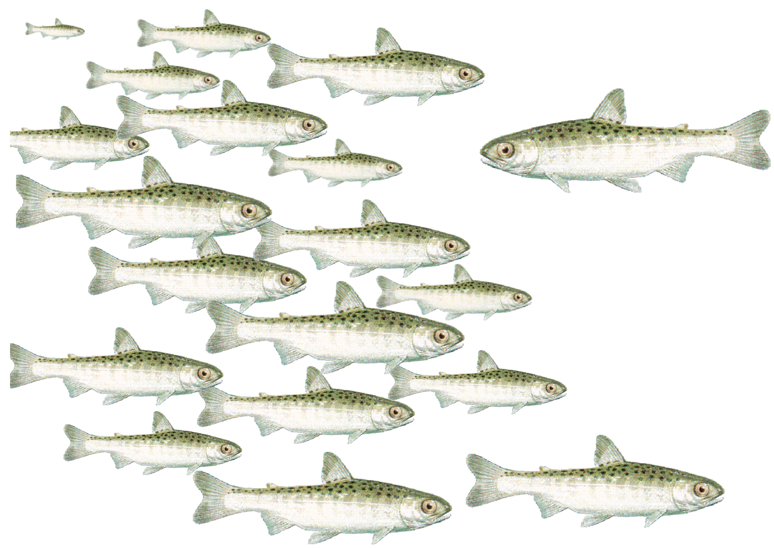
STATE OF WASHINGTON September 2022

Evaluation of Juvenile Salmon Production in 2021 from the Cedar River and Bear Creek



by Peter Lisi

Washington Department of Fish and Wildlife
Fish Program
Science Division

FPA 22-11

Evaluation of Juvenile Salmon Production in 2021 from the Cedar River and Bear Creek

Peter J. Lisi

Wild Salmon Production Evaluation Unit
Science Division, Fish Program
Washington Department of Fish and Wildlife
Olympia, Washington 98501-1091

Supported by
King County Flood Control District Cooperative Watershed Management Grant, Water Resource Inventory Area (WRIA) 8, and Seattle Public Utilities

Table of Contents

List of Tables

List of Figures

Summary

We tracked the daily outmigration of juvenile salmonids in 2021 from the Cedar River and Bear Creek using rotary screw traps. This represents the 30th consecutive year of juvenile monitoring in the Cedar River and 23rd consecutive year in Bear Creek. The Cedar River trap was installed on January 27th and operated until July 13th for 148 of 167 days (89%). We estimate 1,159,150 ± 400,691 (± 95% CI) natural-origin sockeye fry; 57,918 ± 15,870 Chinook sub-yearlings; and 38,235 ± 12,509 age 1+ coho migrants entered Lake Washington from the Cedar River in 2021. The juvenile sockeye production estimate represents a recovery from record low outmigration in 2020 (32,495), but is still much lower (~ 1/8th) than the median natural production over last decade (2010 - 2020 median: 8,725,471). The production estimate for Cedar River Chinook in 2021 was also lower (~1/6th) than the median annual production over last decade (median: 347,663). Age 1+ Coho smolt production dropped to a 10-year low or about ½ the median production observed annually in the last decade (median: 83,060).

The Bear Creek rotary screw trap was installed on February 4th and operated until July 1st for 142 of 147 days (97%). We estimated 20,243 ± 9,605 (± 95% CI) natural-origin sockeye fry; 14,600 ± 2,215 sub-yearling Chinook; 12,856 ± 3,594 age 1+ coho smolt; and 13,997 ± 6,374 juvenile cutthroat trout. Sockeye fry production was very low (~1/20th) relative to the median number of outmigrants observed over the last 10 years (median 2010-2020: 428,533). Chinook production was also lower (~½) than the median production observed over the last decade (median: 32,733). Coho age 1+ smolt production estimate was slightly lower than the median migration observed annually in the last decade (median: 17,752). We observed daily average water temperatures surpassing 24℃ in Bear Creek that stressed and killed a number of cutthroat trout and other native fishes.

PIT tagging projects on juvenile Chinook continued in 2021 at the Cedar River and Bear Creek smolt traps. About 7.0% of the Chinook (51 of 728) and 27.4% of the coho (40 of 146) tagged at the Cedar River were detected at the Ballard Locks. In comparison, 8.7% of the Chinook (124 of 1431) and 38.7% of the Coho (58 of 150) tagged at Bear Creek were detected at the Ballard Locks. Included in the detection rate calculations are 90 smaller sized Chinook sub-yearlings (45 to 65mm in fork length) that we tagged in April and early May using 9mm PIT tags. So far, the detection rates appear to be lower for smaller sized outmigrants tagged at the Cedar River (3.0%; 2 of 66 tagged) and Bear (4.1%; 1 of 24 tagged) in April and May.

Introduction

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

In 1992, the Washington Department of Fish and Wildlife (WDFW) initiated an evaluation of sockeye fry migrants in the Cedar River to investigate the sources of low adult sockeye returns. In 1999, the Cedar River juvenile monitoring study was expanded in scope to include juvenile migrant Chinook salmon. This new scope extended the trapping season to a six-month period and consequently, also allowed estimation of coho abundance 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 operated in the Sammamish River during the downstream sockeye migration. In 1999, the monitoring site was relocated to Bear Creek to evaluate Chinook and sockeye production. Since 1999, the Bear Creek juvenile monitoring study also estimates coho production and movement of steelhead and cutthroat trout.

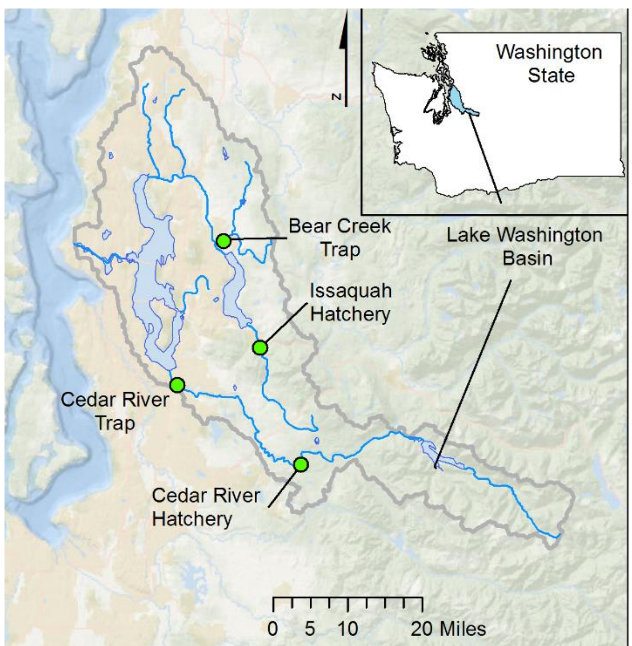


Figure 1. Map of the Lake Washington Basin flowing through Seattle WA. Rotary screw traps are used to monitor abundance of juvenile migrant salmonids in the Cedar River and Bear Creek. Two salmon hatcheries supplement the watershed in the basin with Chinook, coho, and sockeye.

The primary goal of this study was to estimate the abundance of natural-origin sockeye fry, natural-origin Chinook, and natural-origin coho migrating from the Cedar River and Bear Creek into Lake Washington in 2021. These data allow an estimate of egg to fry survival of the 2020 brood for Chinook and Sockeye. Daily abundance estimates also characterized the migration timing of each species into Lake Washington.

Methods

Fish Collection

Trapping Gear and Operation

Cedar River

A rotary screw trap operated in the lower Cedar River during the late winter and spring out migration period to assess migration of sockeye and Chinook fry, larger sub-yearling Chinook, coho, steelhead, and resident cutthroat. The Cedar River screw trap is a 5-ft diameter rotary scrap trap supported by a 12-ft x 30-ft steel pontoon barge (Seiler et al., 2003). The screw trap was deployed at river mile (R.M) 1.6, under the I-405 Bridge (Figure 1) during the migration period from mid-January through mid-July. Catches were enumerated by species at dusk and dawn to discern diel movements. Fork lengths were randomly sampled on a weekly basis from all sockeye, Chinook, coho, and cutthroat.

Over the duration of the Cedar River juvenile monitoring study, trapping operations moved in response to changes in channel morphology. From 1992 to 2016, a small floating inclined-plane trap operated nightly from January through early April (Seiler et al., 2003). In the summer of 1998, dredging in the lower Cedar River forced the inclined-plane trap location to relocate in 1999 from R.M 0.25 to R.M 0.8 to operate under suitable river velocities. Beginning in 1999, WDFW also began operating a rotary screw trap at R.M 1.6 for the period April to July to enumerate Chinook salmon.

Since 2017, only a single rotary screw was operated for the duration of the season at R.M 1.6. We made this change for three reasons. First, dredging in 2016 resulted in major channel modifications in the lower Cedar River that compromised the inclined-plane trapping site. Second, for the purposes of data comparability, we sought to use a single gear type over the duration of the trapping season rather than the incline-plane early and rotary screw trap later in the season. Finally, the rotary screw trap simplifies trap staffing because unlike the incline plane trap, it does not require a trap operator to be present during all hours of operation. Thus, the inclined-plane trap was retired.

The Cedar River Hatchery at Landsburg releases sockeye fry into the Cedar River during the winter and spring to contribute to sockeye returns to the Cedar River and to help promote Lake Washington fisheries. The hatchery released sockeye fry into the Cedar River over 4 nights throughout the migration period. Hatchery staff released fry at three separate locations and often at two locations on the same night (Table 2). The Issaquah Salmon Hatchery also raised and released fingerling sockeye into the lower Cedar River site (R.M 2.5) to test the efficacy of extended hatchery rearing. To avoid complications estimating hatchery and natural-origin components, the trap did not operate on hatchery release nights. We estimated missed catch of natural-origin sockeye during hatchery nights when the trap was out of the water. Residual hatchery sockeye can migrate for up to three nights after a hatchery release (Kiyohara 2013). We frequently observe that well fed hatchery origin fish are as much as 3-4 mm larger in fork length and have a distinctly larger body mass compared to natural origin sockeye fry (Lisi 2020, Figure

2). When possible, we separated out any residual catch of hatchery sockeye fry based on body length and condition differences to natural origin sockeye. In 2021, the Issaquah hatchery raised sockeye eggs from the Cedar River and replanted them at a larger size releasing 111,619 on May 12th (73.8 mm FL; CV = 6.6%) and 25,468 (126.6 mm CV = 6.8%) on November 1st, 2021. These fish were large enough to be externally marked (adipose fin clip) and were thus easily separated from our daily catch.

In 2021, the Cedar River screw trap was deployed on January 27th and operated until July 13th for 148 of 167 days (89%). A snowstorm stopped trap operations from February 12th to the 15th. The trap was out due to high flow events on February 22 and May 16. The trap cone stopped during debris jams on 5 nights during February 26, April 7, May 13, May 15, and June 29. The trap did not operate on 4 nights to avoid catch of hatchery released sockeye salmon on March 15, March 29, April 19, and May 12 (Table 2), which were extremely abundant and compromised our ability to count natural-origin sockeye fry and Chinook when present. The trap did not fish for three nights from June 26th to the 28th during a heatwave and the 4th of July holiday.

Bear Creek

Like the Cedar River, trapping operations changed in response to flow conditions, project objectives, and safety concerns. From January to April in years 1999 through 2011, an inclined-plane trap operated 100 yards downstream of the Redmond Way Bridge. A rotary screw trap fished for the remainder of the season from April to July. The inclined-plane trap was retired after 2011. The rotary screw trap operation now begins in late January to cover the early fry migration period as well as the spring parr and smolt migrations.

In 2021, a rotary screw trap operated from February 4th to July 1st approximately 100 yards downstream of the Redmond Way Bridge at the railroad trestle (Figure 1). The trap was permanently removed from this site at the end of the field season to make way for the Sound Transit light rail construction project on July 1st. Technicians enumerated the catch by species once daily. The trap fished continuously for 142 of 147 days (97%), except for debris outages on February 11th and 12th , April 2nd, and June 8th. The trap did not operate during the peamouth chub migration on May 1st. Fork lengths were randomly sampled on a weekly basis from sockeye, Chinook, coho, and cutthroat.

PIT Tagging

During screw trap operation at both sites, a portion of natural-origin Chinook migrants were monitored using 12 mm APT (Biomark Corp, Boise Idaho) passive integrated transponder (PIT) tags. Tagging occurred two to three times a week, from April through June following standard protocols outlined by the Columbia River Basin Fish and Wildlife Authority PIT Tag Steering Committee (2014). Chinook longer than 65 mm fork length (FL) and displayed good physical health received a 12 mm PIT tag. We also tagged smaller parr 45-65 mm FL using 9 mm tags (HPT tags; Biomark Corp, Boise Idaho) to better understand survival of smaller Chinook during earlier outmigration into Lake Washington. Chinook 45-65 mm are typically captured in the trap in late March and April when water temperatures start to warm. Tagged salmon were released the same day of capture or held overnight in perforated buckets. We also tagged age 1+

Coho salmon smolt using 12 mm tags. Additionally, any age 1+ steelhead smolt were PIT tagged using 12 mm tags.

The Ballard Hiram M. Chittenden Locks demarcate the freshwater to marine boundary between the Lake Washington watershed and Puget Sound (Figure 1). The Ballard Locks have several PIT tag detection arrays in smolt flumes; the adult fish ladder; and north filling culvert. We calculate travel time as the difference between release date and detection date of an individual fish. The detection rate is the total number of unique individuals detected relative to the total released at each site.

Trap Efficiencies

Throughout the season, mark and recapture of sockeye fry, Chinook, coho, and cutthroat provide an estimate of trap efficiency for each species. Fry were marked in a solution of Bismarck brown dye (14 ppm for 1 hour) in an aerated bucket of stream water. Only healthy, marked fry were released above the trapping site. The trap efficiency for a day or night period is the total recaptured fish relative to the total number of released fish. In the Cedar River, efficiency trials were occasionally supplemented with hatchery sockeye fry to increase the size of release groups. Predator gut contents were examined during the fry season and always after mark release trials to search for marked fish that may have been consumed in the trap live box.

Larger Chinook parr were PIT tagged while coho and cutthroat were marked with alternating caudal fin clips. Fish were anesthetized before clipping or tagging in a dilute solution of MS-222 and stream water. Marks alternated on weekly intervals or more frequently with significant changes in river discharge. Beginning in early April, a subset of Chinook parr larger than 65 mm FL received PIT tags. Similar to fin clips, PIT tags enable stratified releases and recaptures. Before releasing, fish recovered from marking in perforated buckets suspended in the trap live box.

Trap efficiency trials occurred weekly throughout the trapping period, with frequency determined by the catch of each species. Releases of marked sockeye and chinook fry in the Cedar River occurred 350 meters upstream of the trap at the Renton Community Center, whereas Chinook parr and coho smolt were released at the Maplewood Roadside Park (1.2 miles upstream). Fry were released 100 yards upstream of the Bear Creek trap at the Redmond Way Bridge and Chinook parr, cutthroat, and Coho were released 700 yards upstream at the Union Hill Bridge. Prior to analysis, we removed all recapture events for which the trap did not continuously fish for 48 hours after release because those marks were not available for recapture.

Analysis

The abundance of juvenile migrant salmonids was estimated using a mark-recapture approach and a single trap design (Volkhardt et al. 2007). We used Bayesian Time-Stratified Population Analysis System (BTSPAS, Bonner and Schwarz 2011) to estimate juvenile abundance for Chinook, sockeye, coho, and cutthroat trout. The method uses Bayesian p-splines and hierarchical modeling of trap efficiencies to estimate abundance while accounting for uncertainty during missed trapping periods or time strata with minimal or no efficiency data

(Bonner and Schwarz 2011). The analysis framework can include statistical covariates (flow), stratification by period (fry vs parr), or test the effect of delayed recaptures. The strength and complexity of different models can be compared against one another based on model fit but penalized for the number of additional parameters.

Catches and abundance estimates were stratified at daily or weekly scales depending on the assumptions for mark-recapture trials. For instance, daily stratification periods are appropriate for PIT tagged Chinook juveniles where tracking of individual fish is possible and delayed recaptures can be identified. Daily scale stratification periods are also appropriate for large batch releases of fry are marked by a tissue stain (Bismarck Brown) and when recaptures occur with 24 hours. In contrast, weekly stratification is more appropriate for estimating abundance and variance on fin-clipped coho smolt or cutthroat trout when clips are rotated at weekly intervals and recaptures with similar marks occur throughout each week. For any missed trapping periods, the model produced estimates with known precision using the entire season's dataset by fitting a spline through missed periods. When producing abundance estimates at the weekly scale (coho or cutthroat) and a night is missed, we expanded the catch by adjacent night catches prior to fitting the model. For Chinook and sockeye, we added periods prior to our trapping season set to zero to initiate the abundance estimate, beginning with January 1 at the Cedar River and Bear Creek. If no or very few fish are captured during the first five days of trapping, a pre-estimate is not conducted. Confidence intervals for the pre-trapping period were estimated using a lognormal approximation (moment matching). The analysis was executed in R v.3.5.1 (R Core Team, 2021) using the package BTSPAS (Bonner and Schwarz 2021).

Our previous abundance estimation approach (e.g., Kiyohara 2013, 2016, Lisi 2020) (1) accounted for missed catch and variance during day or night periods though linear interpolation, (2) pooled efficiency strata by week into similar strata, (3) estimated abundance for each stratum, and (4) extrapolated migration prior to and post trapping. This technique stratified efficiency periods to account for heterogeneity in capture rates throughout the season and pooled across strata that were statistically similar using a *G*-test (Sokal and Rohlf 1981). This approach can produce abundance and uncertainty estimates that may be biased when annual catches are small and efficiency strata become more pooled at lower sample sizes. Total variance using this approach does not account for pooling decisions and may underestimate true variability in sample size. Missed fishing periods may also under-estimate compounding error rates that occur when a large number of days are missed sequentially. Last, our previous technique was unable to account for the statical advantage of uniquely placed marks on individual fish during PIT tagging or statistical covariates like river flow. We are simultaneously conducting both analysis approaches to compare the estimates, but have only presented the BTSPAS data here. So far, they have resulted in strikingly similar mean outmigration estimates especially when catches remain high, the amount of missed trapping days is low, and efficiency trails are performed consistently throughout the season. We transitioned over to BTSPAS to prepare for expected shifts in salmon returns and potentially more missed monitoring periods with expected hydrological extremes under climate change.

Egg-to-Migrant Survival and Productivity

Egg-to-migrant survival is the abundance of natural-origin juvenile migrants (age 0+) relative to the previous fall egg deposition by female adult spawners for sockeye and Chinook. The potential egg deposition (PED) is the product of the number of female spawners and their fecundity. Weekly fall spawning surveys estimate the number of sockeye spawners (assuming

50% are female) in Cedar River and Bear Creek using an area under the curve methodology to estimate biomass (data provided by A. Bosworth WDFW). Cedar River sockeye fecundity during the broodstock collection for the hatchery averaged 2,941 eggs per female in 2020 (data provided by M. Sedgwick WDFW). The fecundity of Bear Creek sockeye is assumed to be the same as the fecundity of Cedar River broodstock sockeye.

Productivity for Chinook in both the Cedar River and Bear Creek is the number of age 0+ out migrants produced per female spawner. The number of female Chinook is based on weekly fall redd counts and assumed to represent one female per redd for both the Bear and Cedar systems. Two life-history forms of sub-yearling Chinook salmon are observed in Puget Sound: small fry that migrate immediately after emergence and larger parr that spend several weeks to months rearing in freshwater streams. Fry are defined as fish emigrating between January and early April (8^{th}) and larger parr are defined as fish emigrating after April 8^{th}. Here, Chinook freshwater productivity is the number of migrants (both fry and parr combined) per female. Average fecundity for the Cedar River and Bear Creek is assumed to be similar to the fecundity of Soos Creek Hatchery Chinook on the Green River (4,500 eggs per female). For a few years, the egg-to-migrant survival rate of Chinook appears suspiciously high (e.g., 61.9% in 2011 Cedar). We measured fecundity in the Lake Washington basin at the Issaquah Salmon Hatchery from 2014 to 2016 (N = 280 females). Average fecundity during this period exceeded 4,500 eggs per female (Issaquah median = 5,222; mean = 5,265; standard deviation = 1,316). Fecundity in each female typically varies as a function of body size and age. The relationship between female body size (post-orbital to hypural-plate (POH) in mm) and fecundity can be explained using a power function (Fecundity = $0.0438*\text{POHmm}^{1.8021}$, $R^2 = 0.44$). For each year and stream, we estimated fecundity for each carcass on the spawning ground based on the POH length (carcass length data provided by A. Bosworth) and then calculated the average fecundity for the population based on the 2014 – 2016 measurements.

Cedar River

Sockeye

Production Estimate

We estimated 1,159,150 ± 400,691 (± 95% CI) natural-origin sockeye fry entered Lake Washington from the Cedar River in 2021 (Table 1). Fry migration began prior to our first day of trapping as noted by sockeye catches on the first several nights of trapping (Figure 2). We estimate 5,293 (95% CI: 938 to 17,213) fry migrated prior to the onset of trapping. Efficiency data were estimated daily from 13 release efficiency trials of natural sockeye fry and 4 from hatchery origin sources. Releases occurred in the evening just upstream of the Renton Community Center about 300 yards upstream of the trap. The estimated median daily efficiency was 3.6%. Trap efficiencies were lower during periods of high water (~2.3%) but fished at a higher efficiency ~5% to 6 % after river flows stabilized.

The Cedar River Sockeye Hatchery released 547,296 fry from March 15 through April 19 on 3 different nights (Table 2). The screw trap did not operate during release nights to reduce the impact on these fish and because their abundance can compromise our ability to accurately estimate natural-origin sockeye. Hatchery fry were 3 to 7 mm longer in fork length when compared to natural origin fry (Figure 2). The Issaquah hatchery also raised and released fingerling sized hatchery sockeye into the lower Cedar River on May 12 and November 1. These fish were externally marked with fin clips, so they were easily separated in the catch from large natural origin migrants.

The median migration date for natural-origin sockeye was April 2nd. Cedar River sockeye fry are migrating about 9.8 days earlier per decade (1992-2020 data), but the run in 2021 appeared to be a strong departure from the general trend (Table 3) peaking in early April rather than early March. Natural fry remained small during this time (< 30mm FL). Hatchery sockeye median migration date was March 27 (Table 3), about 5 days earlier than the natural origin median migration date (Table 3).

Table 1. Abundance of natural-origin sockeye fry entering Lake Washington from the Cedar River in 2021. Table includes total catch (actual plus estimated), abundance of fry migrants, 95% confidence intervals (C.I.), coefficient of variation (*CV*), and trap efficiency.

Period	Catch	Abundance	Lower CI	Upper CI	*CV*
Pre trapping: Jan 1- Jan 26	--	5,293	938	17,213	85.7%
Trapping: Jan 27-July 12	39,749	1,153,857	853,098	1,526,630	14.9%
Jan 1-July 12	39,749	1,159,150	785,459	1,559,841	17.6%

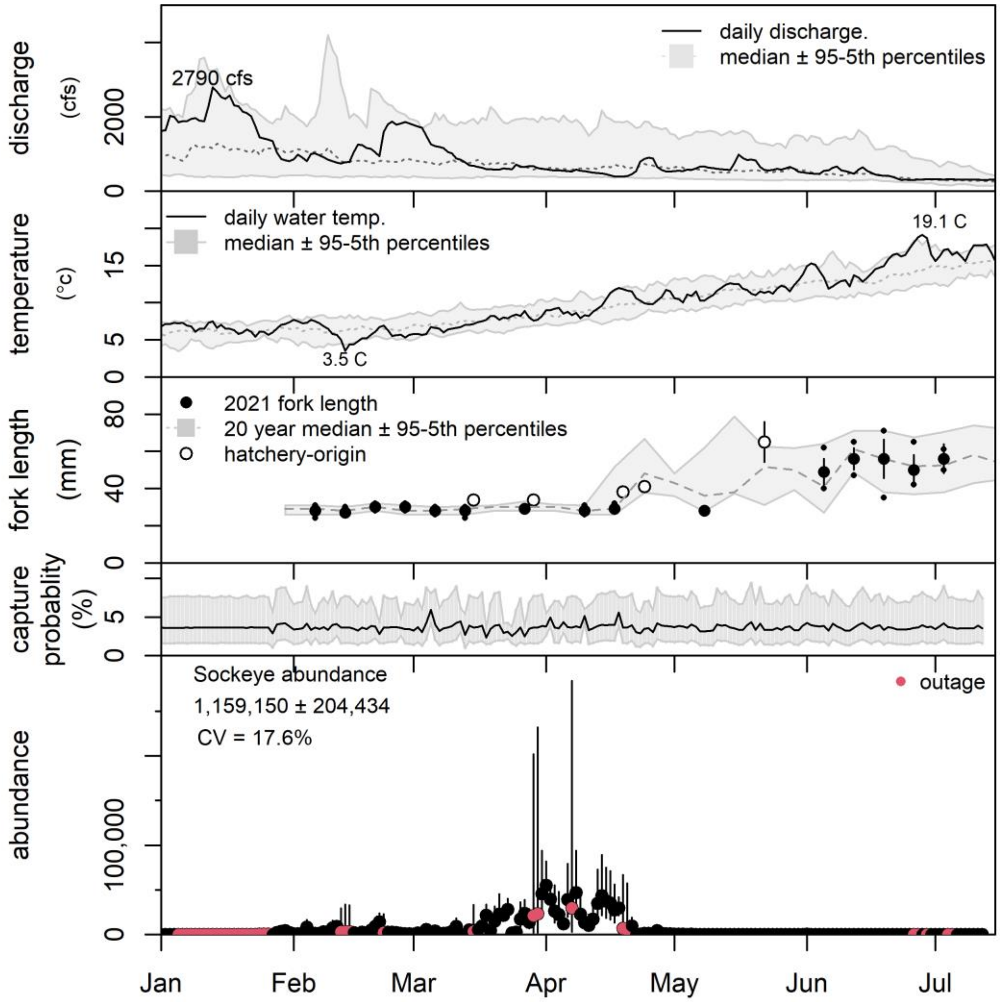


Figure 2. Top two panels: daily river discharge and water temperature during the trapping period (USGS gage #12119000). The grey dotted line is the historical median daily flow (1989-2020) or temperature (2007-2020). The shaded regions indicate the historical 95th or 5th percentiles in discharge or water temperature. Middle panel: average fork length of natural-origin and hatchery origin sockeye fry with vertical lines as ± 1 standard deviation. The shaded regions and dashed line indicate the historical median of natural origin fry plus the 95th or 5th percentiles weekly fork length 1999-2020. Second from the bottom: daily capture probability of sockeye and 95% credible intervals. Bottom panel: Estimated daily migration of natural-origin sockeye fry migrating from the Cedar River into Lake Washington between January and July 2021. Pre-trapping migration estimates are included (Jan. 1 - Jan. 26). Missed days for outages shown in red points.

Table 2. Release schedule of 547,296 hatchery sockeye fry from the Cedar River Sockeye Hatchery released at three different release points along the Cedar River in 2021: lower (river mile, R.M. 2.1), middle (R.M. 13.5) and upper location (R.M. 21.8). The Issaquah hatchery also raised Cedar River 137,087 sockeye for an extended period and released them in the lower Cedar River as sub yearling fingerlings in May and November of 2021.

Release date	Lower	Middle	Upper	Total
March 15	102,400	100,033	50,200	252,633
March 29	61,673	60,947	30,274	152,894
April 19	57,104	56,685	27,980	141,749
Total	221,177	217,665	108,454	547,296

Period	Release date	Lower	Middle	Upper	Total
Extended	May 12	111,619			111,619
Extended	November 1	25,468			25,468
		137,087			137,087

Table 3. Median migration dates of natural-origin, hatchery, and average combined sockeye fry from the Cedar River for trap years 1992 to 2021. Does not included extended rearing sockeye from Issaquah 2019-2021.

Trap year	Natural	Hatchery	Combined	Diff (H-N)
1992	03/18	02/28	03/12	19
1993	03/27	03/07	03/25	20
1994	03/29	03/21	03/26	8
1995	04/05	03/17	03/29	19
1996	04/07	02/26	02/28	41
1997	04/07	02/20	03/16	46
1998	03/11	02/23	03/06	16
1999	03/30	03/03	03/15	27
2000	03/27	02/23	03/20	33
2001	03/10	02/23	03/08	15
2002	03/25	03/04	03/19	21
2003	03/08	02/24	03/03	12
2004	03/21	02/23	03/15	27
2005	03/02	02/23	03/01	7
2006	03/20	03/06	03/16	14
2007	03/23	02/20	02/26	31
2008	03/16	03/06	03/15	10
2009	03/19	03/06	03/13	13
2010	03/07	03/08	03/07	-1
2011	03/25	02/18	03/01	35
2012	03/22	03/08	03/18	14
2013	03/07	03/06	03/07	1
2014	03/02	03/11	03/04	-9
2015	03/07	03/12	03/07	-5
2016	03/07	03/14	03/14	-7
2017	02/28	03/08	03/03	-8
2018	03/11	03/14	03/13	-3
2019	03/05	03/13	03/09	-8
2020	02/26	03/18	03/07	-20
2021	04/02	03/27	03/30	6

Egg-to-Migrant Survival of Natural-Origin Fry

Egg-to-migrant survival of the 2020 Cedar River sockeye brood was 38.1% (Table 4). Egg-to-migrant survival was based on 1,159,150 natural-origin fry from 3,040,994 eggs deposited by 1,034 females (J. Short WDFW, personal communication). Average fecundity for the 2020 brood was 2,941 eggs per female sockeye (M. Sedgwick, WDFW). Salmon eggs and alevins incubating within streambed redds are susceptible to flooding and scour, so peak winter discharges often explain annual variation in egg-to-fry survival. River flows surpassed known scouring thresholds (2,200 ft^3 sec^{-1}, Gendaszek et al. 2017) during egg incubation. Peak flows were above 2,200 ft^3 sec^{-1} for about one week in January (Figure 2). The Cedar River USGS station (12119000) showed a daily average of 2,790 ft^3 sec^{-1} on Jan 13th, 2021. Most of the migration occurred when daily flows were moderate from late February through April (Figure 2).

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 - 2019. Incubation period is defined as November 1 to February 29.

Brood yr	Trap	Spawners	Females	Fecundity	Egg deposition	Fry	Survival	Peak flow	Flow date
1991	1992	76,592	38,296	3,282	125,687,226	9,800,000	7.80%	2,060	1/28/1992
1992	1993	99,849	49,924	3,470	173,237,755	27,100,000	15.64%	1,570	1/26/1993
1993	1994	74,677	37,338	3,094	115,524,700	18,100,000	15.67%	927	1/14/1994
1994	1995	107,767	53,883	3,176	171,133,837	8,700,000	5.08%	2,730	12/27/1994
1995	1996	21,443	10,721	3,466	37,160,483	730,000	1.96%	7,310	11/30/1995
1996	1997	228,391	114,196	3,298	376,616,759	24,390,000	6.48%	2,830	1/2/1997
1997	1998	102,581	51,291	3,292	168,848,655	25,350,000	15.01%	1,790	1/23/1998
1998	1999	48,385	24,193	3,176	76,835,676	9,500,000	12.36%	2,720	1/1/1999
1999	2000	21,755	10,877	3,591	39,060,930	8,058,909	20.63%	2,680	12/18/1999
2000	2001	146,060	73,030	3,451	252,025,754	38,447,878	15.26%	627	1/5/2001
2001	2002	117,225	58,613	3,568	209,129,787	31,673,029	15.15%	1,930	11/23/2001
2002	2003	192,395	96,197	3,395	326,590,484	27,859,466	8.53%	1,410	2/4/2003
2003	2004	109,164	54,582	3,412	186,233,926	38,686,899	20.77%	2,039	1/30/2004
2004	2005	114,839	57,419	3,276	188,106,200	37,027,961	19.68%	1,900	1/18/2005
2005	2006	49,846	24,923	3,065	76,388,804	10,861,369	14.22%	3,860	1/11/2006
2006	2007	105,055	52,527	2,910	152,854,370	9,246,243	6.05%	5,411	11/9/2006
2007	2008	45,066	22,533	3,450	77,738,114	25,072,141	32.25%	1,820	12/3/2007
2008	2009	17,300	8,650	3,135	27,118,177	1,630,081	6.01%	9,390	1/8/2009
2009	2010	12,501	6,250	3,540	22,125,910	12,519,260	56.58%	2,000	11/19/2009
2010	2011	59,795	29,898	3,075	91,935,489	4,517,705	4.91%	5,960	1/18/2011
2011	2012	23,655	11,827	3,318	39,243,121	14,763,509	37.62%	2,780	1/30/2012
2012	2013	88,974	44,487	3,515	156,371,805	55,793,120	35.68%	1,513	12/7/2012
2013	2014	140,682	70,341	3,362	236,486,442	37,975,769	16.06%	1,762	11/20/2013
2014	2015	10,450	5,225	3,368	17,597,800	13,878,932	78.87%	2,162	1/8/2015
2015	2016	7,191	3,596	3,070	11,038,185	2,163,843	19.60%	4,661	12/7/2015
2016	2017	7,573	3,787	3,144	11,904,756	2,530,668	21.26%	2,140	2/10/2017
2017	2018	31,290	15,645	3,050	47,717,250	8,725,471	18.29%	2,330	2/6/2018
2018	2019	3,686	1,843	3,152	5,810,979	2,264,857	38.98%	2,040	12/30/2018
2019	2020	1,607	804	3,268	2,627,472	32,495	1.24%	8,450	2/8/2020
2020	2021	2,068	1,034	2,941	3,040,994	1,159,150	38.12%	2,790	1/13/2021

Chinook

Production Estimate

For the purposes of the Lake Washington juvenile monitoring project, a timeframe traditionally defines the fry and parr run, we acknowledge some parr sized fish may be included in the fry estimation and fry sized fish in the parr component. Fry are defined as those fish emigrating from January to April 8th and Chinook parr start emigrating on April 9th (Figure 3) as this traditionally the time period when fry <45mm are not observed in the catch and a greater proportion of parr > 45mm FL are captured. Weekly lengths of sub-yearling Chinook migrants averaged 38 - 44 mm from January through March. Average fork length increased to 47-61 mm in April. In May, parr averaged 62-79 mm and 90 mm in fork length in June (Figure 3). Some smaller body sized Chinook (~73 mm) were captured in late June, coinciding with the June heatwave. No heat related mortalities were observed even as daily water temperatures averaged 19.1℃ on June 26th.

The total production of Chinook sub-yearling (parr and fry) in 2021 was 57,918 ± 15,870 (±95% C.I.). During the parr transition period, the overall migration decreases and larger size parr appear in the catch (Figure 3). We estimated 40,191 ± 7,981 fry and 17,727 ± 6,654 parr in 2021 (Table 5). The fry component includes a small pre-trapping estimate of 1,217 migrants. The Chinook fry migration increased quickly over the season to one prominent peak in early February then slowly decreased for the remainder of season (Figure 3). Parr displayed sporadic movements under 1,000 fish per day in late May and early June (Figure 3). Fry trap efficiencies averaged 3.6% while trap efficiencies for parr was higher (5.6%) when water levels were much lower.

Table 5. Abundance of Chinook migrants from the Cedar River in 2021. Table includes catch, abundance of fry and parr life history types, 95% confidence intervals (C.I.), coefficient of variation (*CV*).

Life history	Period	Catch	Abundance	SD	Lower CI	Upper CI	*CV*
Pre fry-trapping	Jan 1 - Jan 26	--	1,217	418	598	2,216	34.4%
Fry- trapping	Jan 27 - April 8	1,194	38,974	2,574	34,171	44,258	6.6%
Fry total	Jan 1 - April 8	1,194	40,191	4,702	32,210	48,172	10.1%
Parr total	April 9 - July 12	916	17,727	3,395	11,073	24,381	19.2%
	Total	2,110	57,918	8,097	42,048	73,788	14.0%

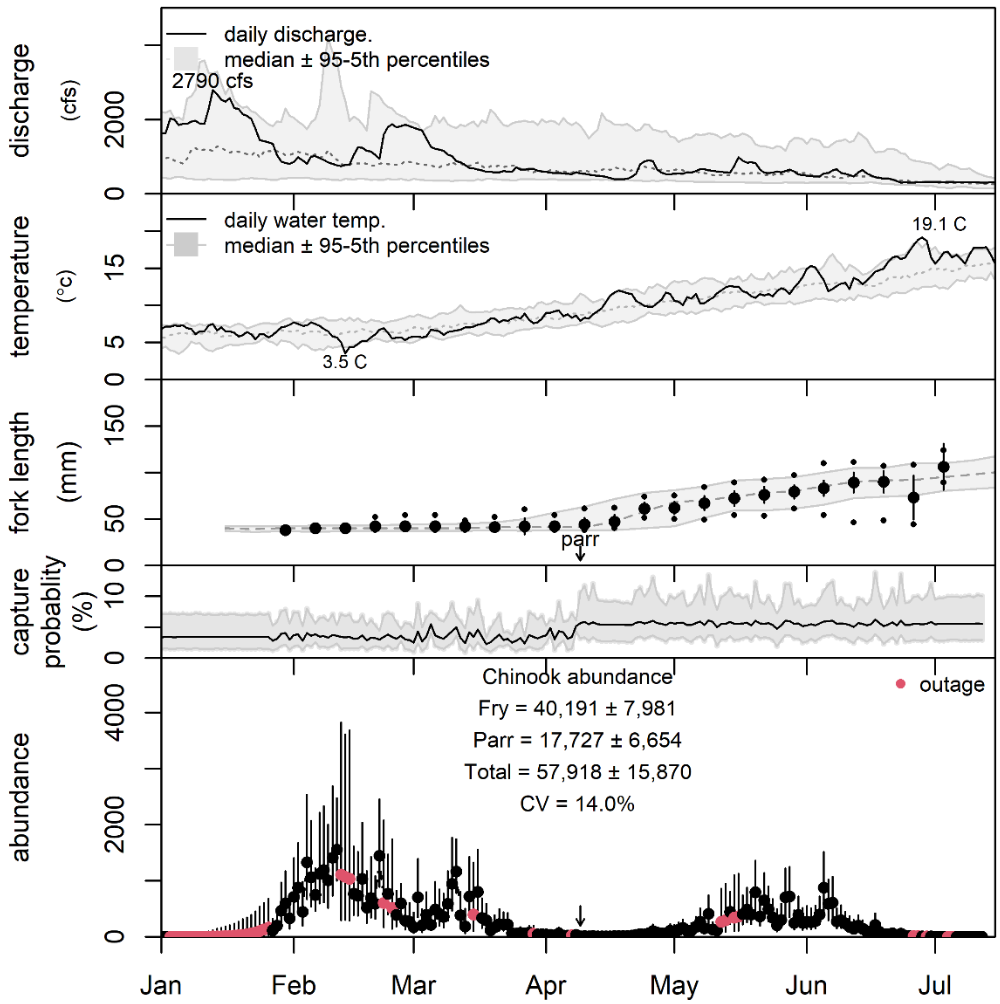


Figure 3. Top two panels: daily river discharge and water temperature during the spring outmigration period (USGS gage #12119000). The grey dotted line is the historical median daily flow (1989-2020) or temperature (2007-2020). The shaded regions indicate the historical 95th or 5th percentiles in water temperature or discharge. Middle panel: mean weekly Chinook body fork length with vertical lines as ± 1 standard deviation and '·' ± maximum and minimum weekly fork length. The shaded regions indicate the historical median plus the 95th or 5th percentiles weekly fork lengths from 1999-2020. Second from the bottom panel shows the daily capture probabilities and 95% credible intervals. Bottom panel: Estimated daily migration of Chinook fry and parr migrating from the Cedar River into Lake Washington between January and July 2021 and 95% credible intervals. Missed days for outages or pre-trapping migration are shown in red points. Parr life history type designation starts on April 9th.

Productivity

Egg-to-migrant survival of the 2020 brood Cedar River Chinook was 6.2% (Table 6). Survival was based on 57,918 sub-yearling migrants and 940,500 eggs from 209 female spawners (J. Short, WDFW; Karl Burton SPU, personal communication). The egg-to-migrant survival (assuming 4,500 eggs per female) is below the 2025 goals for the Cedar (≥13.8%, WRIA 8 Conservation plan 2017). We calculated an alternative egg-to-migrant survival estimate using the relationship between body size and fecundity (Appendix A). This alternative calculation produced an egg-to-migrant survival of 5.2%, below the WRIA 8 conservation plan 2025 goals.

Table 6. Abundance of Chinook fry and parr and productivity (juveniles per female) among brood years since 1998. Productivity is based on 4,500 eggs per females and weekly fall redd surveys. An alternative survival estimate uses Chinook fecundity on the spawning ground based on the size of female carcasses found on the spawning ground.

Trap Brood	Trap Year	Fry	Parr	Total	±95%CI	%Fry	%Parr	Redds	Fry per Female	Parr per Female	Total per Female	Egg Survival	Alt. Egg Survival
1998	1999	63,702	17,230	80,932	7,732	79%	21%	173	368	100	468	10.4%	--
1999	2000	46,500	18,223	64,723	5,609	72%	28%	182	255	100	356	7.9%	--
2000	2001	10,833	21,416	32,249	5,220	34%	66%	53	204	404	608	13.5%	--
2001	2002	79,799	39,875	119,674	41,349	67%	33%	398	201	100	301	6.7%	6.3%
2002	2003	194,657	40,740	235,397	51,485	83%	17%	281	693	145	838	18.6%	14.8%
2003	2004	65,752	55,124	120,876	2,518	54%	46%	337	195	164	359	8.0%	6.0%
2004	2005	74,292	60,006	134,298	42,912	55%	45%	511	145	117	263	5.8%	4.4%
2005	2006	98,967	18,592	117,559	16,233	84%	16%	339	292	55	347	7.7%	6.1%
2006	2007	110,961	14,225	125,186	16,912	89%	11%	587	189	24	213	4.7%	3.7%
2007	2008	705,583	64,208	769,791	76,106	92%	8%	899	785	71	785	19.0%	15.5%
2008	2009	127,064	12,388	139,452	38,399	91%	9%	599	212	21	233	5.2%	3.8%
2009	2010	115,474	36,916	152,390	13,058	76%	24%	285	405	130	535	11.9%	8.7%
2010	2011	177,803	10,003	187,806	63,560	95%	5%	266	668	38	706	15.7%	11.0%
2011	2012	863,595	38,919	902,514	165,973	96%	4%	324	2,665	120	2,786	61.9%	45.9%
2012	2013	874,658	19,219	893,877	77,993	98%	2%	433	2,020	44	2,064	45.9%	41.3%
2013	2014	1,426,631	32,130	1,458,761	390,039	98%	2%	740	1,928	43	1,971	43.8%	33.1%
2014	2015	326,901	20,762	347,663	90,223	94%	6%	232	1,409	89	1,499	33.3%	29.4%
2015	2016	941,443	31,198	972,641	408,314	97%	3%	723	1,302	43	1,345	29.9%	23.6%
2016	2017	151,262	23,457	174,719	37,722	87%	13%	418	362	56	418	9.3%	8.1%
2017	2018	492,574	31,804	524,378	78,450	94%	6%	819	601	39	640	14.2%	12.0%
2018	2019	186,407	38,250	224,657	60,588	83%	17%	325	574	118	691	15.4%	13.5%
2019	2020	22,410	14,783	37,193	21,438	60%	40%	342	66	43	109	2.4%	2.0%
2020	2021	40,191	17,727	57,918	15,870	69%	31%	209	192	85	277	6.2%	5.2%

Coho

Production Estimate

Total Cedar River coho age 1+ smolt production was 38,235 ± 12,509 (± 95% C.I., CV = 16.67%) migrants (Table 7, Figure 4) with a median migration date of May 11th. Catches and mark groups were stratified into weekly groups. Total catch of coho migrants in the trap was 1,874. We observed two life history forms in the Cedar River: typical 1+ yearling coho and sub-yearling age 0+ coho fry and parr (Figure 4). Catch of young of the year (age 0+) were not included in the abundance estimate (*N* = 33). Coho numbers increased when river flow receded in March and following flow pulse on May 11th. The production estimate for coho was down from previous years, but was expected to be lower given the 2020 February flooding during young of the year incubation and emergence (Table 8).

Table 7. Weekly catch, missed catch, total catch, mark releases, recaptures, and abundance of coho smolt migrants from Cedar River in 2021. Table includes a modeled estimate of median trap efficiency (eff.) and coefficient of variation (*CV %*).

Start	End	Catch	Missed Catch	Total Catch	Marks	Recaps.	*Eff.*	Abundance	*CV%*
27-Jan	30-Jan	2	0	2	0	0	5.0%	32	91%
31-Jan	6-Feb	0	0	0	0	0	4.4%	27	74%
7-Feb	13-Feb	2	0	2	0	0	4.8%	43	58%
14-Feb	20-Feb	1	0	1	0	0	4.5%	43	58%
21-Feb	27-Feb	10	0	10	0	0	6.3%	109	49%
28-Feb	6-Mar	2	0	2	0	0	4.8%	45	56%
7-Mar	13-Mar	0	0	0	0	0	4.3%	31	61%
14-Mar	20-Mar	0	0	0	0	0	4.3%	30	67%
21-Mar	27-Mar	2	0	2	0	0	4.7%	48	65%
28-Mar	3-Apr	4	1	5	0	0	4.9%	99	55%
4-Apr	10-Apr	10	2	12	0	0	4.9%	248	43%
11-Apr	17-Apr	18	0	18	0	0	4.3%	492	46%
18-Apr	24-Apr	93	3	96	0	0	5.2%	2,251	29%
25-Apr	1-May	171	0	171	133	9	5.0%	3,518	24%
2-May	8-May	414	0	414	187	8	4.9%	8,526	21%
9-May	15-May	395	176	571	202	10	5.3%	12,115	21%
16-May	22-May	366	0	366	180	9	5.0%	7,478	22%
23-May	29-May	157	0	157	32	2	4.8%	3,359	30%
30-May	5-Jun	23	0	23	0	0	3.9%	747	63%
6-Jun	12-Jun	12	0	12	0	0	4.5%	305	54%
13-Jun	19-Jun	8	0	8	0	0	5.2%	130	50%
20-Jun	26-Jun	2	0	2	0	0	5.0%	32	69%
27-Jun	3-Jul	0	0	0	0	0	4.7%	7	114%
4-July	12-Jul	0	0	0	0	0	4.8%	2	250%
	Total	1,692	182	1,874	734	38	4.9%	38,235	16.7%

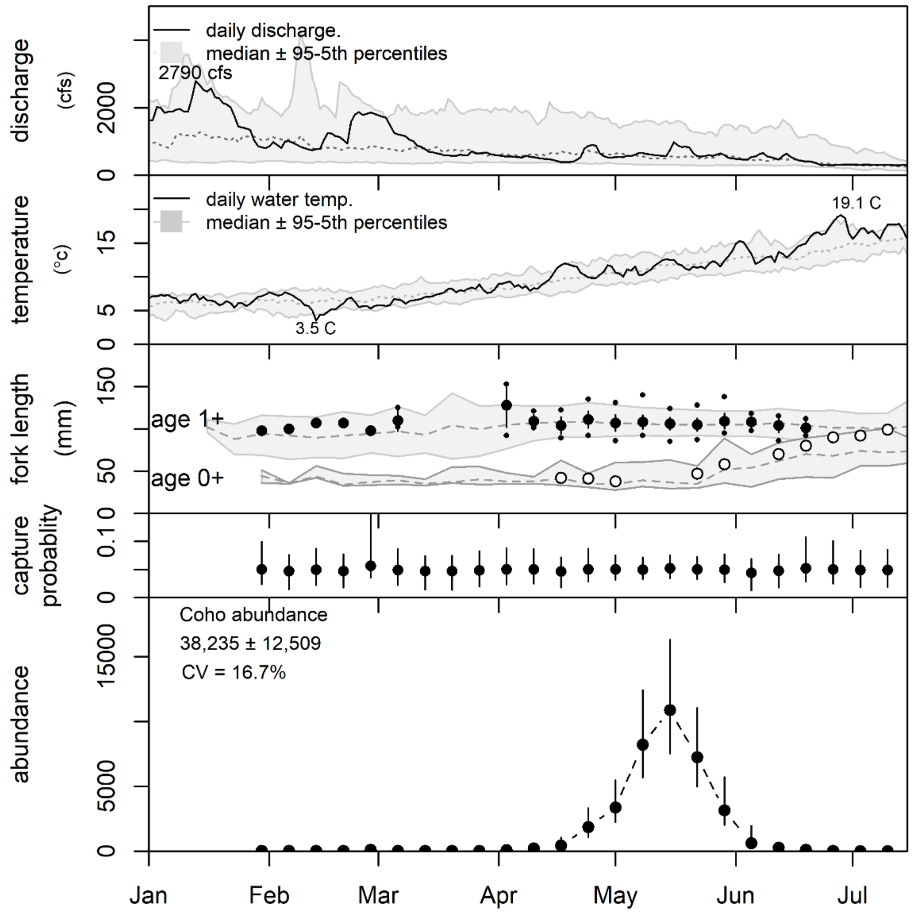


Figure 4. Top panels: daily river discharge or water temperature (USGS gage #12119000). The shaded region is the historical 5th and 95th percentiles of daily flow (1989-2020) or temperature (2007-2020) with the dotted line as the historical median. Middle panel: mean weekly coho body fork length from the Cedar River in 2021 with vertical lines as ± 1 standard deviation and '.' ± maximum and minimum weekly fork length. Age 1+ smolts in filled points and age 0+fry and parr in open points. The shaded regions and dashed line indicate the historical median plus the 95th or 5th percentiles weekly fork length 1999-2020. Fourth panel: capture probabilities estimated at weekly time scale from mark release groups (median ± 95% CI). Bottom panel: Estimated weekly migration (median ± 95% CI) of yearling coho in 2021 based on screw trap catches from January 27 to July 13.

Table 8. Annual catch, abundance estimate, and 95% C.I. of natural-origin juvenile coho yearlings emigrating from Cedar River from brood years 1997 to 2019.

Brood	Trap	Total Catch	Start	End	Abundance	Lower CI	Upper CI	*CV*
1997	1999	5,018	03/18	07/27	39,088	35,241	42,935	5.00%
1998	2000	2,446	04/27	07/13	32,169	30,506	33,833	--
1999	2001	6,262	04/08	07/22	82,462	60,293	104,661	13.70%
2000	2002	3,716	04/01	07/22	60,513	50,286	70,740	8.60%
2001	2003	3,964	04/10	07/12	74,507	58,947	90,067	10.70%
2002	2004	2,808	04/14	07/20	70,044	46,735	93,353	17.00%
2003	2005	2,918	04/01	07/28	72,643	42,725	102,561	21.40%
2004	2006	795	04/01	07/16	38,023	16,416	59,629	28.90%
2005	2007	482	04/01	07/20	33,994	8,291	59,697	40.80%
2006	2008	315	04/14	07/19	13,322	3,392	23,372	--
2007	2009	5,805	04/21	07/18	52,691	45,600	59,782	6.87%
2008	2010	6,528	04/22	07/04	83,060	70,049	96,071	7.99%
2009	2011	4,930	04/27	07/16	52,458	44,645	60,271	7.60%
2010	2012	2,912	04/18	07/14	48,168	38,493	57,843	10.25%
2011	2013	4,623	04/17	07/17	115,185	90,688	139,682	10.90%
2012	2014	8,071	04/16	07/16	129,666	104,393	154,940	9.94%
2013	2015	5,209	04/08	07/08	107,874	91,047	124,701	7.96%
2014	2016	2,720	04/14	07/14	60,621	41,862	79,379	15.79%
2015	2017	2,798	01/12	07/12	91,295	61,769	120,821	16.50%
2016	2018	5,848	01/12	07/15	179,946	127,504	232,388	14.87%
2017	2019	3,335	01/14	07/15	62,328	44,894	79,762	14.27%
2018	2020	2,097	01/22	07/13	45,132	21,258	69,006	16.30%
2019	2021	1,874	01/27	07/13	38,235	25,727	50,743	16.67%

Trout and Incidental Catch

Life history strategies used by trout in the Cedar River include anadromous, adfluvial, fluvial, and resident forms. Catches and estimates reported herein are for trout that were visually identified as either *Oncorhynchus clarkii* (cutthroat trout) or *Oncorhynchus mykiss* (steelhead/rainbow trout). Steelhead smolts were identified when the fish had silver coloration upon capture. We did not identify trout fry to species or life-history type. Nine steelhead smolts, 206 juvenile cutthroat trout, and 73 unidentifiable trout fry. One adult cutthroat trout was captured in the screw trap. Catch of these fishes were too few to estimate abundance. Other salmonids include 35 hatchery Chinook parr.

Twenty-two species of fish were documented in the Cedar River over the last 6 years, but only 16 species in 2021. Other fishes encountered in the trap during include 49 lamprey (*Lampetra* spp.), 394 three-spine stickleback (*Gasterosteus aculeatus*), 229 sculpin (*Cottus* spp.), 28 large-scale suckers (*Catostomus macrocheilus*), 9 whitefish *(Prosopium spp*), 3 peamouth chub (*Mylocheilus caurinus*), 4 rockbass (*Ambloplites rupestris*), and 35 longnose dace (*Rhinichthys cataractae*) and 3 speckled dace (*Rhinichthys osculus*) See Appendix A for the full species catch over the last 6 years.

Bear Creek

Sockeye

Production Estimate

We estimated that 20,243 ± 9,605 (± 95% CI, CV = 24.2%) natural-origin sockeye fry out-migrated from Bear Creek in 2021 (Figure 5, Table 9). Catch was near zero during the first nights days of trapping, so we did not estimate a preseason catch. Median migration date for natural-origin sockeye was Mach 3rd, which is about 12 days earlier than the historical median (March 15th). We captured 1,832 sockeye fry during the trapping period (Table 9). Only three efficiency trials could be completed from February to March (Table 9) with a median daily efficiency of 7.7%. The difficulty of completing weekly efficiency trails and low catch likely contributed to a larger uncertainty (CV = 24%), so the estimate should be viewed with some skepticism.

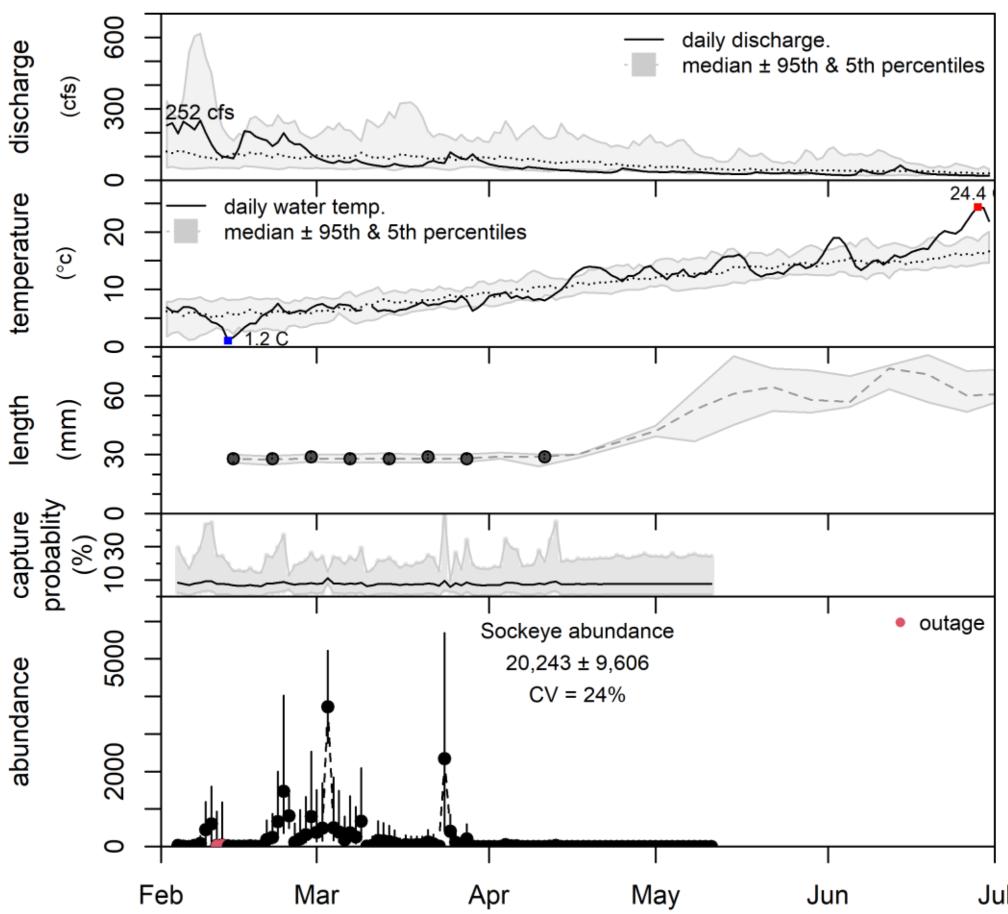


Figure 5. Top panels: Daily river discharge and water temperature. The shaded region represents the historical 5th and 95th percentiles of daily flow since 1987 and temperature since 1995 with the grey dotted line as the historical daily median. Center panel: Mean weekly sockeye fork

length with vertical lines as ± 1 standard deviation and '.' ± maximum and minimum weekly fork length. The shaded regions and dashed line indicate the historical median plus the 95th or 5th percentiles weekly fork length since 1999. Second from the bottom: capture probabilities from efficiency trails of marked catches. Bottom Panel: Estimated daily migration of sockeye fry from Bear Creek in 2021. Missed days for outages shown in red points.

Table 9. Abundance of sockeye fry migrants from Bear Creek in 2021. Table includes 95% confidence intervals (C.I.) of abundance, coefficient of variation (*CV*) and trap efficiency *(Eff)*.

Period	Total catch	Abundance	Lower CI	Upper CI	*CV*	*Eff.*
February 4 - July 1	1,581	20,243	10,637	29,849	24.2%	7.7%

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2020 brood of Bear Creek sockeye was 2.8 % (Table 10). The survival estimate is based on a total of 20,243 fry migrants and a potential egg deposition (PED) of 720,545 eggs from 245 female sockeye enumerated in Bear Creek in the fall of 2020. Peak stream flows during the egg incubation were mild, reaching 252 $ft^3 s^{-1}$ on February 8, 2021 (median peak flows = 467 $ft^3 s^{-1}$). Lower peak incubation flows are typically associated with a lower likelihood of redd scour and therefore better egg-to-migrant survival (see Cedar River 2019 broodyear). However, Bear Creek sockeye production appears to improve when peak incubation stream flows are higher. The long-term data (Table 10) suggests that a different mechanism likely impacts the egg-to-migrant survival for sockeye fry in Bear Creek (e.g., temperature, predation, turbidity).

Table 10. Egg-to-migrant survival of Bear Creek sockeye by brood year. Potential egg deposition (PED) is based on fecundity of sockeye broodstock in the Cedar River. Median run date based on a cumulative distribution when 50% of the migration passed.

Brood yr	Spawners	Females	Fecundity	Egg deposition	Fry production	Egg Survival	Peak Flow	Flow date	Run timing
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	3/22
2001	8,378	4,189	3,568	14,946,352	2,659,782	17.8%	626	11/23/2001	3/13
2002	34,700	17,350	3,395	58,903,250	1,995,294	3.4%	222	1/23/2003	3/15
2003	1,765	883	3,412	3,011,090	177,801	5.9%	660	1/30/2004	3/11
2004	1,449	725	3,276	2,373,462	202,815	8.5%	495	12/12/2004	3/10
2005	3,261	1,631	3,065	4,999,015	548,604	11.0%	636	1/31/2005	3/10
2006	21,172	10,586	2,910	30,805,260	5,983,651	19.4%	581	12/15/2006	3/18
2007	1,080	540	3,450	1,863,000	251,285	13.5%	1,055	12/4/2007	3/20
2008	577	289	3,135	904,448	327,225	36.2%	546	1/8/2009	3/28
2009	1,568	784	3,540	2,775,360	129,903	4.7%	309	11/27/2009	3/16
2010	12,527	6,264	3,075	19,260,263	8,160,976	42.4%	888	12/13/2010	3/14
2011	911	455	3,318	1,509,690	266,899	17.7%	348	11/23/2011	3/26
2012	4,219	2,110	3,515	7,414,893	1,553,602	21.0%	467	1/10/2013	3/18
2013	2,003	1,001	3,362	3,365,362	438,534	13.0%	244	1/12/2014	3/20
2014	2,130	1,065	3,368	3,586,920	1,590,812	44.4%	206	2/7/2015	2/19
2015	414	207	3,070	635,490	81,125	12.8%	350	1/29/2016	3/4
2016	1,031	516	3,144	1,622,304	512,651	31.6%	645	2/10/2017	3/21
2017	1,721	861	3,050	2,626,050	1,385,897	52.8%	419	1/12/2018	3/15
2018	658	329	3,153	1,037,757	22,536	2.2%	238	12/30/2018	4/3
2019	610	305	3,268	996,740	73,076	7.3%	1,045	2/6/2020	3/7
2020	490	245	2,941	720,545	20,243	2.8%	252	2/8/2021	3/3

Chinook

Production Estimate

Two life-history forms of sub-yearling Chinook salmon are commonly observed in Puget Sound: small fry that migrate immediately after emergence while parr are those that rear and grow before migrating. Within the Lake Washington juvenile monitoring project, a timeframe traditionally defines the fry and parr run, we acknowledge there may be some parr sized fish included in the fry estimation and fry sized fish in the parr component. Weekly lengths of sub-yearling Chinook migrants averaged 38-44 mm in early March. Average fork length quickly increased to 64 mm by mid-April. Parr reached 80 mm in May and averaged that size through all of June (Figure 6). This is in contrast to the Cedar River, where fish appear to continue to grow throughout June.

The total production of Chinook sub-yearling (parr and fry) was 14,600 ± 2,215 (±95% C.I., CV = 7.7% Table 11). Fry represented 10.6% of the total migration (1,543 ± 449). Only 104 chinook fry were caught between February 4 to April 8th. We did not estimate a preseason catch as very few fry were captured during the first 5 nights of trapping. Parr represented 89.4% of total production in Bear Creek (13,057 ± 1,020; Figure 6). The median dates of the fry and parr migration were February 22nd and May 16th (respectively, Figure 6). Parr migrated out of Bear Creek rapidly as average water temperatures surpassed 20°C in late June (Figure 6). The Chinook abundance estimate was based on a total catch (actual plus estimated missed catch) of 104 Chinook fry and 4,919 parr. Trap efficiencies for the fry period were estimated from 3 surrogate sockeye fry efficiency trials through April 8 (~6.4%). Efficiency from 15 PIT tagged parr trials averaged 38.6% throughout the parr migration (Table 11).

Table 11. Abundance of natural-origin sub-yearling Chinook emigrating from Bear Creek in 2021. Table includes abundance of juvenile migrants, 95% confidence intervals (C.I.), coefficient of variation (*CV*), and median efficiency strata for each period.

Life history	Period	Total Catch	Abundance	Lower CI	Upper CI	*CV*	*Eff.*
Fry	February 4 -April 8	104	1,543	1094	1,992	14.8%	6.6%
Parr	April 9 – July 1	4,815	13,057	11,077	15,037	7.7%	38.6%
	Total	4,919	14,600	12,385	16,815	7.7%	

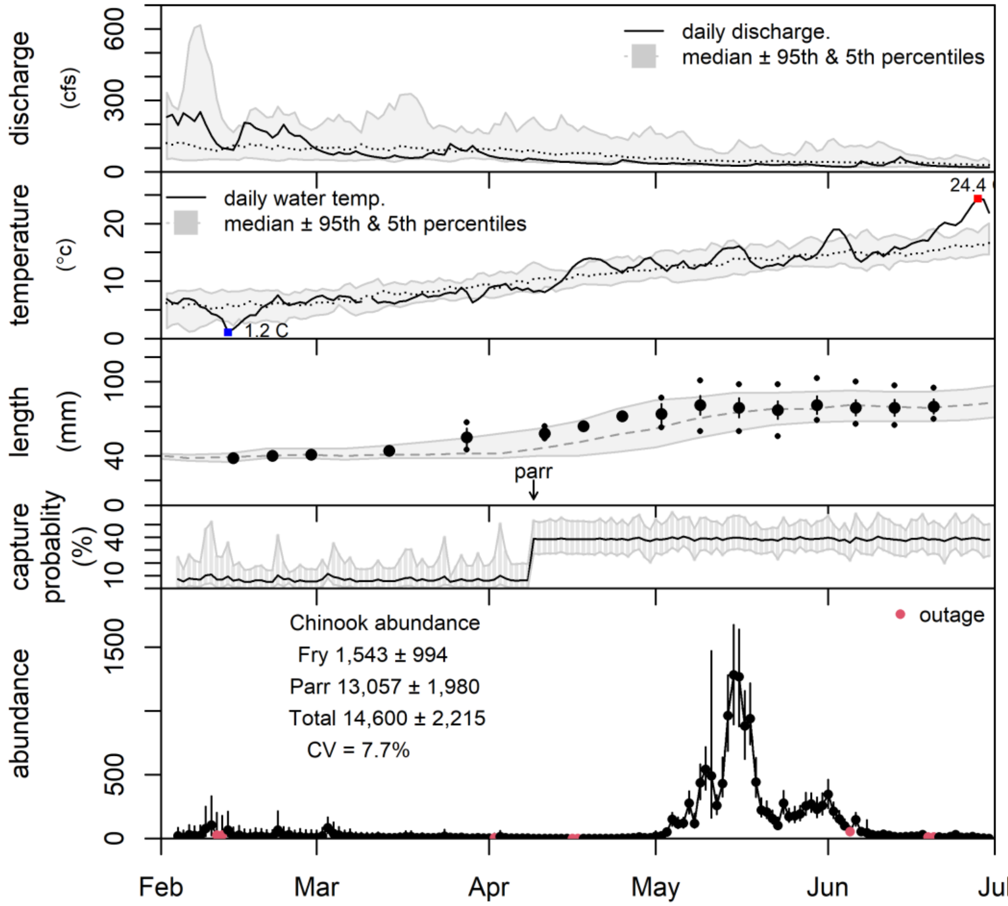


Figure 6. Top panels: daily river discharge and water temperature. The shaded region represents the historical 5th and 95th percentiles of daily flow (since 1987) or temperature (since 1995) with the grey dotted line as the historical daily median. Center panel: Mean weekly sockeye fork length with vertical lines as ± 1 standard deviation and '.' ± maximum and minimum weekly fork length. The shaded regions and dashed line indicate the historical median plus the 95th or 5th percentiles weekly fork length since 1999. Second from the bottom: capture probabilities from efficiency trails of marked catches. Bottom Panel: Estimated daily migration of Chinook fry and parr from Bear Creek in 2021. Missed days for outages shown in red points. Parr life history type designation starts on April 9th.

Productivity

Egg-to-migrant survival of the 2020 brood of Bear Creek Chinook was 7.1% (Table 12). The survival estimate is based on 14,600 sub-yearling migrants and a potential egg deposition of eggs deposited in 46 Chinook redds assuming 4,500 eggs per female. For the 2020 brood, the Bear Creek Chinook population appeared to produce a higher egg-to-migrant survival rate (7.1%) than the Cedar River (6.3%) and a higher estimate of parr per female (283) than the Cedar River (86). For 10 of the last 10 years, egg-to-migrant survival rate in Bear Creek exceeded the 2025 WRIA 8 goals for this population (≥4.4%). Three out of the last 10 years surpassed 2055 WRIA 8 goals for this Chinook population (≥10%). Chinook productivity (juveniles per spawner) appears to be improving over time in Bear Creek.

As an alternative approach to estimate egg-to-migrant survival, we also estimated the average Chinook fecundity on the spawning ground based on the post-orbital eye to hypural plate length (POH) of female carcasses (data provided by A. Bosworth, Appendix B). This formulation can be a more conservative estimate of annual survival rate relative to our previous estimate of fecundity of 4,500 eggs per female, depending on the average size of females. Most Bear Creek Chinook spawners in 2020 were smaller in body size (585mm, Appendix B), and therefore we estimate a slightly lower fecundity (4,248 eggs per female). The alternative survival estimate (7.5%) is only marginally higher than a survival formulation assuming 4,500 eggs per spawner (7.1%). Chinook spawners in Bear Creek closely match the body size and ages found spawning in Issaquah Creek due to the high prevalence of hatchery spawners in Bear Creek and Issaquah Creek (pHOS > 90%).

Table 12. Abundance and productivity (juveniles per female) of natural-origin Chinook in Bear Creek. Fry are assumed to have migrated between January 1 and April 8. Parr are assumed to have migrated after April 9. Data are for 1998 to 2020 brood years. Egg survival based off 4,500 eggs per female spawner. We provide an alternative estimate of survival by adjusting fecundity according to the length of fish observed on the spawning ground that year.

brood year	trap year	fry	parr	total	% fry	% parr	female spawners	fry/ female	parr / female	total / female	egg survival	alt. egg survival
1998	1999	1,720	13,282	15,002	11.5%	88.5%	159	10	83	94	2.1%	
1999	2000	14,116	18,104	32,220	43.8%	56.2%	293	48	61	109	2.4%	
2000	2001	419	10,087	10,506	4.0%	96.0%	133	3	76	79	1.8%	
2001	2002	5,427	15,891	21,318	25.5%	74.5%	138	39	115	154	3.4%	2.8%
2002	2003	645	16,636	17,281	3.7%	96.3%	127	5	131	136	3.0%	2.5%
2003	2004	2,089	21,558	23,647	8.8%	91.2%	147	14	147	161	3.6%	2.8%
2004	2005	1,178	8,092	9,270	12.7%	87.3%	121	10	67	77	1.7%	1.3%
2005	2006	5,764	16,598	22,362	25.8%	74.2%	122	47	136	183	4.1%	3.2%
2006	2007	3,452	13,077	16,529	20.9%	79.1%	131	26	100	126	2.8%	2.2%
2007	2008	1,163	11,543	12,706	9.2%	90.8%	89	13	130	143	3.2%	2.9%
2008	2009	14,243	50,959	65,202	21.8%	78.2%	132	108	386	494	11.0%	8.3%
2009	2010	1,530	7,655	9,185	16.7%	83.3%	48	32	159	191	4.3%	3.3%
2010	2011	901	16,862	17,763	5.1%	94.9%	60	15	281	296	6.6%	5.2%
2011	2012	4,000	18,197	22,197	18.0%	82.0%	55	73	331	404	9.0%	6.8%
2012	2013	24,776	19,823	44,599	55.6%	44.4%	147	169	135	303	6.7%	6.1%
2013	2014	24,266	38,509	62,775	38.7%	61.3%	48	506	802	1,308	29.1%	22.8%
2014	2015	25,500	7,233	32,733	77.9%	22.1%	60	425	121	546	12.1%	10.6%
2015	2016	23,753	20,371	44,124	53.8%	46.2%	138	172	148	320	7.1%	6.5%
2016	2017	21,672	14,037	35,709	60.7%	39.3%	115	188	122	311	6.9%	6.7%
2017	2018	24,193	28,427	52,620	46.0%	54.0%	161	151	178	329	7.3%	7.5%
2018	2019	2,592	17,650	20,242	12.8%	87.2%	90	29	196	225	5.0%	5.0%
2019	2020	8,882	12,967	21,849	40.7%	59.3%	46	193	282	475	10.6%	10.2%
2020	2021	1,543	13,057	14,600	10.6%	89.9%	46	33	284	317	7.1%	7.5%

Coho

Production Estimate

Total catch (actual and estimated missed) in the Bear Creek screw trap was 2,277 yearling coho. Three sub-yearlings were excluded from the production estimate. The median migration date was May 5th. The total production of coho juvenile smolts was 12,856 ± 3,594 (95% C.I., Table 13, Figure 7, CV = 14.2%). The 2021 run was below the median migration for Bear Creek (median = 29,343, range = 6,004 – 62,970, Table 14). Long term coho production appears to be declining in Bear Creek.

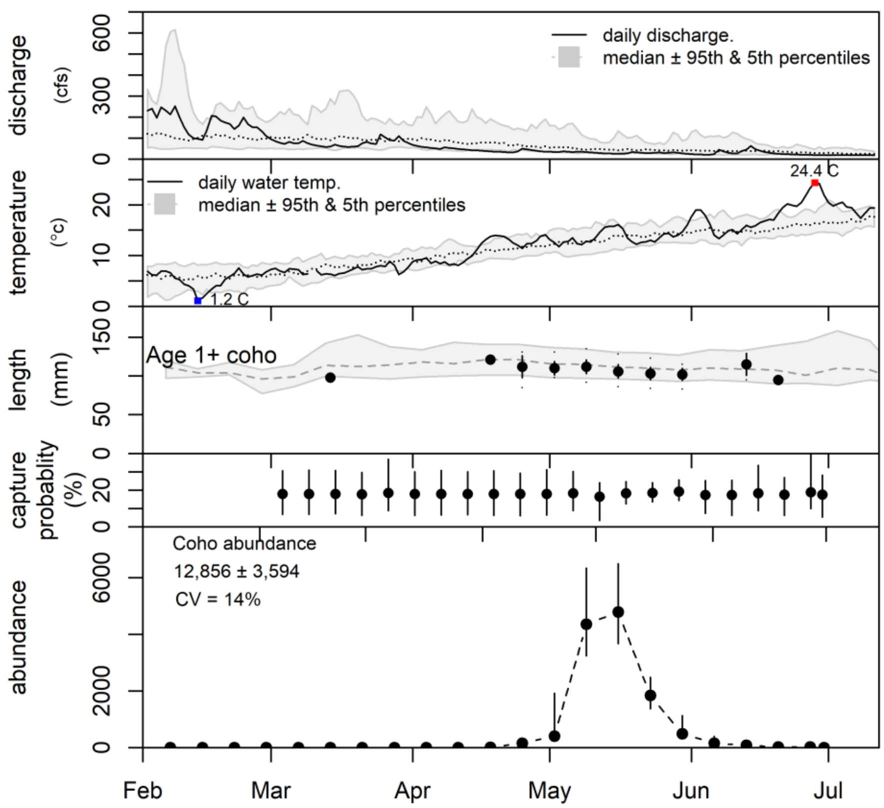


Figure 7. Top panels: daily river discharge and water temperature. The shaded region represents the historical 5th and 95th percentiles of daily flow since 1987 or temperature since 1995 with the grey dotted line as the historical daily median. Center panel: Mean weekly age 1+ coho smolt fork length from Bear Creek in 2021 with vertical lines as ± 1 standard deviation and '.' ± maximum and minimum weekly fork length The shaded regions and dashed line indicate the historical median plus the 95th or 5th percentiles weekly fork length 1999-2020. Age 1+ smolts in filled points and sub yearlings age 0+ in open points. Second from the bottom: capture probabilities from efficiency trails of marked catches. Bottom panel: Weekly coho age 1+ smolt migration at the Bear Creek screw trap in 2021.

Table 13. Abundance of natural-origin juvenile age 1+ coho smolt emigrating from Bear Creek in 2021, 95% confidence intervals (C.I.), coefficient of variation (*CV*) and modeled trap efficiency (*Eff.*) for the period. Sub-yearlings were excluded from the abundance estimate.

Week Start	Week End	Catch	Missed Catch	Total Catch	Marks	Recaps.	*Eff.*	Abundance	*CV%*
4-Feb	7-Feb	0	0	0	0	0	18.0%	0	0
8-Feb	14-Feb	0	0	0	0	0	18.0%	0	0
15-Feb	21-Feb	0	0	0	0	0	18.1%	0	0
22-Feb	28-Feb	0	0	0	0	0	17.9%	1	165%
1-Mar	7-Mar	1	0	1	0	0	18.6%	2	94%
8-Mar	14-Mar	0	0	0	0	0	17.9%	1	140%
15-Mar	21-Mar	0	0	0	0	0	18.1%	0	0
22-Mar	28-Mar	0	0	0	0	0	18.0%	0	0
29-Mar	4-Apr	0	0	0	0	0	17.9%	1	301%
5-Apr	11-Apr	0	0	0	0	0	17.9%	2	211%
12-Apr	18-Apr	2	0	2	0	0	18.0%	13	102%
19-Apr	25-Apr	29	0	29	0	0	18.3%	168	47%
26-Apr	2-May	65	0	65	0	0	16.5%	584	79%
3-May	9-May	800	0	800	74	12	18.3%	4466	18%
10-May	16-May	891	0	891	125	22	18.6%	4867	15%
17-May	23-May	356	0	356	125	27	19.3%	1864	15%
24-May	30-May	84	0	84	0	0	17.4%	555	105%
31-May	6-Jun	25	0	25	0	0	17.4%	176	59%
7-Jun	13-Jun	14	3	17	0	0	18.4%	96	50%
14-Jun	20-Jun	4	0	4	0	0	17.6%	29	74%
21-Jun	27-Jun	6	0	6	0	0	18.8%	27	59%
28-Jun	30-Jun	0	0	0	0	0	17.7%	3	156%
	Total	2,277	3	2,280	324	61	18.0%	12,856	14.2%

Table 14. Annual catch, abundance estimate, and 95% C.I. of natural-origin juvenile coho smolt emigrating from Bear Creek from brood years 1997 to 2019.

Brood year	Trap	Total Catch	Start Date	End Date	Abundance	Lower CI	Upper CI	*CV*
1997	1999	14,934	02/23	07/13	62,970	50,645	75,295	10.00%
1998	2000	7,737	01/24	07/13	28,142	26,133	30,151	3.64%
1999	2001	6,617	04/10	07/12	21,665	18,947	24,383	6.40%
2000	2002	17,381	04/12	07/15	58,212	52,791	63,633	4.80%
2001	2003	15,048	04/09	07/08	48,561	42,304	54,818	6.60%
2002	2004	9,111	04/05	06/26	21,085	18,641	23,529	5.90%
2003	2005	16,191	04/08	07/14	43,725	43,638	43,813	0.10%
2004	2006	11,439	04/08	06/29	46,987	44658	49316	9.70%
2005	2007	2,802	04/15	07/11	25,143	20,220	30,066	9.90%
2006	2008	1,572	04/16	07/09	12,208	9,807	14,609	9.90%
2007	2009	3,926	04/22	06/30	33,395	26,840	39,951	10.02%
2008	2010	1,954	04/22	07/04	13,100	11,427	14,773	6.52%
2009	2011	4,871	04/27	07/16	34,513	25,700	43,326	13.03%
2010	2012	3,989	01/25	07/14	16,059	14,734	17,384	4.21%
2011	2013	1,288	01/28	07/10	17,752	9,986	25,518	22.30%
2012	2014	4,682	01/28	07/09	36,119	28,866	43,371	10.25%
2013	2015	5,205	01/28	07/01	30,544	30,025	31,064	0.87%
2014	2016	1,848	01/28	07/14	11,545	8,717	14,343	12.50%
2015	2017	439	01/31	07/10	6,004	2,142	9,866	32.80%
2016	2018	4,667	01/25	07/11	37,631	28,305	46,957	12.64%
2017	2019	3,615	01/29	07/08	19,386	14,643	24,129	21.07%
2018	2020	1,425	02/10	07/19	11,854	6,977	16,731	12.1%
2019	2021	2,280	02/04	07/01	12,856	9,261	16,451	14.2%

Trout

Trout in Bear Creek were identified to species when possible. The Bear Creek trap caught 1,355 juvenile cutthroat trout. The trap also caught 13 cutthroat adult and 14 trout fry, but these individuals were excluded from our production estimate. We estimate that 13,997 ± 6,374 cutthroat juveniles passed the trap (CV = 24.2%). The cutthroat estimate is a measure of the number of juveniles moving downstream past the trap, and therefore does not necessarily represent the number of cutthroat migrating downstream towards Lake Washington. Efficiency was 9.8 % and estimated from twenty-two trials of 243 fin clipped cutthroat that were captured and released between March 15 and May 22nd. An unusual late migration occurred at the end of the season at a time of lethal temperatures to trout (24℃).

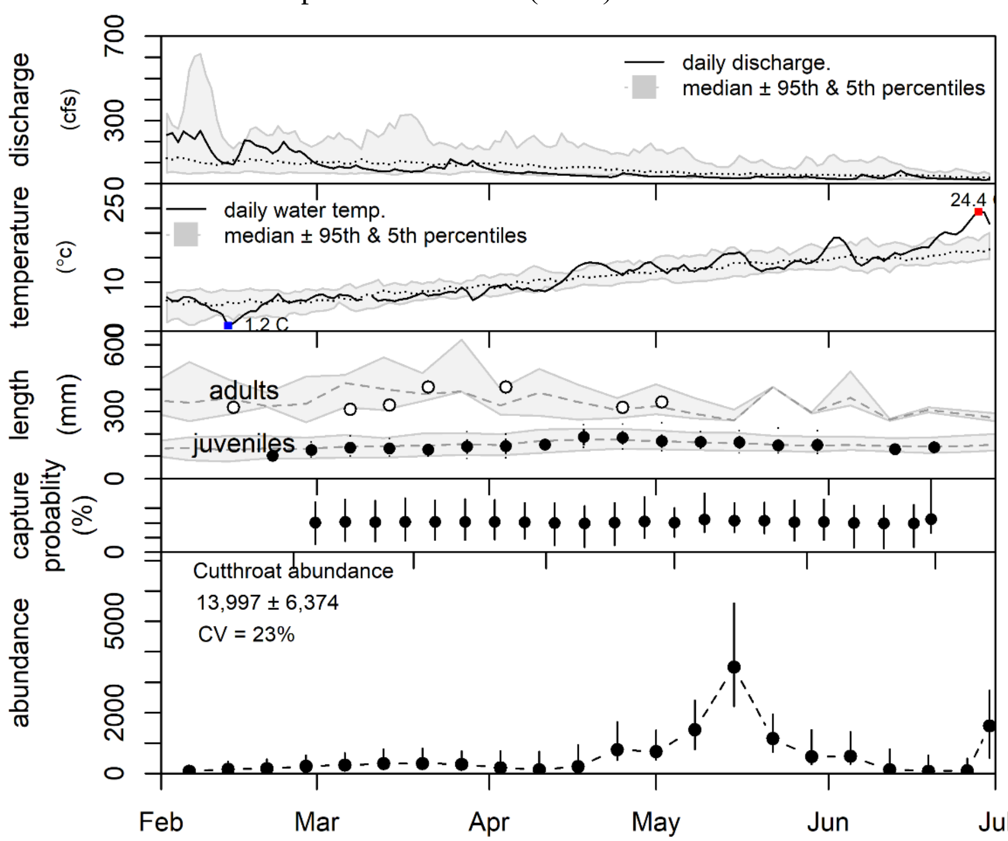


Figure 8. Top panel: Daily river discharge and water temperature. The shaded region represents the historical 5th and 95th percentiles of daily flow since 1987 or temperature since 1995 with the grey dotted line as the historical daily median. Center panel: Mean weekly cutthroat juveniles and adult cutthroat fork length from Bear Creek in 2021 with vertical lines as ± 1 standard deviation and '.' ± maximum and minimum weekly fork length The shaded regions and dashed line indicate the historical median plus the 95th or 5th percentiles weekly fork length 1999-2020. Age 1+ juveniles in filled points and adults in open points. Second from the bottom: capture probabilities from efficiency trails of marked catches. Bottom panel: Daily juvenile cutthroat migration at the Bear Creek screw trap in 2021.

Table 15: Annual catch, abundance estimate, and 95% C.I. of natural-origin juvenile cutthroat smolts emigrating from Bear Creek from trap years 1999 to 2021.

Year	Start	End	Catch	Total catch	Abundance	Lower CI	Upper CI	*CV*
1999	02/23	07/13	545	545	3,413			
2000	01/24	07/13	1,023	1,023	5,683			
2001	04/10	07/12	548	548	2,869			
2002	04/12	07/15	555	557	2,775			
2003	04/09	07/08	927	927	4,635			
2004	04/05	06/26	1,163	1,163	4,540	3,133	5,947	15.8%
2005	04/08	07/14	1,238	1,238	4,441	3,928	4,954	5.9%
2006	04/08	06/29	623	623	5,106	4,403	5,805	26.9%
2007	04/15	07/11	507	507	3,869	2,705	3,869	15.1%
2008	04/16	07/09	320	320	2,751	1,660	3,842	19.0%
2009	04/22	06/30	408	408	4,401	2,650	6,152	20.3%
2010	04/22	07/04	759	759	5,209	4,440	5,978	14.8%
2011	04/27	07/16	634	634	4,569	3,166	5,972	14.4%
2012	01/25	07/14	1,116	1,116	16,248	9,462	23,106	21.4%
2013	01/28	07/10	894	1,051	8,551	5,232	11,870	19.8%
2014	01/28	07/09	712	712				
2015	01/28	07/01	1,037	1,037				
2016	01/28	07/14	674	674				
2017	01/31	07/10	1,110	1,110				
2018	01/25	07/11	1,323	1,323				
2019	01/29	07/08	1,643	1,685	12,075	8,477	15,672	15%
2020	2/10	07/19	538	538	5,488	2,089	8,887	9.7%
2021	02/4	07/1	1,355	1,391	13,997	7,623	20,271	23.2%

Incidental Catch

In addition to target species, the screw trap captured 192 hatchery sized trout that escaped shortly after planting in Cottage Lake, the most the trap has captured in the last 20 years. Other native species include 498 lamprey (*Lampetra* spp), 83 three-spine stickleback (*Gasterosteus aculeatus*), 163 sculpin (*Cottus* spp.), 3059 peamouth chub (*Mylocheilus caurinus*), 97 large-scale suckers (*Catostomus macrocheilus*), 1 longnose dace (*Rhinichthys cataractae*) and 1 redside shiner (*Richardsonius balteatus*). Redside shiners are resident in Lake Washington, but this is our first record of the species in Bear Creek. We also caught several warmwater non-native species: 93 green sunfish (*Lepomis cyanellus*), 35 bluegill (*Lepomis macrochirus*), 19 pumpkinseed sunfish (*Lepomis gibbosus*), 23 rock bass (*Ambloplites rupestris*), 9 brown bullhead catfish (*Ameiurus nebulosus*), 5 weatherfish (*Misgurnus aguillicaudatus*), 3 yellow perch (*Perca flavescens*), 2 warmouth (*Lepomis gulosus*), 1 black crappie (*Pomoxis nigromaculatus*) and 1 largemouth bass (*Micropterus salmoides*). In total, we have observed 30 species since 2016, but only 25 in 2021 (Appendix B).

The June 26th to June 29th heatwave (air temperatures reaching 108°F or 42°C), was associated with a greater mortality of several native species in Bear Creek. Pygmy whitefish are rarely seen, but we captured 22 during this time and half (10) were mortalities. Other mortalities include 5 Chinook parr, 1 adult cutthroat, 48 juvenile cutthroat, 1 longnose dace, 13 three-spine stickleback, 7 lamprey, and 1 sculpin. While many non-native species were captured during the heatwave, all appeared in good condition despite warmer thermal conditions.

PIT Tagging

To support the ongoing, multi-agency evaluation of salmonid survival within the Lake Washington watershed, a small percentage (Tables 16 and 17) of natural-origin Chinook parr received 12 mm or 9mm passive integrated transponder (PIT) tags. Tagging occurred three to five times a week during the parr migration with a goal of 100 to 400 tags per week. Chinook parr were kept from the previous day if the catch was low to increase the number of tags released per day. PIT tagged fish were also released as part of the efficiency trials to help estimate the total parr outmigration. In 2021, smaller 9 mm tags were inserted into sub yearlings between 45 mm to 65mm in fork length to better understand survival of smaller sized Chinook during earlier entry into Lake Washington.

From April 5th through June 18th, we PIT tagged 728 (all size classes) natural-origin Chinook parr in the Cedar River and detected 7.0% of them at the Ballard locks. The median migration date of Chinook parr through the Ballard Locks was June 22nd. The first Chinook was detected on May 25th and the last on June 28th. Travel duration from the Cedar River to the Ballard Locks averaged 23.7 days and ranged from 5 days to 44 days. Only 2 of the 66 parr (3.0 %) under 65 mm were detected at the Locks. These fish reared longer and were detected 38 and 42 days after tagging on June 8th and 10th. We also tagged three steelhead and 146 coho smolt. None of the steelhead were detected at the Locks, but 27% of the coho were detected.

In Bear Creek, we tagged 1,431 parr (all size classes) between April 5th and June 9th, 2021 (Table 16) and detected 8.7% of them at the Ballard Locks (Table 16). The first Chinook was detected on May 12th and the last was detected June 25th (Table 16). Individual travel times from Bear Creek to the locks averaged 24.2 days and ranged from 5 days to 60 days. We tagged only 24 parr smaller than 65mm and detected only 1 (4.1%); this individual was detected 60 days after tagging. We also tagged 150 Coho smolt and detected 58 of them (38.7%) at the Ballard Locks.

Table 16. Weekly releases and detections of natural-origin Chinook parr PIT tagged from the Cedar River and Bear Creek screw traps in 2021. All size classes represented.

Week		N. Tagged		N. Detected		% Detected	
Start	End	Bear	Cedar	Bear	Cedar	Bear	Cedar
5-Apr	10-Apr	4	1	1	0	25%	0.0%
11-Apr	17-Apr	1	2	0	0	-	0.0%
18-Apr	24-Apr	2	7	0	0	-	0.0%
25-Apr	1-May	11	31	1	4	11%	12.9%
2-May	8-May	159	51	19	4	12%	7.8%
9-May	15-May	341	74	46	11	14%	14.9%
16-May	22-May	464	126	44	7	10%	5.6%
23-May	29-May	217	146	12	13	6%	8.9%
30-May	5-Jun	147	82	2	8	1%	9.8%
6-Jun	12-Jun	61	165	0	4	0%	2.4%
13-Jun	18-Jun	24	43	0	0	0%	0.0%
	Total	1,431	728	125	51	8.7%	7.0%

Table 17. Biological and migration timing data of PIT tagged natural-origin Chinook released from the Cedar River screw trap, tag years 2010 to 2021. Detection data is from the Locks. *2020 had known detection problems during peak out-migration resulting in low detection rates.

Year	N. Tagged	Length (mm) Ave	Min	Max	N. Detected	% Detected	Mean Travel Days	First Detection	Last Detection	Median Detection Date
2010	2,232	84.2	65	127	482	21.6%	29.9	05/24	08/25	06/24
2011	594	87.3	65	118	116	19.5%	19.3	05/26	08/27	06/07
2012	1,671	84.0	64	123	212	12.7%	30.0	05/29	09/14	07/08
2013	711	81.3	58	108	209	29.4%	17.3	05/26	07/17	06/19
2014	1,944	83.8	65	122	172	8.8%	24.8	05/24	07/29	06/13
2015	861	88.2	64	115	63	7.3%	19.5	05/21	06/21	05/29
2016	1,372	87.0	65	138	128	9.3%	22.5	05/19	07/15	06/04
2017	823	85.8	65	113	36	4.4%	22.5	06/04	07/22	06/17
2018	700	80.2	64	103	47	6.7%	24.0	05/27	07/10	06/20
2019	1,554	83.3	65	115	243	15.6%	23.0	05/22	07/14	06/13
2020	505	85.1	65	131	13	2.5%*	22.0	05/28	07/20	06/22
2021	728	81.0	49	123	51	7.0%	23.7	05/25	06/28	06/12

Table 18. Biological and migration timing data of PIT tagged natural-origin Chinook released from the Bear Creek screw trap, tag years 2010 to 2021. Detection data is from the Locks. *2020 had known detection problems during peak out-migration.

Year	N. Tagged	Length (mm) Ave	Min	Max	N. Detected	% Detected	Mean Travel Days	First Detection	Last Detection	Median Detection Date
2010	589	77.9	65	99	103	17.5%	26.1	06/06	07/07	06/23
2011	2,316	79.9	65	102	337	14.6%	15.1	05/23	07/29	06/05
2012	2,721	75.2	62	97	316	11.6%	31.3	05/22	08/13	06/21
2013	1,858	79.3	58	102	518	27.9%	12.3	05/16	07/20	06/12
2014	1,968	77.6	62	103	324	16.5%	23.9	05/20	07/14	06/12
2015	1,414	84.7	65	108	114	8.1%	17.7	05/19	06/18	05/28
2016	2,766	83.3	65	108	287	10.4%	23.2	05/07	06/29	05/31
2017	3,211	80.9	65	108	387	12.1%	22.0	05/21	07/05	06/09
2018	2,578	78.1	63	107	279	10.8%	22.0	05/17	07/04	06/05
2019	1,655	78.0	65	117	226	13.7%	21.0	05/19	07/13	06/08
2020	782	80.3	63	102	24	3.2%*	27.0	05/21	06/26	06/19
2021	1,431	79.0	54	113	51	7.0%	24.2	05/12	06/25	06/10

Flume operation and usage

Since 2000, 6 ft diameter smolt flumes have operated seasonally in the north and south spillways. In some years, additional 2.25 ft and 4 ft diameter flumes were installed in the north and south spillways. Each flume has two pass-through style antennas. The adult ladder has two antennas that are located at the downstream end of the viewing chamber and two located at the upstream end of the viewing chamber that have all operated continuously since installation in 2004. Each end of the viewing chamber has an antenna located at the overflow weir at the surface and one submerged. The large lock filling culvert has a series of five antennas that have operated continuously since November 2015. Tunnel style flumes were replaced with water slide style flumes in 2018. Currently, detections from the ladder and flume antennas transfer through a 5G receiver to a modem located in the large lock control center. The modem uploads data to an online server (Biomark Corp., Boise, Idaho), which allows remote monitoring of voltage, noise, digital test tags, and PIT tag detections from all the antennas. Six-foot slide flumes were installed on April 20th, 2021 in the north and south spillways and removed in the first week of August. A 4-ft flume was installed in the south spillway temporarily on April 20th, but developed a crack immediately after running for a day and removed for the season.

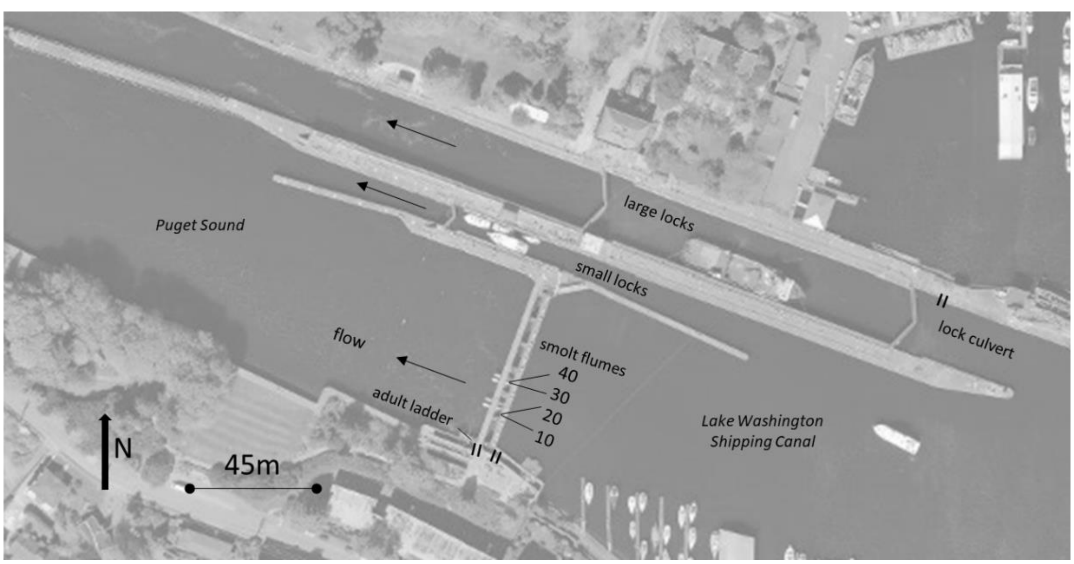
Flume operation and usage by migrants in the north and south spillway has varied over time (Table 19). In 2021, an equal share of migrants passed through the south and north 6’ flumes (47.7% in each). From 2004-2014, the south spillway accounted for slightly more (64% geometric mean) of the migrants annually. During this period of relatively high detection rates (Table 17 and 18), both 6 ft and secondary 4 ft flumes were installed in the south spillway while a 6 ft and a 2.25 ft flumes were installed in the north spillway (Table 19). Usage appears to depend on whether more than one flume was installed in each spillway. Since 2015, overall detection rates decreased (Table 17 and 18) when the secondary smaller flumes were not installed in either spillway (Table 19). We recommend reinstalling secondary flumes to determine if detection rates improve. We acknowledge that a decrease in annual detection rates since 2015 (Tables 17 and 18) could represent a decrease in detection efficiency or represent a lower survival during migration through Lake Washington or both.

Over the history of the PIT tagging effort, tagged salmonids are known to pass through the Ballard Locks undetected. One hypothesis is that Chinook smolt seek a cooler migration route by moving through the deep areas of the small or large lock chambers to avoid stressful surface temperatures as Lake Union stratifies. Installation of antennas in one of two large-lock filling culverts (north culvert) offers a chance to test this hypothesis. In 2021, 7 of 176 (4%) of Chinook were detected at the north filling culvert and were not detected previously on the other flumes. Inspection in the fall of 2021 confirmed that the 1 of the 5 antennas was not communicating throughout the 2021 season. Nevertheless, data from other years where all 5 antennas were in operation in the filling culvert (2018-2020, Table 19) suggest that outmigrants are not moving through the deep channels of the large lock filling culvert. Tagged Chinook can still migrate undetected through the small locks and surface waters of the large locks.

To help coordinate seasonal operation of the flumes or other fish passage studies, we characterized the outmigration period for natural origin Chinook salmon since 2000. Chinook were PIT tagged at Bear Creek and Cedar River smolt traps and detected at arrays located in the smolt flumes, the north filling culvert, or the adult ladder. Across all years, the earliest migrant was detected on May 7th and the last on September 14th. The majority of the migrants were detected on June 10th (median) between June 3rd and June 23rd (25th and 75th outmigration quantiles, Figure 9). Chinook migrants are typically detected at the Locks during daylight hours, with peak outmigration around dawn and fewer detections throughout the afternoon (Figure 10).

Table 19. Smolt flume use by PIT tagged hatchery-origin or natural origin Chinook released from Issaquah hatchery, Bear Creek, or Cedar River for study years 2004 to 2021. The table represents the number of unique PIT tagged Chinook smolts leaving the Ballard Locks. We determined the percent detected in the adult ladder, in flumes draining the north and south spillway, and the large lock filling culvert. The flumes entrances vary in size, measuring 2.25, 4.0 or 6.0 feet in diameter. The naming convention has varied from time to time in the south bay and north bay flumes as noted in the table for future reference. A schematic of the Ballard Locks system indicates approximately where the flumes, ladder or culvert arrays are located. The tunnel style flumes and readers were replaced with slide style flumes as noted with an in the north bay and the south bay in 2018. A set of deep antennas were installed in the large lock north culvert in the fall of 2015 and were operational in 2016. To account for any recycling that might occur between readers, we filtered the data by the first detection for each fish. Data were restricted to detections occurring within 300 days after juvenile Chinook were released.

			South Bay 5		North Bay 4		
Year	Chinook Unique Detections	Adult Ladder	10 or 5B 6’ flume	20 or 5C 4’ flume	30 or 4B 6’ flume	40 or 4A 2.25’ flume	North Lock filling culvert
2004	544	0.4%	57.5%	20.2%	17.8%	4.0%	-
2005	898	0.2%	46.7%	19.5%	30.6%	3.0%	-
2006	191	0%	68.0%	10.5%	19.9%	1.6%	-
2007	773	0%	22.1%	25.4%	47.7%	4.8%	-
2008	285	0%	57.5%	15.8%	24.9%	1.8%	-
2009	571	0%	45.7%	16.1%	35.6%	2.6%	-
2010	582	0%	51.0%	22.7%	23.7%	2.6%	-
2011	449	0%	67.3%	9.8%	21.4%	1.6%	-
2012	526	0%	64.5%	10.8%	21.3%	3.4%	-
2013	727	0.7%	35.4%	21.6%	40.3%	2.1%	-
2014	646	0.3%	34.2%	1.2%	63.6%	0.6%	-
2015	319	0.3%	2.8%	-	96.9%	-	-
2016	521	0.4%	26.3%	-	72.6%	-	0.8%
2017	558	0.2%	43.2%	7.5%	48.4%	-	0.7%
2018	619	0%	33.0%	-	63.0%	-	4.0%
2019	797	0.5%	43.4%	-	54.7%	-	1.4%
2020	65	0%	32.3%	-	66.2%	-	1.5%
2021	176	0.6%	47.7%		47.7%		4.0%



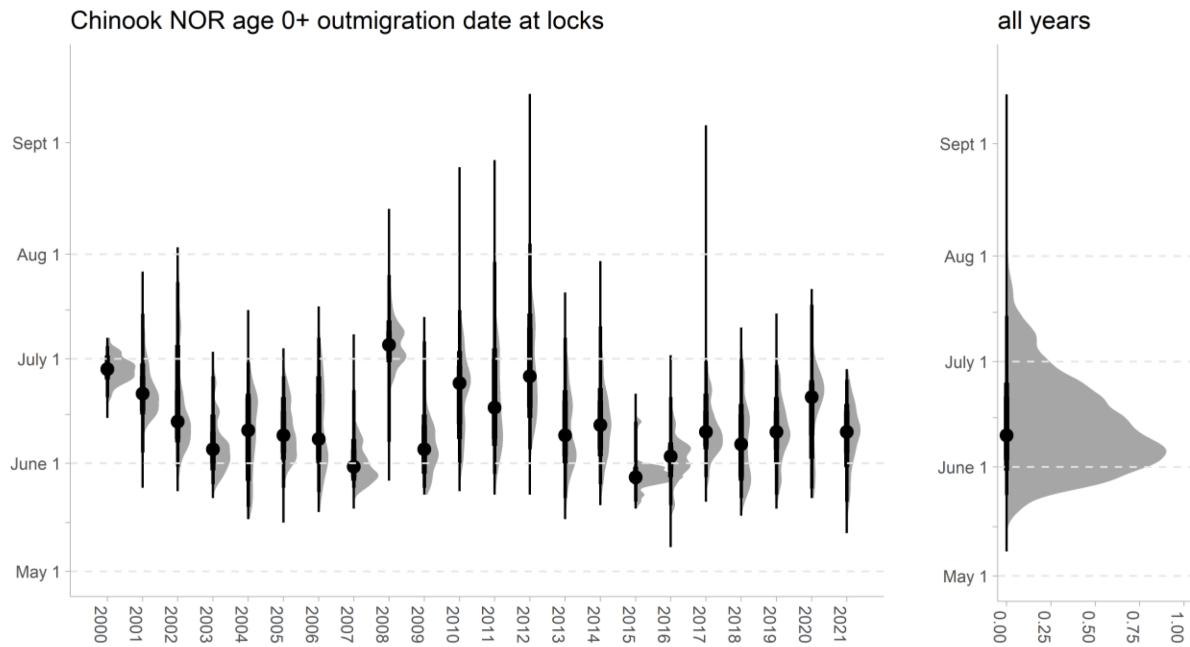


Figure 9. Median outmigration date (points) for natural origin Chinook salmon at the Ballard Locks. Chinook were PIT tagged at Bear Creek and Cedar River smolt traps and detected at arrays located in smolt flumes, the north filling culvert, or the adult ladder from late May through August. Thin vertical lines extend to the range; thicker lines extend to the quartile range (25th and 75th) and grey polygons illustrate probability density distributions from detection frequencies. Right plot is a composite of all data to illustrate the typical outmigration period. To account for any recycling that might occur between readers, we filtered the data by the first detection for each fish. Data were restricted to detections occurring within 300 days after juvenile Chinook were released.

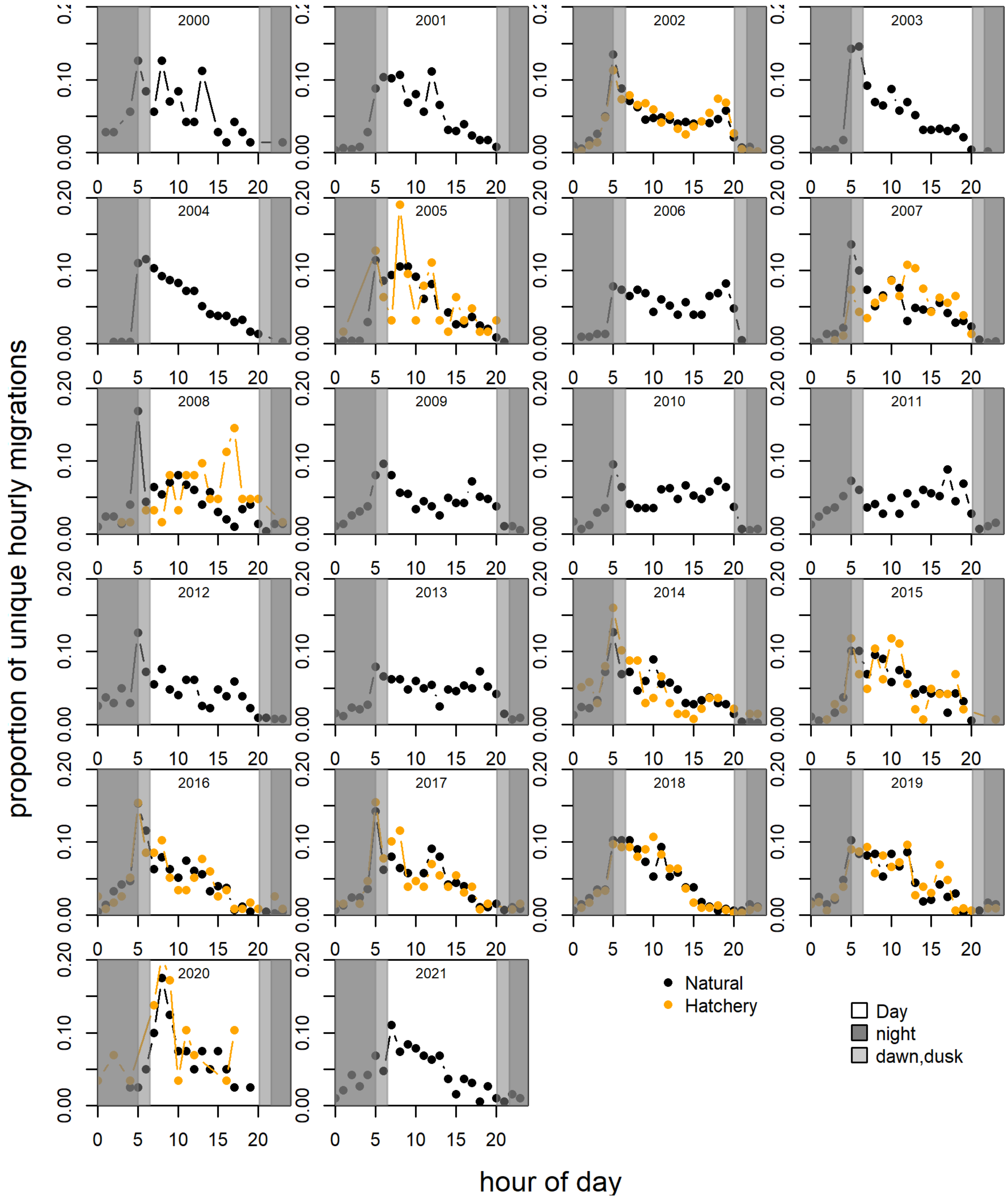


Figure 10. Proportion of hourly migrations for uniquely PIT tagged hatchery or natural origin Chinook at the Hiram M. Chittenden Ballard Locks. Dark shaded regions represent night hours, lightly shaded is astronomical twilight to sunrise, and open background is daytime periods from sunrise to sunset for June 1st. On an annual basis, Chinook are detected at the Ballard Locks arrays (flumes, culvert, or ladder) primarily during daytime hours with prominent peaks at dawn or shortly after dawn. To account for any recycling that might occur between readers, we filtered the data by the first detection for each fish. Data were restricted to detections occurring within 300 days after juvenile Chinook were released.

Appendix A

Catch of Fishes and Migration Estimates by Strata for Cedar River Sockeye, Chinook, and Coho Salmon in 2021

Appendix A1. Alternate estimation of the egg to juvenile survival rate of Cedar River Chinook estimated by the average post orbital eye to hypural plate length (POH mm) of female carcasses.

Brood	♀ POH (mm)	♀Carcasses	Est. Fecundity	♀ Spawners	Egg Deposition	Juvenile Prod.	Est. Survival
2001	623	124	4,758	398	1,893,684	119,674	6.3%
2002	685	165	5,645	281	1,586,245	235,397	14.8%
2003	705	136	5,946	337	2,003,802	120,876	6.0%
2004	707	232	5,976	511	3,053,736	134,298	4.4%
2005	690	122	5,720	339	1,939,080	117,559	6.1%
2006	692	239	5,749	587	3,374,663	125,186	3.7%
2007	678	323	5,542	899	4,982,258	769,791	15.5%
2008	716	199	6,114	599	3,662,286	139,452	3.8%
2009	720	78	6,176	285	1,760,160	152,390	8.7%
2010	736	65	6,425	266	1,709,050	187,806	11.0%
2011	713	75	6,068	324	1,966,032	902,514	45.9%
2012	640	109	4,994	433	2,162,402	893,877	41.3%
2013	706	146	5,961	740	4,411,140	1,458,761	33.1%
2014	647	60	5,093	232	1,181,576	347,663	29.4%
2015	688	185	5,690	723	4,113,870	972,641	23.6%
2016	650	67	5,136	418	2,146,848	174,719	8.1%
2017	664	172	5,337	819	4,371,003	524,378	12.0%
2018	650	82	5,136	325	1,669,200	224,657	13.5%
2019	679	80	5,556	342	1,900,152	37,193	2.0%
2020	660	50	5,279	209	940,500	57,918	5.2%

Appendix A2: Actual catch of all species and salmon life-history types in the Cedar River screw trap from 2016 to 2021. Year 2016 includes incline place catch.

species #	Common name	Genus species	2016	2017	2018	2019	2020	2021
1	sockeye fry (natural)	*Oncorhynchus nerka*	7,925	41,250	167,717	231,910	757	39,749
2	coho smolt (wild)	*Oncorhynchus kisutch*	2,597	2,618	5,537	3,359	1,585	1,698
3	Chinook fry (natural)	*Oncorhynchus tshawytcha*	3,601	2,766	9,868	21,275	543	1,194
~	Chinook parr (natural)	*Oncorhynchus tshawytcha*	1,799	1,362	1,770	3,389	619	916
4	Three spine stickleback	*Gasterosteus aculeatus*	191	26	78	50	355	394
5,6	sculpin (prickly/coast)	*Cottus asper / C. aleuticus.*	93	221	183	107	563	229
7	cutthroat juvenile	*Oncorhynchus clarkii*	48	197	120	134	94	206
8	trout fry 0+	*Oncorhynchus mykiss*	0	1	16	43	9	73
9,10	lamprey (river/brook)	*L. ayresii / L. richardsoni*	27	82	47	32	52	49
~	Chinook parr (hatchery)	*Oncorhynchus tshawytcha*	40	85	259	352	21	35
11	longnose dace	*Rhinichthys cataractae*	3	2	9	53	9	35
~	coho 0+	*Oncorhynchus kisutch*	31	32	62	313	13	33
12	largescale sucker	*Catostomus macrocheilus*	7	14	7	11	3	28
~	steelhead smolt (wild)	*Oncorhynchus mykiss*	17	8	6	6	2	9
13	whitefish	*Prosopium spp.*	10	2	1	2	0	9
14	rock bass	*Ambloplites rupestris*	1	0	0	5	0	4
15	peamouth chub	*Mylocheilus caurinus*	5	6	4	2	2	3
16	speckled dace	*Rhinichthys osculus*	2	1	0	1	0	3
~	cutthroat adult	*Oncorhynchus clarkii clarkii*	1	2	4	1	0	1
17	pink salmon	*Oncorhynchus gorbuscha*	1	0	19	0	0	0
~	coho smolt (hatchery)	*Oncorhynchus kisutch*	0	0	5	0	9	0
18	pumpkinseed	*Lepomis gibbosus*	0	1	1	3	0	0
19	warmouth	*Lepomis gulosus*	4	0	0	0	0	0
20	chum fry	*Oncorhynchus keta*	1	0	0	2	0	0
~	Chinook age 1+	*Oncorhynchus tshawytcha*	0	0	1	1	0	0
21	bluegill	*Lepomis macrochirus*	1	0	0	0	0	0
22	smallmouth bass	*Micropterus dolomieu*	1	0	0	0	0	0

Appendix B

Catch of all Fishes and Migration Estimates by Strata for Bear Creek Sockeye, Chinook, and Coho Salmon 2021.

Appendix B1. Alternate estimation of the egg to juvenile survival rate for Bear Creek Chinook estimated by the average post-orbital eye to hypural plate length (POH mm) of female carcasses on the spawning ground.

Brood	♀POH (mm)	♀Carcasses	Est. Fecundity	♀Spawners	Egg Deposition	Juvenile Prod.	Egg. Survival
2001	670	121	5,424	138	748,512	21,318	2.8%
2002	674	174	5,483	127	696,341	17,281	2.5%
2003	691	83	5,735	147	843,045	23,647	2.8%
2004	699	73	5,855	121	708,455	9,270	1.3%
2005	687	138	5,675	122	692,350	22,362	3.2%
2006	685	103	5,645	131	739,495	16,529	2.2%
2007	641	74	5,009	89	445,801	12,706	2.9%
2008	704	79	5,930	132	782,760	65,202	8.3%
2009	698	6	5,840	48	280,320	9,185	3.3%
2010	690	55	5,720	60	343,200	17,763	5.2%
2011	707	27	5,976	55	328,680	22,197	6.8%
2012	636	85	4,938	147	725,886	44,599	6.1%
2013	691	19	5,735	48	275,280	62,775	22.8%
2014	650	22	5,136	60	308,160	32,733	10.6%
2015	635	78	4,924	138	679,512	44,124	6.5%
2016	613	29	4,621	115	531,415	35,709	6.7%
2017	597	78	4,406	161	704,960	52,620	7.5%
2018	605	34	4,509	90	405,810	22,242	5.0%
2019	616	10	4,662	46	214,452	21,849	10.6%
2020	585	37	4,248	37	195,408	14,600	7.5%

Appendix B2. Actual catch composition of salmonids and incidental species in Bear Creek 2016-2021. The screw trap documented 30 unique species and several salmonid life history types.

Species #	Common name	*Genus species*	2016	2017	2018	2019	2020	2021
1	sockeye fry (natural)	*Oncorhynchus nerka*	3,564	25,656	145,059	938	1,224	1,180
2	Chinook parr (natural)	*Oncorhynchus tshawytcha*	4,852	6,792	9,795	8,726	2,982	4,845
3	coho 1+ smolt (wild)	*Oncorhynchus kisutch*	1,675	427	3,935	3,423	1,425	2,197
4	peamouth chub	*Mylocheilus caurinus*	1,825	639	1,934	3,476	1,915	3,059
5	cutthroat (juvenile)	*Oncorhynchus clarkii clarkii*	674	1,110	1,323	1,643	539	1,355
~	Chinook fry (natural)	*Oncorhynchus tshawytcha*	1,180	677	2,712	108	269	101
6,7	lamprey (river/brook)	*Lampetra ayresii; L. richardsoni,*	910	645	842	352	551	498
8,9	sculpin (prickly/coast)	*Cottus asper; C. aleuticus*	285	304	573	550	462	163
10	three spine stickleback	*Gasterosteus aculeatus*	188	558	487	227	520	83
11	green sunfish	*Lepomis cyanellus*	306	128	59	31	125	93
12	rainbow trout (hatchery)	*Oncorhynchus mykiss*	2	24	59	93	17	192
~	coho fry	*Oncorhynchus kisutch*	11	13	45	248	2	3
13	largescale sucker	*Catostomus macrocheilus*	16	10	26	96	21	97
~	cutthroat (adult)	*Oncorhynchus clarkii clarkii*	47	21	12	52	7	13
14	bluegill	*Lepomis macrochirus*	19	7	21	7	11	35
15	rock bass	*Ambloplites rupestris*	3	13	6	14	40	23
16	brown bullhead	*Ameiurus nebulosus*	23	22	16	14	9	9
~	trout 0+ fry	*Oncorhynchus mykiss*	7	8	3	9	28	29
17	pumpkinseed	*Lepomis gibbosus*	22	6	11	7	4	19
18	whitefish	*Prosopium spp*	1	1	3	5	0	22
19	weatherfish	*Misgurnus aguillicaudatus*	0	0	0	2	6	5
20	warmouth	*Lepomis gulosus*	13	11	1	0	0	2
21	yellow perch	*Perca flavescens*	1	2	0	1	0	3
22	longnose dace	*Rhinichthys cataractae*	0	3	4	7	1	1
23	redside shiner	*Richardsonius balteatus*	0	0	0	0	0	1
24	largemouth bass	*Micropterus salmoides*	0	0	0	0	0	1
25	black crappie	*Pomoxis nigromaculatus*	3	0	0	0	0	1
26	speckled dace	*Rhinichthys osculus*	2	3	1	3	1	0
~	coho 1+ hatchery	*Oncorhynchus kisutch*	0	0	4	9	1	0
27	smallmouth bass	*Micropterus dolomieu*	1	0	6	1	0	0
28	northern pikeminnow	*Ptychocheilus oregonensis*	1	1	3	0	0	0
~	steelhead smolt (wild)	*Oncorhynchus mykiss*	2	1	0	0	0	0
29	tench	*Tinca tinca*	0	0	0	2	0	0
30	goldfish	*Carassius auratus*	0	0	0	1	0	0

Acknowledgements

Evaluation of juvenile salmon production in the Cedar River and Bear Creek was made possible by multiple agencies. A King County Flood Control District Cooperative Watershed Management grant, administered by Water Resources Inventory Area (WRIA) 8, funded the Cedar River screw trap and PIT tagging effort. WDFW state general funded Bear Creek monitoring. Seattle City Light provided additional funds for trapping at the Cedar River during the sockeye fry migration. The WRIA 8 Technical Committee lead by Lauren Urgenson, Carrie Byron, and Jason Mulvihill-Kuntz provided technical review and funding oversight.

Success of these projects relied on the hard work of a number of dedicated WDFW personnel. Escapement data were developed by individuals from several agencies: Aaron Bosworth and Joe Short from WDFW; Jason Schaffler, Ava Fuller, Erik Warner, Curtis Nelson, Derek Hicks, and Jessie Nitz from the Muckleshoot Indian Tribe (MIT); Karl Burton and Carol Volk from SPU. WDFW scientific technicians Paul Lorenz, Dan Estell, and Alanna Sutton worked long hours in order to operate juvenile traps, and identify, count, and mark juvenile salmon. Dave Seiler, Greg Volkhardt, and Kelly Kiyohara provided juvenile evaluations for many years; these reports are invaluable guides for the continuity of the project. WDFW biologists Pete Topping and Joe Anderson provided valuable experience and logistical support for the juvenile trapping operation. The WDFW Hatcheries Program Michael Sedgwick, Cody Warren, and Jordan Tolliver successfully collected adult sockeye broodstock, incubated eggs, and released millions of sockeye fry into the Cedar River. Carol Volk and Karl Burton from SPU provided project management. Katie Whitlock helped to coordinate Ballard Lock inspections during annual dewatering and antenna tunning. Lauren Urgenson, Joe Anderson, Ian Anderson (WDFW), and Karl Burton provided useful review of this report.

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

Cedar River

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 and temperature monitoring.

Bear Creek

WDFW Enforcement, the City of Redmond Police Department and Redmond Town Center Security staff provided a measure of security. King County provided continuous flow and temperature monitoring at Union Hill. Sound Transit helped coordinate the removal of the smolt trap at the end of the 2021 field season. We thank the City of Redmond staff Chris Tolonen, Emily Flanagan, and Tom Hardy for helping coordinate trap removal and site permitting.

References

Bonner, S.J. and Schwarz, C.J. (2011), Smoothing Population Size Estimates for Time-Stratified Mark–Recapture Experiments Using Bayesian P-Splines. Biometrics, 67: 1498-1507. https://doi.org/10.1111/j.1541-0420.2011.01599.x

Bonner, S. J. and Schwarz, C. J. (2021). BTSPAS: Bayesian Time Stratified Petersen Analysis System. R package version 2021.11.2.

Carlson, S. R., L. G. Coggins, and C. O. Swanton. 1998. A simple stratified design for mark-recapture estimation of salmon smolt abundance. Alaska Fishery Research Bulletin 5:88-102.

Columbia Basin Fish and Wildlife Authority PIT Tag Steering Committee. 2014. PIT Tag Marking Procedures Manual version 3.Gendaszek A.S., Burton K., Magirl C.S., Konrad C.P. 2017. Streambed scour of salmon spawning habitat in a regulated river influenced by management of peak discharge. Freshwater Biology, 00:1–11

Hall, J. E., C. M. Greene, O. Stefankiv, J. Anderson, B. Timpane-Padgham, T. J. Beechie, and G. R. Pess. 2018. Large river habitat complexity and productivity of Puget Sound Chinook salmon. PLoS One 13(11):e0205127.

King County WRIA 8 Steering Committee. 2017. Lake Washington/Cedar/Salmon Watershed (WRIA 8) Chinook Salmon Conservation Plan 10 year update. Seattle, WA.

Kiyohara, K. 2013. Evaluation of Juvenile Salmon Production in 2013 from the Cedar River and Bear Creek. WDFW, Olympia, WA

Kiyohara, K. 2016. Evaluation of Juvenile Salmon Production in 2016 from the Cedar River and Bear Creek. WDFW, Olympia, WA

Lisi, P. J. Evaluation of Juvenile Salmon Production in 2020 from the Cedar River and Bear Creek. 2020. WDFW, Olympia, WA

Seiler, D., G. Volkhardt and L. Kishimoto. 2003. Evaluation of downstream migrant salmon production in 1999 and 2000 from three Lake Washington tributaries: Cedar River, Bear Creek and Issaquah Creek. WDFW Olympia WA. 199.

Sokal, R. R. and Rohlf, F. J. 1981. Biometry, 2nd edition. W. H. Freeman and Company, New York.

Volkhardt, G. C., S. L. Johnson, B. A. Miller, T. E. Nickelson, and D. E. Seiler. 2007. Rotary screw traps and inclined plane screen traps. Pages 235-266 in D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O-Neil, and T. N. Pearsons, editors. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland.