.4%
2002	645	16,636	17,281	3.7%	96.3%	127	5	131	136	3.0%
2003	2,089	21,558	23,647	8.8%	91.2%	147	14	147	161	3.6%
2004	1,178	8,092	9,270	12.7%	87.3%	121	10	67	77	1.7%
2005	5,764	16,598	22,362	25.8%	74.2%	122	47	136	183	4.1%
2006	3,452	13,077	16,529	20.9%	79.1%	131	26	100	126	2.8%
2007	1,163	11,543	12,706	9.2%	90.8%	89	4	143	147	3.2%
2008	14,243	50,959	65,202	21.8%	78.2%	132	108	386	494	11.0%
2009	1,530	7,655	9,185	16.7%	83.3%	48	32	159	191	4.3%
2010	901	16,862	17,763	5.1%	94.9%	60	15	281	296	6.6%
2011	4,000	18,197	22,197	18.0%	82.0%	55	73	331	404	9.0%
2012	24,776	19,823	44,599	55.6%	44.4%	147	169	135	303	6.7%
2013	24,266	38,509	62,775	38.7%	61.3%	48	506	802	1,308	29.1%
2014	25,500	7,233	32,733	77.9%	22.1%	60	425	121	546	12.1%
2015	23,753	20,371	44,124	53.8%	46.2%	138	172	148	320	7.1%

Size

The minimum weekly average lengths of sub-yearling Chinook migrants was less than 50.0 mm FL until late March then increased to average 69 mm FL by mid-April. In early May Chinook ranged in size from 66 mm to 131 mm FL. By the end of June Chinook averaged 92.7 mm FL (Figure 10).

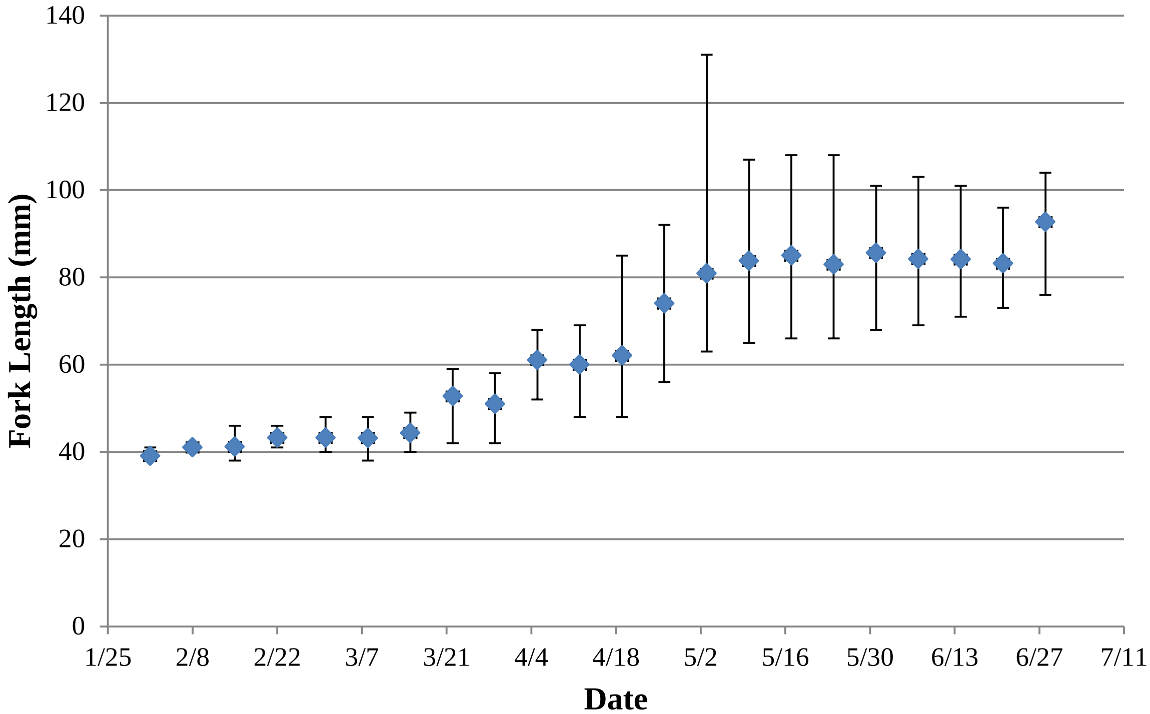

Figure 10. Fork lengths of sub-yearling Chinook sampled from Bear Creek in 2016. Data are mean, minimum, and maximum lengths for each statistical week.

Coho

Total catch (actual and estimated missed) in the Bear Creek screw trap was 1,875 sub-yearling and yearling coho. This included an actual catch of 1,612 coho migrants and an estimated missed catch of 263 coho due to trap outages. Only 11 coho sub-yearlings were caught, primarily fry, and contributed less than 0.5% of the total catch.

Production Estimate

Abundance of coho was based on total catch and 14 efficiency trials, which were aggregated into a single stratum. The capture rate of coho was 16.0%. Coho production was estimated to be 11,545 ± 2,828 (±95% C.I.) smolts (Table 12, Figure 11, Appendix B 3). Similar to the Cedar River, coho fry and sub-yearlings may exit Bear Creek and rear downstream for an unknown period of time before migrating to the marine waters of Puget Sound. Coho abundance is a measurement of total coho exiting Bear Creek in any given year.

Table 12. Abundance of natural-origin juvenile coho emigrating from Bear Creek in 2016. Table includes abundance of juvenile migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*).

Capture Method	Period	Total Catch	Abundance	95% C.I. Low	95% C.I. High	*CV*
Screw Trap	January 28 - July 14	1,875	11,545	8,717	14,343	12.50%

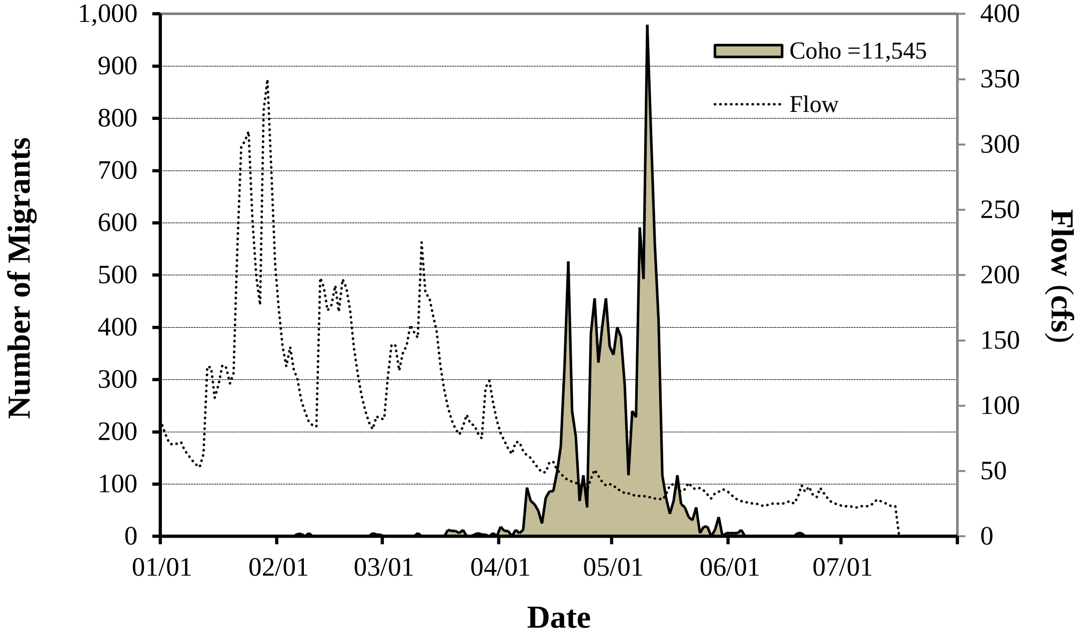

Figure 11. Daily migration of juvenile coho in Bear Creek from January 28 to July 14, 2016. Graph also shows mean daily flows during this period. Flow data were measured at King County gage 02a at Union Hill Road in 2016 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Size

Over the trapping period, fork lengths of sub-yearling and yearling coho ranged from 54 mm to 165 mm FL and averaged 114.9 mm FL (Figure 12). Weekly mean lengths ranged from 72.3 mm to 120.5 mm FL during trap operation.

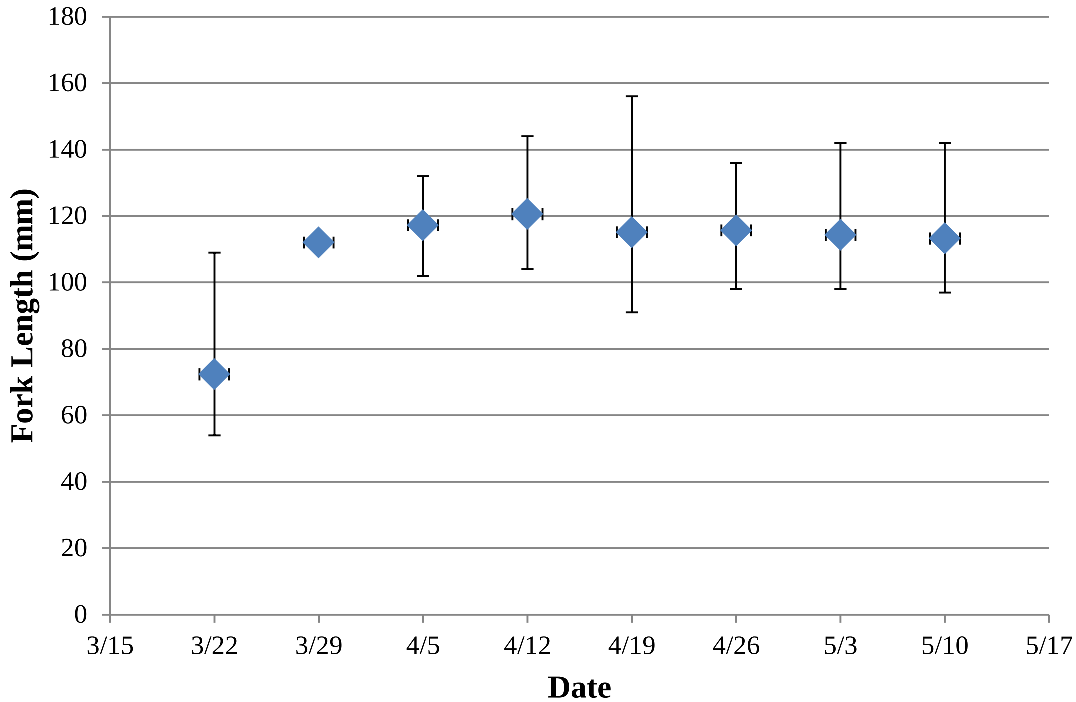

Figure 12. Fork lengths of migrating juvenile coho caught at the Bear Creek screw trap in 2016. Data are statistical week mean, minimum, and maximum lengths.

Trout

The identification of trout in Bear Creek poses the same difficulties discussed earlier in the Cedar River section. Trout were identified to species when possible based on visual identification. The cutthroat estimate does not differentiate migration for different life history strategies and is a measure of the number of cutthroat moving past the trap, not necessarily the number of cutthroat migrating downstream towards Lake Washington and the marine waters of Puget Sound.

Production Estimate

Only two steelhead were captured during the entire 2016 trapping season in Bear Creek. Seven unidentifiable trout fry were also captured.

Total catch of juvenile cutthroat trout was 679. Catch was sporadic, making it difficult to conduct more than one trap efficiency release. We did not estimate cutthroat movement. A total of 51 cutthroat adults were captured throughout trap operations. Abundance was not estimated due to sporadic catches preventing us from forming trap efficiency trials.

Size

The juvenile steelhead captured measured 192mm and 258mm in fork length.

Juvenile cutthroat trout fork lengths averaged 157.4 mm FL and ranged between 87 mm to 249 mm FL throughout the trapping season (Table 13). Average fork lengths showed no consistent trend across weeks. Adult cutthroat trout fork lengths ranged in size from 268 mm to 485 mm FL and averaged 352.4 mm for the season.

Table 13. Cutthroat fork length (mm), standard deviation (SD), range, sample size (n), and catch by statistical week in the Bear Creek screw trap, 2016.

Statistical Week			Fork Length (mm)					
			Avg.	SD	Range		n	Catch
Begin	**End**	**No.**			**Min**	**Max**		
02/08	02/02	5						10
02/01	02/07	6	109.7	6.03	104	116	3	27
02/08	02/14	7						14
02/15	02/21	8	104.3	14.99	89	127	7	19
02/22	02/28	9	97.0	9.54	87	106	3	12
02/29	03/06	10	140.0	n/a	140	140	1	29
03/07	03/13	11	122.0	13.95	104	134	4	22
03/14	03/20	12	158.9	32.70	120	220	7	21
03/21	03/27	13	138.0	21.42	110	162	4	32
03/28	04/03	14	194.0	14.14	184	204	2	18
04/04	04/10	15	176.3	22.88	138	208	19	33
04/11	04/17	16	172.1	17.03	147	200	13	117
04/18	04/24	17	170.8	37.34	107	249	16	56
04/25	05/01	18	163.4	26.38	126	193	7	55
05/02	05/08	19						58
05/09	05/15	20	162.6	14.81	142	184	10	85
05/16	05/22	21						42
05/23	05/29	22						6
05/30	06/05	23						10
06/06	06/12	24	153.5	3.54	151	156	2	5
06/13	06/19	25						4
06/20	06/26	26						4
06/27	07/03	27						
Season Totals			**157.4**	**33.71**	**87**	**249**	**98**	**679**

Incidental Species

In addition to target species, the screw trap captured seven trout fry, one hatchery trout plants from Cottage Lake and 47 cutthroat adults (larger than 250 mm). Other species caught included lamprey (*Lampetra* spp.), green sunfish (*Lepomis cyanellus*), three-spine stickleback (*Gasterosterus aculeatus*), sculpin (*Cottus* spp.), whitefish (*Prosopium* spp.), peamouth (*Mylocheilus caurinus*), dace (*Rhinichthys* spp), bluegill (*Lepomis macrochirus*), large-scale suckers (*Catostomus macrocheilus*), small mouth bass (*Micropterus dolomieu*), pumpkinseed (*Lepomis gibbosus*), northern pike *(Esox lucius)*, rock bass (*Ambloplites rupestris*), peamouth (*Mylocheilus caurinus*), yellow perch (*Perca flavescens),* warmouth (*Lepomis gulosus*), black crappie (*Pomoxis nigromaculatus),* and brown bullhead catfish (*Ameriurus nebulosus*).

PIT Tagging

To support the ongoing, multi-agency evaluation of salmonid survival within the Lake Washington watershed, natural-origin Chinook were tagged with passive integrated transponder (PIT) tags. Tagging occurred two to three times a week. Due to low catches of Chinook parr, fish were held from the previous day in order to increase the number of tags released per day. Only the Chinook parr migrants were represented in the tag groups.

Tagging occurred in the Cedar River from April 20 through June 16, 2016. Over the season, a total of 1,372 natural-origin Chinook parr were PIT tagged in the Cedar River watershed. This total includes 1,289 Chinook tagged at the Cedar River screw trap and 83 Chinook tagged at the Landsburg Dam (Table 14). This combined tag group comprised 4.4% of the estimated Chinook parr production from the Cedar River in 2016. A total of 128 Chinook PIT tags (9.3%) were detected as they moved through the smolt flumes at the Chittenden Locks while exiting Lake Washington. The first Chinook was detected on May 19, 2016 and the last on July 15, 2016 (Table 15). Median migration date of Chinook detected moving through the Locks was June 4, 2016. Individual travel times from the Cedar River to the Locks averaged 22.5 days (SD = 6.7) and ranged from 8 days to as long as 41 days to make it to the Locks. Average fork length of Chinook PIT tagged during the season was 83.3 mm and ranged from 65 mm to 138 mm. Average fork length of Chinook detected at the Chittenden Locks during the sample period was 87.6 mm, with a range of 72 mm to 110 mm.

In Bear Creek tagging occurred from April 18 through June 15, 2016. A total of 2,766 Chinook were tagged throughout the season and represented 14.5% of estimated Chinook parr production. A total of 288 Chinook PIT tags (10.4%) were detected as they moved through the smolt flumes at the Chittenden Locks (Table 14). The first Chinook was detected at the Locks was May 7, 2016 and the last was detected June 29, 2016 (Table 16). Individual travel times from Bear Creek to the Locks averaged 23.2 days (SD = 6.0). Travel time ranged from 7 days to 49 days to travel from Bear Creek to the Locks. Average fork length of Chinook PIT tagged at Bear Creek was 83.3 mm and ranged from 65 mm to 108 mm. Average fork length of Chinook detected at the Chittenden Locks was 84.7 mm and ranged from 65 mm to 108 mm.

In 2016, 2,993 hatchery Chinook were PIT tagged at Issaquah Hatchery between April 18 and May 5. These fish comprised three similar size groups to represent each of the three Chinook hatchery releases scheduled for 2016. Fork lengths of Chinook at tagging ranged from 64 mm to 93 mm and averaged 76.7 mm. The tagging occurred roughly 11 to 13 days prior to release, so the length of fish at release is unknown but assumed to accurately represent the hatchery population. Healthy Chinook were placed back into the general hatchery population before releases that occurred on three separate days: May 1, 8, and 17, 2016. Issaquah Hatchery Chinook were first detected at the Chittenden Locks on May 19 and continued through June 27, 2016. Average travel time was 28.7 days for all fish released from Issaquah and ranged from 25 to 31 day for individual releases. Detection rate for all fish released at Issaquah was 3.1%, and ranged from 1.2% to 5.5% for individual release groups. This is considerably lower than both Cedar River and Bear Creek Chinook. However all three sites showed a pattern of declining detection rates over the course of the tag dates. Average detection rate in 2015 (3.8%) was similar to the detection rate in 2016 (3.1%) (Table 17).

The portion of PIT tagged Chinook detected at the Locks from both the Cedar River and Bear Creek in 2016 appears to be rather low compared to previous years (Table 15, Table 16). In 2016, smolt flumes, and their respective antenna, were operational from April 17 to July 27. All four flumes were operated from the start of the operational period until May 7. The small flumes were turned off on May 5 and two large flumes were operational until July 5. The remainder of the operational period only one large flume was operational. Since the first and last tag detections occurred a number of days following the start of operations and prior to the end of operations, we feel we did not miss a significant number of tagged fish due to the operational period of the flumes.

During the 2016 outmigration period there was a new antenna installed in one of the large Locks filling culverts to assess the frequency in which juvenile tagged Chinook are encountered either using the culvert as an exit route or simply being within range of the antenna. Of the 509 detections at the Ballard facility, all smolt flumes and filling culvert antenna, only three were detected at the filling culvert.

It is unclear where along the migration route the loss of hatchery Chinook was highest. Installation of PIT tag antenna along the migration corridor may help identify mortality hotspots. One hypothesis is that hatchery Chinook simply chose an alternate route through the Chittenden Locks at a higher rate than the natural-origin Chinook from Cedar River and Bear Creek, or that hatchery Chinook residualize in either Lake Sammamish or Lake Washington resulting in lower detections of hatchery Chinook than natural origin Chinook.

Table 14. Natural-origin Chinook parr PIT tagged from the Cedar River and Bear Creek screw traps in 2016. Cedar River data includes fish tagged at Landsburg.

Statistical Week			Cedar River Screw Trap/Landsburg							Bear Creek Screw Trap						
			# Tagged	Length (mm)			Portion of Parr Migration Tagged	# Detected @ Locks	% of Tags Detected	# Tagged	Length (mm)			Portion of Parr Migration Tagged	# Detected @ Locks	% of Tags Detected
Begin	End	No.		Avg	Min	Max					Avg	Min	Max			
18-Apr	24-Apr	17	1	68.0	68	68	0.5%		0.0%	93	73.5	65	82	17.1%	11	0.0%
25-Apr	1-May	18	59	77.3	65	89	4.1%	8	13.6%	326	79.4	65	99	18.0%	22	6.7%
2-May	8-May	19	109	82.0	66	99	8.1%	26	23.9%	514	83.7	65	107	13.3%	106	20.6%
9-May	15-May	20	206	84.2	66	104	6.0%	28	13.6%	865	84.9	66	108	10.7%	128	14.8%
16-May	22-May	21	444	86.4	67	108	8.7%	53	11.9%	473	82.9	66	108	18.4%	14	3.0%
23-May	29-May	22	163	87.7	68	114	1.6%	11	6.7%	203	85.5	68	101	21.5%	4	2.0%
30-May	5-Jun	23	173	89.8	74	110	3.1%	1	0.6%	195	84.2	69	103	20.5%	2	1.0%
6-Jun	12-Jun	24	92	97.6	81	138	4.0%		0.0%	79	84.2	71	101	34.6%		0.0%
13-Jun	19-Jun	25	125	95.8	76	113	14.2%	1	0.8%	18	83.1	73	96	12.3%		
	Season Total		**1,372**	**87.0**	**65**	**138**	**4.4%**	**128**	**9.3%**	**2,766**	**83.3**	**65**	**108**	**14.5%**	**287**	**10.4%**

Table 15. Biological and migration timing data of PIT tagged natural-origin Chinook released from the Cedar River screw trap, tag years 2010 to 2016. Detection data is from the Hiram Chittenden Locks.

Tag Year	# Tagged	Length (mm)			Portion of Parr Migration	# Detected @ Locks	% of Tags Detected	Avg Travel Time (days)	First Detection	Last Detection	Median Date
		Avg	Min	Max							
2010	2,232	84.2	65	127	6.1%	482	21.6%	29.9	05/24	08/25	06/24
2011	594	87.3	65	118	5.8%	116	19.5%	19.3	05/26	08/27	06/07
2012	1,671	84.0	64	123	4.3%	212	12.7%	30.0	05/29	09/14	07/08
2013	711	81.3	58	108	3.7%	209	29.4%	17.3	05/26	07/17	06/19
2014	1,944	83.8	65	122	5.9%	172	8.8%	24.8	05/24	07/29	06/13
2015	861	88.2	64	115	4.2%	63	7.3%	19.5	05/21	06/21	05/29
2016	1,372	87.0	65	138	4.4%	128	9.3%	22.5	05/19	07/15	06/04

Table 16. Biological and migration timing data of PIT tagged natural-origin Chinook released from the Bear Creek screw trap, tag years 2010 to 2016. Detection data is from the Hiram Chittenden Locks.

Tag Year	# Tagged	Length (mm)			Portion of Parr Migration	# Detected @ Locks	% of Tags Detected	Avg Travel Time (days)	First Detection	Last Detection	Median Date
		Avg	Min	Max							
2010	589	77.9	65	99	7.8%	103	17.5%	26.1	06/06	07/07	06/23
2011	2,316	79.9	65	102	26.3%	337	14.6%	15.1	05/23	07/29	06/05
2012	2,721	75.2	62	97	12.2%	316	11.6%	31.3	05/22	08/13	06/21
2013	1,858	79.3	58	102	9.8%	518	27.9%	12.3	05/16	07/20	06/12
2014	1,968	77.6	62	103	4.8%	324	16.5%	23.9	05/20	07/14	06/12
2015	1,414	84.7	65	108	19.4%	114	8.1%	17.7	05/19	06/18	05/28
2016	2,766	83.3	65	108	14.5%	287	10.4%	23.2	05/07	06/29	05/31

Table 17. PIT tag and migration timing of natural-origin Chinook released from Issaquah hatchery, years 2014 and 2016. Detection data is from the Hiram Chittenden Locks.

Tag Year	Release Date	# Tagged	# Detected @ Locks	% of Tags Detected	Avg Travel Time (days)	First Detection	Last Detection
2014	23-May	5000	137	2.74%	34	06/08	07/27
2015	1-May	1193	60	5.03%	26	05/21	06/13
2015	4-May	1186	49	4.13%	24	05/18	06/13
2015	8-May	1189	33	2.78%	21	05/21	06/13
2016	1-May	999	55	5.51%	31	5/19	6/28
2016	8-May	999	27	2.70%	25	5/19	6/27
2016	18-May	995	12	1.21%	25	6/7	6/27

Appendix A

Catch and Migration Estimates by Strata for Cedar River
Sockeye, Chinook, and Coho Salmon, 2016.

Appendix A 1. Catch and migration by strata for Cedar River natural-origin sockeye fry, 2016.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
Pre-Trap	1/1/2016	1/24/2016			68,334	$3.5x10^{8}$
1	1/25/2016	3/14/2016	9,505	0.65%	1,422,858	$4.5x10^{10}$
2	3/15/2016	3/18/2016	1,008	3.54%	26,764	$4.1x10^{7}$
3	3/19/2016	4/21/2016	6,854	1.20%	555,180	$7.7x10^{9}$
Post Trap	4/22/2016	6/30/2015			90,707	$5.3x10^{8}$
		Total	**17,367**		**2,163,843**	**$5.4x10^{10}$**

Appendix A 2. Catch and migration by strata for Cedar River natural-origin Chinook fry, 2016.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
Pre Trap	1/1/2016	1/24/2016			181,410	$5.5x10^{9}$
1	1/25/2016	3/14/2016	6,264	0.79%	728,108	$3.8x10^{10}$
2	3/15/2016	3/18/2016	191	3.54%	5,081	$1.6x10^{6}$
3	3/19/2016	4/13/2016	331	1.20%	26,844	$2.0x10^{7}$
		Total	**6,787**		**941,443**	**$4.3x10^{10}$**

Appendix A 3. Catch and migration by strata for Cedar River natural-origin Chinook parr, 2016.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	4/14/2016	5/25/2016	1,213	9.13%	13,038	$3.3x10^{6}$
2	5/26/2016	5/31/2016	348	1.33%	13,241	$5.7x10^{7}$
3	6/1/2016	6/3/2016	72	14.85%	459	$1.3x10^{4}$
4	6/4/2016	7/14/2016	223	3.39%	4,459	$4.8x10^{6}$
		Total	**1,856**		**31,198**	**$6.1x10^{7}$**

Appendix A 4. Catch and migration by strata for Cedar River natural-origin coho migrants, 2016.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	4/14/2016	5/16/2016	2,004	5.87%	33,583	$1.9x10^{7}$
2	5/17/2016	7/14/2016	716	2.36%	27,038	$7.2x10^{7}$
		Total	**2,720**		**60,621**	**$9.2x10^{7}$**

Appendix B

Catch and Migration Estimates by Strata for Bear Creek
Sockeye, Chinook, Coho Salmon, and Cutthroat Trout, 2016.

Appendix B 1 Catch and migration by strata for Bear Creek sockeye, 2016.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	1/27/2016	3/9/2016	4,769	7.66%	61,643	$7.63x10^7$
2	3/10/2016	7/14/2016	972	4.76%	19,482	$3.64x10^7$
		Total	**5,741**		**81,125**	$\mathbf{1.13x10^8}$

Appendix B 2. Catch and migration by strata for Bear Creek natural-origin Chinook, 2016.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
Pre-Trap	1/1/2016	1/26/2016			744	$3.45x10^4$
1	1/27/2016	4/5/2016	1,958	7.62%	24,718	$7.62x10^7$
2	4/6/2016	5/22/2016	4,347	23.78%	18,154	$3.17x10^6$
3	5/23/2016	7/14/2016	816	34.66%	2,330	$6.03x10^4$
		Total	**7,121**		**45,946**	$\mathbf{7.95x10^7}$

Appendix B 3. Catch and migration by strata for Bear Creek natural-origin coho smolts, 2016.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	1/27/2016	7/14/2016	1,875	16.00%	11,545	$2.08x10^6$

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We also appreciate and acknowledge the contributions of the following companies and agencies to these studies:

Cedar River

The Boeing Company provided electrical power and a level of security for our inclined-plane trap.

The Renton Municipal Airport provided security for the inclined-plane trap and other equipment housed at the airport.

The City of Renton Parks Department and the Washington State Department of Transportation provided access and allowed us to attach anchor cables to their property.

The United States Geological Survey provided continuous flow monitoring.

Seattle Public Utilities communicated changes in flow due to dam operation.

Bear Creek

The City of Redmond Police Department and Redmond Town Center Security staff provided a measure of security for the crew and trap.

King County DNRP provided continuous flow monitoring.

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