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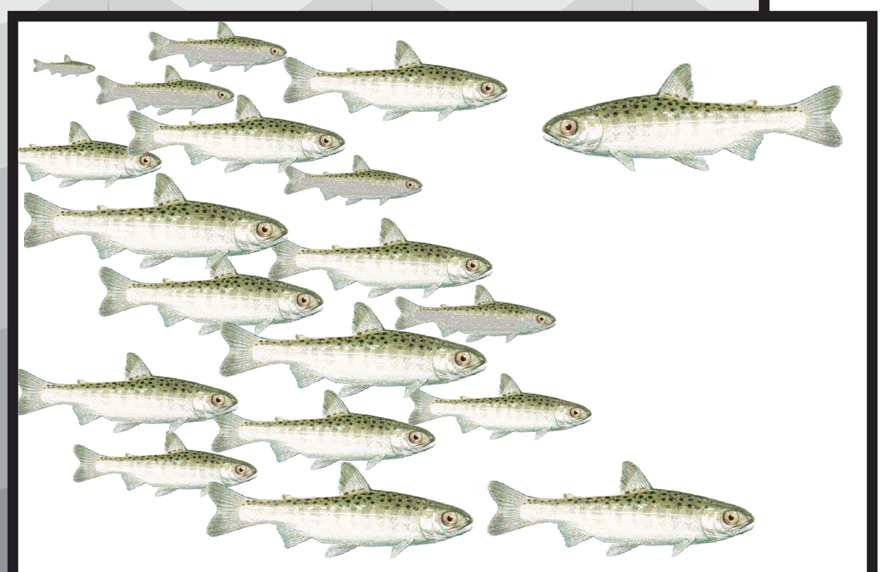
Evaluation of Juvenile Salmon Production in 2012 from the Cedar River and Bear Creek



by Kelly Kiyohara

Washington Department of
FISH AND WILDLIFE
Fish Program
Science Division
Wild Salmon Production/Evaluation

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Evaluation of Juvenile Salmon Production in 2012 from the Cedar River and Bear Creek

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Success of these projects relied on the hard work of a number of dedicated Washington Department of Fish and Wildlife (WDFW) personnel. Escapement data were collected and estimates developed by individuals from several agencies: Aaron Bosworth, Dan Estell, Lacey Jeroue, Jeffery Parr, Tony Parra, and Melissa Reeder from WDFW; Brian Footen, and Jesse Nitz from the Muckleshoot Tribe; Karl Burton, Dwyane Paige, Heidy Barnett, and David Chapin from SPU; and Hans Berge, Dan Lantz, Chris Gregersen, and Jim Lissa from King County DNRP. WDFW scientific technicians Paul Lorenz, Dan Estell, and Randy Jeric worked long hours, usually at night, in order to operate juvenile traps, mark, identify, and count juvenile fish. WDFW biologist Pete Topping provided valuable experience and logistical support for the juvenile trapping operation. The WDFW Hatcheries Program successfully collected adult sockeye brood stock and incubated eggs, releasing over 8.11 million sockeye fry into the Cedar River. Project management was provided by Paul Faulds and Michele Koehler from SPU and Hans Berge from King County.

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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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Executive Summary

This report describes the emigration of five salmonid species from two heavily spawned 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. In each watershed, the abundance of juvenile migrants is the measure of freshwater production above 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 coho production estimates to be derived, and steelhead and cutthroat trout movement to be assessed.

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 production estimates to be derived for coho, and described ancillary data on movement patterns of steelhead and cutthroat trout.

The primary study goal of this program in 2012 was to estimate the number of juvenile sockeye and Chinook of natural-origin migrating from the Cedar River and Bear Creek into Lake Washington and the Sammamish River, respectively. This estimate was used to calculate survival of the 2011 brood from egg deposition to lake/river entry and to describe the migration timing of each species.

Cedar River

An inclined-plane trap was operated at RM 0.8, just downstream of the South Boeing Bridge in Renton between January 22 and May 10, 2012. A rotary screw trap was operated at R.M 1.6, just under the I-405 Bridge between April 18 and July 14. The abundance of natural-origin juvenile migrants was estimated for sockeye fry, sub yearling Chinook, and coho smolts. The number of cutthroat and steelhead migrants was not assessed in 2012 due to insufficient catch.

Production of natural-origin sockeye fry in the Cedar River was estimated to be 14.8 million ± 1.3 million (±95% C.I.). This estimate was based on a total catch of 241,886 between January 22 and May 10 and trap efficiencies ranging from 0.5% to 11.5%. Survival of sockeye fry from egg deposition to lake entry was 37.6%, based on an estimated deposition of 39.2 million eggs. Over the season, 8.11 million hatchery-origin sockeye fry were released into the Cedar River at three different locations. A portion of these (2.77 million) were released below the inclined-plane trap at the Cedar River Trail Park where in-river survival is assumed to be 100%. The remaining sockeye (5.34 million) were released above the trap: 3.15 million fry were released at R.M. 13.5, and 2.19 million fry released at R.M. 21.8. Total hatchery abundance from upstream releases is estimated at 3.2 million fry from a total of 5.3 million fry released. Hatchery fry survival from individual releases ranged from an estimated 15.8% to 105.4%, with an overall survival estimate of 65.0%. Over 1.6 million mixed natural and hatchery origin sockeye were estimated to have migrated on February 21. This night was kept separate due to our inability to form separate hatchery and natural-origin estimates and is not included in either the hatchery or natural-origin abundance or survival estimates. An estimated 22.3 million combined natural and hatchery-origin sockeye fry entered Lake Washington from the Cedar River in 2012.

Median migration date for natural-origin sockeye fry was March 22, 2012, 1 day later than the long-term average and fourteen days later than that of the hatchery fry releases. The timing of sockeye out-migration was somewhat correlated with February stream temperatures (R^2=0.41) and the 2012 daily average February temperatures (6.1°C) was cooler than the 21-year average of 6.3 °C.

Production of natural-origin Chinook was estimated to be 902,514 ± 165,973 (±95% C.I.) sub yearlings, based on operation of both the inclined-plane and screw traps. Between January 1 and May 10, 2012, 863,595 ± 165,775 (±95% C.I.) natural-origin Chinook were estimated to have passed the inclined-plane trap. This estimate was based on a total catch of 16,993 and trap efficiencies ranging from 0.5% to 11.48%. Between May 10 and July 31, 2012, 38,918 ± 8,118 (±95% C.I.) natural-origin Chinook were estimated to have passed the screw trap. This estimate is based on a total catch of 2,692 natural-origin juvenile Chinook in the screw trap and trap efficiencies of 5.1% and 38.8%. Egg-to-migrant survival of the 2011 brood year Chinook was estimated to be 61.8%, the highest estimated since trapping began.

Weekly average lengths of sub yearling Chinook increased from 39.0-mm fork length (FL) in January to 95.9-mm FL by July. Migration timing was bi-modal. The small fry emigrated between January and early-May and comprised 93% of all sub yearlings. The large parr emigrated between early-May and July and comprised 7% of the total migration.

A total of 48,168 ± 9,675 (±95% CI) natural-origin coho were estimated to have migrated passed the screw trap in 2012 during the period the trap was operating. Steelhead/rainbow and cutthroat trout production were not estimated in 2012 due to low catches (4 steelhead/rainbow and 103 cutthroat).

Bear Creek

A rotary screw trap was operated 100 yards downstream of the Redmond Way Bridge the entire season, from January 24 and July 14, 2012. The abundance of natural-origin juvenile migrants was estimated for sockeye fry, sub yearling Chinook, coho, and cutthroat trout. No steelhead/rainbow trout were caught in the Bear Creek trap during the 2012 trapping season.

Sockeye fry migration in 2012 was estimated to be 266,899 ± 62,030 (±95% C.I.). This estimate was based on a total catch of 24,494 sockeye fry and trap efficiencies ranging from 2.4% to 16.9%. An egg-to-migrant survival rate of 17.7% was based on an egg deposition of 1.51 million and was the fifth highest estimate of survival since trapping began in 1998.

Production of natural-origin Chinook was estimated to be 22,197 ± 2,304 (±95% C.I.) sub yearlings. This estimate was based on a total catch of 6,229 Chinook and efficiencies ranging from 2.4% and 55.0%. Egg-to-migrant survival of the 2011 brood year natural-origin Chinook was estimated to be 9.0%, the second highest survival measured since 2000.

Weekly average lengths of sub yearling Chinook migrants averaged 38.0-mm FL in February and increased to an average of 82.1-mm FL by July. Migration timing of sub yearling Chinook was bimodal. Small fry emigrated between February and April and comprised 18% of the total migration. Large parr migrants emigrated between May and July and represented 82% of total production in Bear Creek during 2012.

A total of 16,059 ± 1,325 (±95% C.I.) natural-origin coho were estimated to have migrated fron Bear Creek in 2012 and 16,284 ± 6,822 (±95% C.I.) cutthroat trout were estimated to have moved past the trap in Bear Creek in 2012.

Introduction

This report describes the emigration of five salmonid species from two heavily spawned tributaries in the Lake Washington watershed: Cedar River and Bear Creek, also referred to as Big Bear Creek (Figure 1). The abundance of juvenile migrants is the measure of freshwater production above the trapping location in each watershed. Results from the 2012 season contribute to a long-term study conducted by the Washington Department of Fish and Wildlife (WDFW) and focused on the freshwater survival and migration timing of sockeye and Chinook salmon in the Lake Washington watershed.

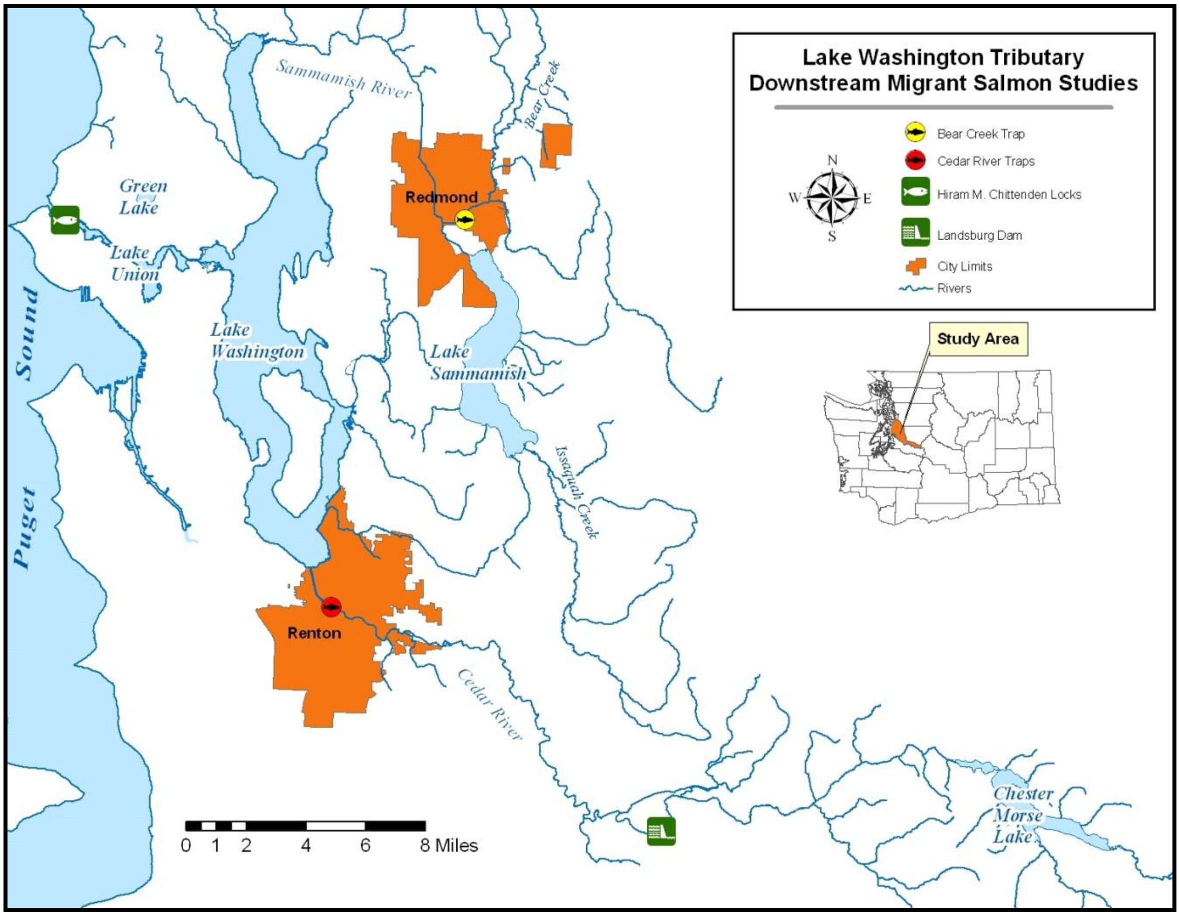

Figure 1. Map of Lake Washington trap sites used to monitor abundance of juvenile migrant salmonids in the Cedar River and Bear Creek, near Renton and Redmond, respectively.

Sockeye salmon have been a management concern in the Lake Washington watershed based on declining returns first observed in the late 1980s. In 1988, over 500,000 sockeye spawners returned through the Ballard Locks. However, by 1991, less than 100,000 sockeye returned. For the 1967 to 1993 broods, marine survival averaged 11% and varied eight-fold (2.6% to 21.4%), with no apparent decline over time (WDFW unpublished). In contrast, freshwater survival, measured by smolts produced per spawner, declined over this same period (WDFW unpublished). These observations suggested that early freshwater survival was an important contributor to the declines of Lake Washington sockeye.

In 1991, a broad-based group was formed to address declines in Lake Washington sockeye. Resource managers developed a recovery program that combined population monitoring with artificial production. A sockeye production program was developed at the Landsburg Hatchery and all released sockeye from this facility were marked with thermally-induced otolith marks (Volk *et al.* 1990). Concurrently, juvenile monitoring of natural and hatchery-origin sockeye entering Lake Washington was initiated in the Cedar River in 1992. In 1997, this effort was expanded to include monitoring natural-origin sockeye fry in the Sammamish River. In 1999, the monitoring site in the Sammamish River was moved to lower Bear Creek. The Cedar River and Bear Creek are two of the more heavily spawned tributaries of Lake Washington and enter the southern and northern ends of the lake respectively.

Since juvenile monitoring in the Cedar River began in 1992, annual sockeye returns have ranged from 12,501 to 230,000 spawners, averaging 86,098 spawners. Survival from egg deposition in the Cedar River to lake entry has ranged between 1.9% and 54.0%. When juvenile monitoring in the Sammamish watershed began in 1997, sockeye had returned to Bear Creek in excess of 50,000 spawners (1996 brood year). Over the duration of the juvenile monitoring study, escapement has ranged from 577 to 43,298 spawners, with an average return of 10,047 sockeye, and survival from egg deposition to migration in Bear Creek has ranged between 3.0% and 42.2%.

Puget Sound Chinook salmon are listed as “threatened” under the authority of the Endangered Species Act (NMFS 1999) and consequently are an important management concern. Baseline information available at the time of listing included escapement estimates in the Cedar River and Bear Creek watersheds, but adult-to-adult survival provides little insight into life stage-specific survival. Combining information from adult spawners and juvenile migrants separates survival into freshwater and marine components and provides a more direct accounting of the role that freshwater habitats play in regulating salmon production (Seiler *et al.* 1981, Cramer *et al.* 1999). As recovery efforts are often associated with particular life stages (e.g., freshwater rearing habitat versus marine harvest), partitioning of survival among life stages has provided valuable information for the recovery planning process (WRIA 8 2005).

Juvenile migrant evaluations of Chinook salmon were initiated in 1999 in both the Cedar River and Bear Creek (Seiler *et al.* 2003). The Chinook migration spans a period of nearly six months and includes an early migration of newly emerged fry and a late migration of large Chinook (parr). Two different gear types have been used to sample the entire Chinook migration. An inclined-plane trap gently captures early-timed fry but is ineffective at capturing larger migrants late in the season. A rotary screw trap more effectively catches the larger later-timed parr migration. Sub yearling Chinook in the Cedar River migrate primarily as fry and immediately migrate to the lake after emerging from the gravel. Estimates of Chinook survival from egg deposition in the Cedar River to lake entry have ranged from 4.7% to 61.8% since the 1999 brood. Sub yearling Chinook in Bear Creek are primarily parr migrants that emerge and rear in freshwater for several months before migrating to the lake. Estimates of Chinook survival from egg deposition to migration in Bear Creek have ranged from 1.7% and 11.0% since the 1999 brood year.

Goals and Objectives

The primary objective of this project is to quantify production of sub yearling sockeye and Chinook in the Cedar River and Bear Creek basins. When possible, production estimates are made for coho salmon and steelhead and cutthroat trout. The compilation and analysis of long-term data on production estimates, egg-to-migrant survival, body size, migration timing, and movement through the Lake Washington system has contributed to the following goals.

Chinook

1. **Estimate in-river survival.** In-river survival is estimated from production of juvenile migrants and estimated egg deposition. Correlation between in-river survival and variables such as spawner abundance, discharge, and habitat condition will identify density dependent and independent factors limiting juvenile production.
2. **Determine variables contributing to juvenile production.** Identifying variables that limit production of both life history stages may inform management on the current carrying capacities for each watershed.
3. **Estimate contribution of lake/marine survival on spawner abundance.** Survival from river out-migration to returning spawners indicates the relative contribution of early riverine survival to lake/locks/marine survival for Chinook abundance.
4. **Identify variables contributing to life history diversity.** Sub yearling Chinook migrate at two different life stages, fry and parr. Identifying habitat or climatic variables that contribute to Chinook life history diversity will develop recovery strategies that support each life history type.

Sockeye

1. **Estimate in-river survival**. Overall success of natural spawning sockeye will be determined from natural-origin fry production and estimated egg deposition. Variation in survival among broods, as a function of spawner abundance and flows will be evaluated to assess stream carrying capacity and the relative importance of environmental variables.
2. **Estimate incidence of hatchery fry entering Lake Washington from the Cedar River.** Relative survival of hatchery and natural-origin sockeye can be determined by comparing the proportion of hatchery and natural-origin sockeye at the fry life history stage with proportions at later life stages (smolts and adults).
3. **Compare migration timing of natural-origin and hatchery fry.** Environmental predictors of the migration timing for natural-origin sockeye fry will contribute to in-season decisions on hatchery releases and allow in-season estimates of the abundance of natural-origin fry. A comparison of migration timing and subsequent survival of hatchery versus natural-origin sockeye fry will contribute to the adaptive management process guiding the production and release of Cedar River Hatchery sockeye fry.

Coho, Cutthroat and Steelhead

Estimate production of coho, cutthroat, and steelhead/rainbow smolts when possible. These estimates provide a measurement of ecosystem health in the Cedar River and Bear Creek. Population levels and ratios between these species are indicative of habitat conditions and responses to watershed management.

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 so as 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 in 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 21 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 (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 2012, the inclined-plane trap was anchored at RM 0.8, just downstream of the South Boeing Bridge (Figure 2). This trap was positioned off the east bank and repositioned within eight feet of the shoreline in response to changing flows. Two scoop traps were fished in parallel throughout the season except on 30 nights when only one trap was operated due to high flows, debris loads or hatchery releases.

The inclined-plane trap began operating on the night of January 22 was operated 70 nights between January 22 and May 10. During each night of operation, trapping began before dusk and continued past dawn. Trapping was also conducted during seven day-light periods between the beginning of February through the middle of April. Captured fish were removed from the trap, identified by species, and counted each hour. 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 ten nights throughout the season; four fry releases occurred at R.M. 13.5 and five releases at R.M. 21.8, and one night when fish were released at both sites. The trap was operating during all hatchery releases that occurred above the trap. Survival of hatchery fry was estimated for all releases.

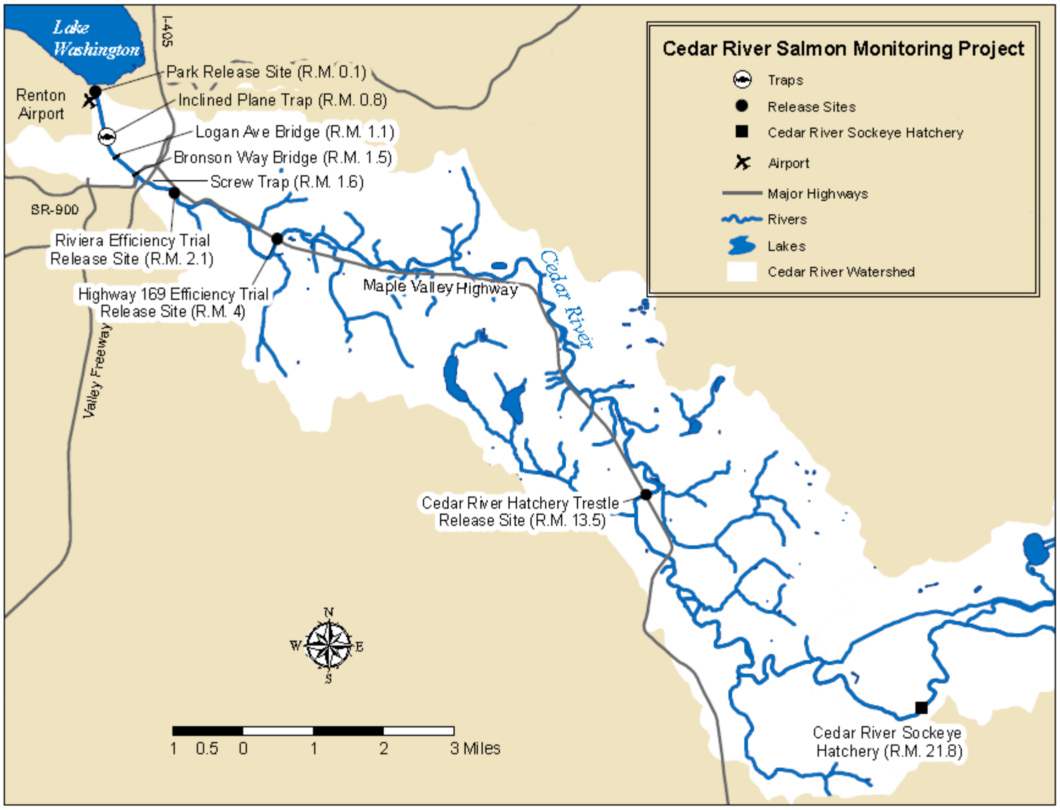

Figure 2. Site map of the lower Cedar River watershed depicting the inclined-plane and screw trap locations and hatchery sockeye release sites for the 2012 trapping season.

In 2012, the screw trap was operated at R.M 1.6, just under the I-405 Bridge (Figure 2), between the evening of April 18 and July 14, except during 10 outage periods (April 20 and 24, May 17, 19, and 31, and June 5, 6, 19, 20, and 26) caused by high debris loads and 13 day periods when trapping was intentionally halted due to public safety concerns or high flows and heavy debris. Catches were 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

Prior to 2012, juvenile migrants were captured using two different types of traps throughout the season, an inclined-plane from January through mid-April, and screw trap from mid-April through July, in lower Bear Creek. In 2012, juvenile salmon migrants were captured using only a screw trap for the entire trapping period to increase fishing time and capture the tail ends of multiple species migration timing. 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 3). The screw trap began fishing on January 25 and fished until July 14 except for 8 outages periods (February 5 and 7, March 14 and 16, April 19, and June 6, 24, and 30) caused by debris and 37 day and night periods when the trap was pulled intentionally due to staff scheduling. Most intentional outages occurred once a week for a 36 hour period. 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.

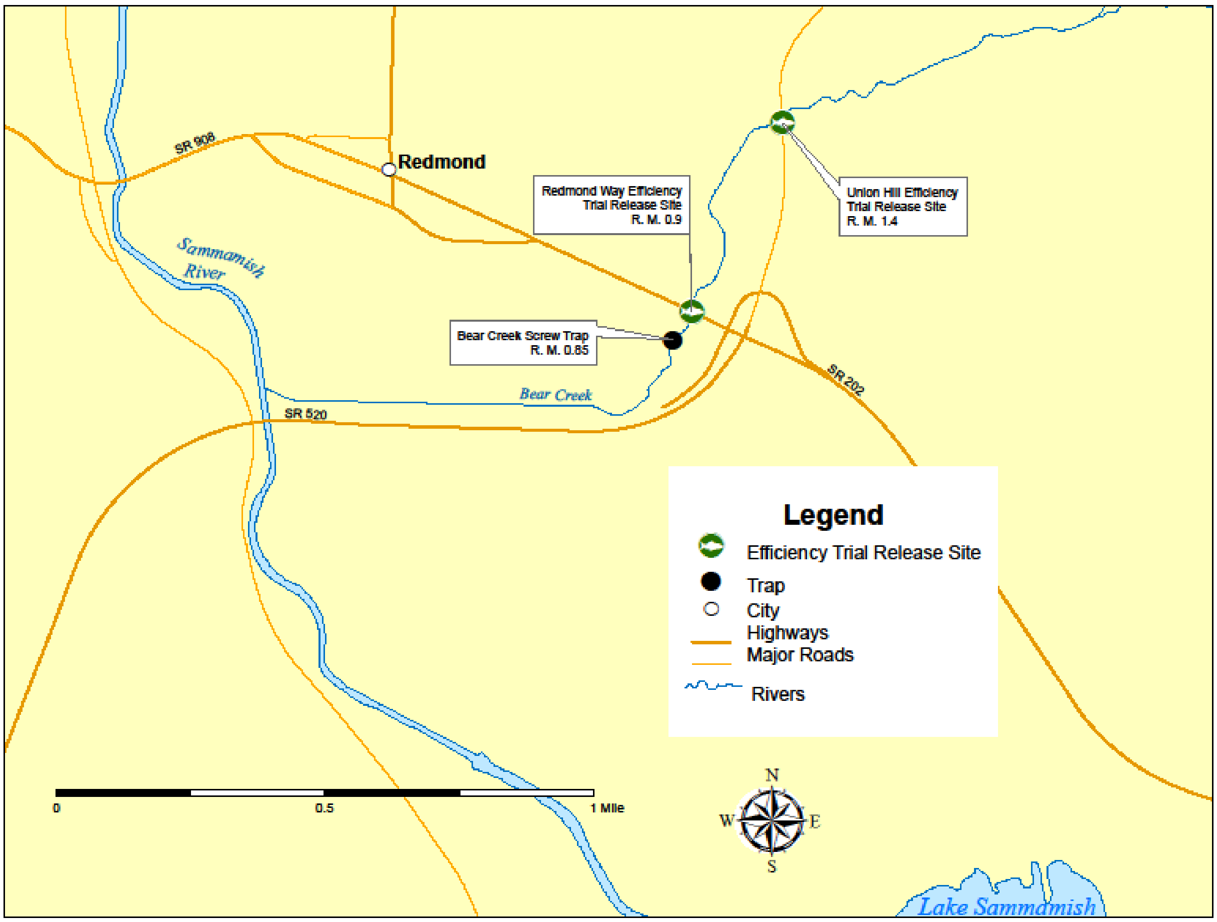

Figure 3. Site map of the Bear Creek watershed in the North Lake Washington watershed showing trap location for the 2012 trapping season.

PIT Tagging

During screw trap operation at both sites, a portion of natural-origin Chinook migrants were tagged with Passively Integrated Transponder (PIT) tags. Captured steelhead were tagged as well. Tagging occurred two to three times a week, depending on catches, between May 8 and July 13, 2012. Fish were often held from the previous day to be tagged to increase the total number of fish tagged per day. 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 Columbia Basin Fish and Wildlife Authority and the PIT Tag Steering Committee (1999).

Upon exiting the Lake Washington watershed through the Hiram Chittenden Locks facility, tagged fish could be detected by a PIT tag antenna if they used one of four smolt flumes or the adult fish ladder. Median migration date was the median date of all detected fish at the smolt flumes at the Hiram Chittenden Locks. Average travel times were calculated using tag date and subsequent detection date at the smolt flumes at the Hiram Chittenden Locks.

Trap Efficiencies

Cedar River

Inclined-Plane Trap

Trap efficiencies of the Cedar River inclined-plane trap were estimated from recaptures of marked natural-origin sockeye fry released above the trap. Fish captured in the early hours of the night were used for efficiency trials. 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. Release groups, ranging from 100 to 4,018 marked sockeye fry (mean = 963.6, SD = 777.6), were released at the Logan Street Bridge (R.M. 1.1) on 47 nights throughout the season. Fish were transported in buckets with battery operated aerators if needed. At the release location, a swinging bucket on a rope distributed marked fry across the middle of the channel. Catches were examined for marked fish and recaptures were noted during each trap check. Sockeye fry were used as surrogates for Chinook fry trap efficiencies.

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 May 8, Chinook parr larger than 65-mm FL were tagged with Passive Integrated Transponder tags (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 approximately 800-yards upstream of the trap (Riviera release location). Efficiency trial releases were conducted every night or every other night, with frequency driven by the availability of each species in the days catch. Chinook efficiency trials ranged in size from 10 to 139 Chinook (mean = 60.9, SD = 38.2) and coho efficiency trials ranged in size from 14 to 145 coho (mean = 69.4, SD = 36.4). 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. Release groups ranged from 56 to 496 sockeye (mean = 328.5, SD = 133.2) and were released approximately 100 yards upstream of the trap at the Redmond Way Bridge. Fry releases occurred on 16 nights throughout the season, 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. All deceased or compromised fish were not included in releases. Catches were examined for marks and recaptures were noted during each trap check. When Chinook fry were not abundant enough to form efficiency trial groups, sockeye fry were assumed adequate surrogates for estimating trap efficiencies.

Trap efficiencies of Chinook parr, coho, and cutthroat in Bear Creek screw trap were estimated for using the same approach described for similar species at the Cedar River screw trap. 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. Chinook efficiency trials ranged in size from 4 to 101 Chinook (mean = 48.9, SD = 17.1) and coho efficiency trials ranged in size from 9 to 100 coho (mean = 57.9, SD = 28.7). Cutthroat efficiency trails ranged from 4 to 40 cutthroat (mean = 16.3, SD = 10.9) per release.

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 the fishing period during the adjacent nights was the same as 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

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

Equation 2

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

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,

$\bar{n}_i$ = 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

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

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:

$$\hat{n}_i = T_i * \bar{R}$$ Equation 4

where:

T_i = Hours during non-fishing period *i*

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

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

$$Var(\hat{n}_i) = T_i^2 * Var(\bar{R})$$ Equation 5

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

$$Var\left(\overline{R}\right) = \frac{\sum_{i=1}^{i=k} (R_i - \overline{R}\ )^2}{k(k-1)} \qquad \text{Equation 6}$$

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:

$$\hat{F}_d = \frac{T_d}{\overline{Q}^{-1} T_n + T_d} \qquad \text{Equation 7}$$

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

$$Var(\hat{F}_d) = \frac{Var(\overline{Q}) T_n{}^2 T_d{}^2}{\overline{Q}^4 \left(\frac{1}{\overline{Q}} T_n + T_d \right)^4} \qquad \text{Equation 8}$$

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.

Hatchery Catch and Survival

Hatchery catch and survival was estimated for nights when releases occurred above the trap. Hatchery fish were released from the Cedar River Sockeye Hatchery at R.M. 21.8 on five occasions, and from the Trestle site (R.M. 13.5) on four occasions. On one additional occasion, fish were released from both sites on the same night. The trap was operating on ten release nights. Due to the inability to visually distinguish hatchery and natural-origin sockeye, the portion of each in the catch is unknown on hatchery release nights. Therefore, on nights of releases, natural-origin nightly migration timing was assumed to be similar to surrounding nights (i.e. hourly catch proportion), and a nightly timing method was applied to estimate natural-origin catch on hatchery release nights. Hatchery catch was the actual catch minus the expected hourly catch. Remaining catch in excess of the expected catch was assumed to be hatchery sockeye. Total hatchery migration was estimated by expanding estimated hatchery catch by the measured nighttime efficiency. If an efficiency trial was not conducted on a hatchery release night, then the appropriate strata efficiency was applied. Survival of releases above the trap was calculated by dividing estimated hatchery abundance at the trap by total number of sockeye released above the trap.

Egg-to-Migrant Survival

Egg-to-migrant survival for sockeye and Chinook was the survival between egg deposition and migration of juveniles into Lake Washington. Survival was estimated by dividing the 2012 abundance of natural-origin juvenile migrants by the 2011 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 and agreed upon in a multi-agency effort. This estimate assumed an even sex ratio for sockeye. Cedar River sockeye fecundity was the average number of eggs per female during 2011 sockeye brood stock collection for the Cedar River Sockeye Hatchery (Cuthbertson 2012). Fecundity of Bear Creek sockeye was assumed to be the same as the fecundity of Cedar River sockeye.

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 et al. 2012). Chinook fecundity was based on a long-term average fecundity at the Soos Creek Hatchery (M. Wilson, Washington Department of Fish and Wildlife, personal communication). Further partitioning of Chinook survival is calculated to estimate the survival and productivity of the fry and parr components.

Cedar River Results

Sockeye

Catch and Estimated Missed Catch

Total catch (actual and estimated missed) in the inclined-plane trap was 449,888 sockeye fry. A total of 241,886 natural-origin sockeye fry were caught in the inclined-plane trap during trap operations. An estimated additional 208,002 sockeye fry should have been caught on nights when hatchery releases occurred or had the inclined-plane trap fished continuously at night between January 22 and May 10, 2012. Seven day intervals were trapped to evaluate day-time migration: February 7, 14, 27, March 19, 26, and April 2 and 10. Flows on these days ranged from 851 cfs to 2,260 cfs at the Cedar River USGS gage (#12119000) and were representative of flows throughout the season. Day-to-night catch ratios ranged from 2.66% to 41.73%. An estimated 26,947 fry should have been caught had the trap fished during all day-time periods. Missed day-time catch represented 6.0% of the season's total catch. Due to a hatchery release on February 21, an unknown portion of the total night's catch of 6,457 is natural-origin sockeye and is not included in the total catch estimated above.

Production Estimate

A total of 46 efficiency trials were conducted in 2012. Efficiency data were aggregated into eighteen strata. Capture rates for these strata ranged from 0.50% to 11.48% (Appendix B).

An estimated 22.3 million sockeye fry entered Lake Washington from the Cedar River in 2012 (Table 1, Figure 4, Appendix B1). This migration included 14.8 million ± 1.3 million (±95% C.I.) natural-origin fry and 6.2 million ± 539,980 million hatchery fry, and 1.6 million ± 596,685 million fry of undetermined hatchery and natural-origin sockeye proportions (see Survival of Hatchery Release Groups section below). Pre-season migration (January 1 through January 21) was estimated to be 127,204 fry, and the post-season migration (May 11 through June 30) was estimated to be 176,183 fry. Both pre- and post-season tails each represent less than 1% of the total natural production. Coefficient of variation (*CV*) associated with the natural-origin migration was 0.61%.

Table 1. Abundance of natural-origin and hatchery sockeye fry entering Lake Washington from the Cedar River in 2012. Table includes abundance of fry migrants, 95% confidence intervals (C.I.), and coefficients of variation (*CV*). Hatchery totals are adjusted to reflect estimated survival of releases above the trap.

Component	Period	Dates	Fry Abundance	95% C.I.		*CV*
				Low	High	
Natural Origin	Pre Trapping	January 1 - 21	127,204	96,326	158,082	2.26%
	During Trapping	January 22-May 10	14,460,122	13,162,403	15,757,841	4.58%
	Post Trapping	May 11- June 30	176,183	86,881	265,485	0.92%
		Subtotal	**14,763,509**	**13,462,355**	**16,064,663**	**0.58%**
Hatchery	Above Trap		3,195,168	2,655,188	3,735,148	8.62%
	Below Trap		2,768,825			
		Subtotal	**5,963,993**			
Mixed H & NO	During Trapping	February 21	1,639,384	1,042,699	2,236,069	0.42%
		Total	**22,366,886**	**20,836,979**	**23,896,792**	**0.61%**

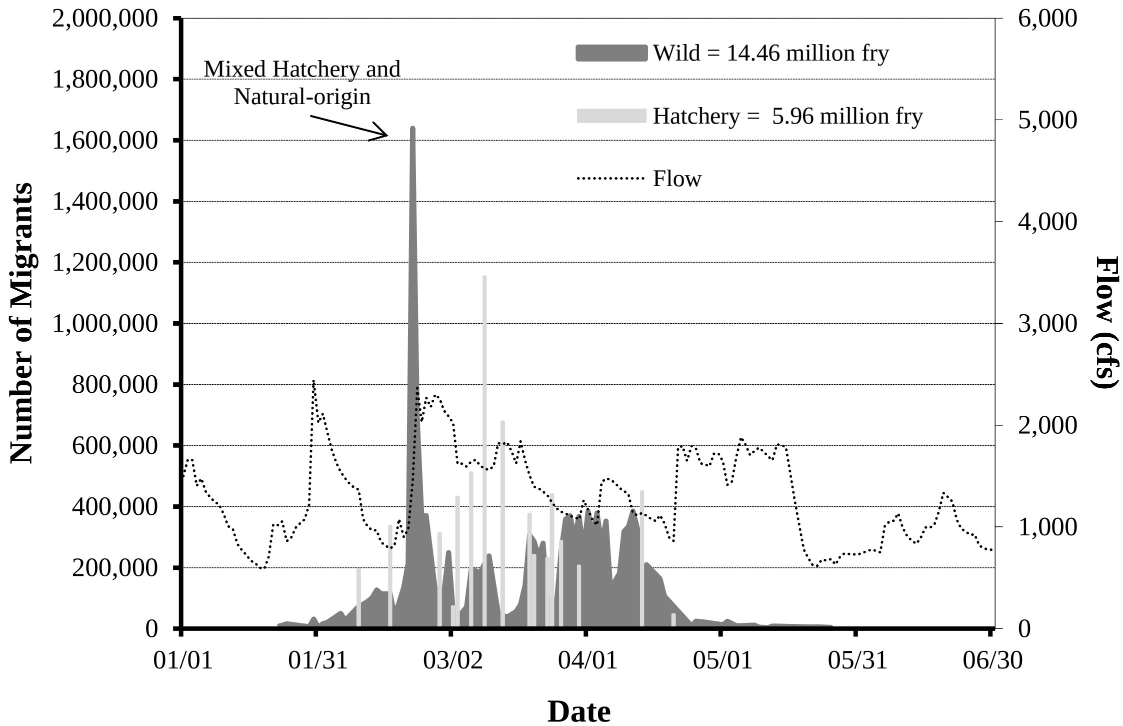

Figure 4. Estimated daily migration of natural-origin and hatchery sockeye fry migrating from the Cedar River into Lake Washington between January 22 and May 10, 2012. Graph includes daily average flows during this period (USGS Renton gage Station #12119000). Includes hatchery sockeye released below the trap. February 21 peak of over 1.6 million is a combination of hatchery and natural-origin migrants.

Survival of Hatchery Release Groups

Over the season a total of 8,110,830 hatchery-produced sockeye were released into the Cedar River. Over 7 separate nights, a total of 2.77 million sockeye were released at R.M. 0.1 (Table

2). Releases at this location are assumed to have 100% survival from point of release to the lake entry. An additional 3.15 million were released at R.M. 13.5 on 5 separate nights. A total of 2.19 million fry were released at the Cedar River Sockeye Hatchery (R.M. 21.8) over 6 different nights. Hatchery abundance and survival was calculated using the nightly timing approach for all night except for April 18 when the interpolation method was applied, as the trap was not fished on nights surrounding the release. Accounting for in-river loss of releases conducted upstream of the inclined-plane trap, total hatchery sockeye fry abundance for all upstream releases combined was estimated at 3.2 million fry. Total in-river survival of hatchery released sockeye planted upstream of the trap is estimated to be 65.0% with survival ranging from 15.8% to 105.4% for individual releases (Table 3). Separate hatchery and natural-origin abundance was not estimated for the February 21 release due to unreasonable estimates using all available methods, resulting in a total night's abundance estimated instead. Total abundance was estimated at 1.6 million sockeye. This estimate is not included in either the hatchery or natural-origin estimates or survival but held separate due to uncertainty in proportions of each origin in the night's catch (see Discussion section). Accounting for the estimated loss of hatchery fish from releases conducted above the trap, and the exclusion of the February 21 hatchery release when no hatchery abundance estimate was made, total hatchery production in the Cedar River is reduced to be 5.96 million sockeye fry. However, it is likely that total hatchery abundance and survival would be greater if the February 21 hatchery component could be estimated.

Table 2. Date, location, and total number of hatchery sockeye fry released into the Cedar River in 2012 (Cuthbertson 2012).

Release Date	Park Release (RM 0.1)	Trestle Release (RM 13.5)	Cedar River Hatchery (RM 21.8)
02/09/2012	194,000		
02/16/2012	335,620		
02/21/2012			427,770
02/27/2012		357,400	
03/01/2012	430,995		462,725
03/05/2012		786,060	
03/08/2012		968,330	360,360
03/12/2012	678,150		
03/18/2012			356,400
03/19/2012	240,600		
03/22/2012	440,620	487,500	
03/25/2012			495,000
03/29/2012		548,460	
04/12/2012	448,840		
04/19/2012			92,000
Total	2,768,825	3,147,750	2,194,255

Table 3. Estimated hatchery sockeye abundance, variance, and survival for releases conducted above the Cedar River inclined-plane trap, 2012. The February 21 release was not estimated due to unreasonable results. Totals do not include February 21. Estimates were formed using the nightly timing approach, except for April 19 which was estimated using the interpolation method. Flow data was measured at the USGS Renton gage Station #12119000.

Date Released	Sockeye Released	Daily Average Flow (cfs)	Estimated Hatchery Sockeye		
			Abundance	Variance	Survival
2/21/2012	427,770	1,466	**Not Estimated**		
2/27/2012	357,400	2,260	311,922	1.61E+10	87.28%
3/1/2012	462,725	2,021	73,174	7.92E+07	15.81%
3/5/2012	786,060	1,639	511,266	6.03E+09	65.04%
3/8/2012	1,328,690	1,572	1,153,556	4.18E+10	86.82%
3/18/2012	356,400	1,507	375,562	7.31E+09	105.38%
3/22/2012	487,500	1,311	231,236	2.91E+09	47.43%
3/25/2012	495,000	1,148	286,689	5.59E+08	57.92%
3/29/2012	548,460	1,072	205,795	1.09E+09	37.52%
4/19/2012	92,000	863	45,968	1.00E+00	49.96%
Total	**4,914,235**	**1,486**	**3,195,168**	**7.59E+10**	**65.02%**

Natural and Hatchery-Origin Timing

In 2012, 65.9% of hatchery sockeye were released upstream of the Cedar River inclined-plane trap while the remaining 34.1% were released below the trap. Releases of hatchery fry began on February 21 and continued through April 19 (Table 2, Figure 4). Median migration date for hatchery fry released into the river was March 8, 14 days earlier than the median migration date of natural-origin sockeye (Table 4).

Migration of natural-origin sockeye fry was under way when trapping began on January 22. The number of natural-origin juvenile migrants slowly increased at the beginning of the season, averaging only 30,000 fry per night until mid-February. The median migration date for natural-origin fry occurred on March 22, 14 days later than the hatchery median migration date of March 8 (Table 4). Natural-origin migration was 25%, 50% and 75% completed by February 27, March 22, and April 4, respectively (Figure 5).

Stream temperatures were correlated with median migration date of sockeye fry. After evaluating temperature data throughout the period of fry incubation and migration, total thermal units in the Cedar River for the month of February best explained observed variation in migration timing (R^2 = 0.41, Figure 6). Temperature data was acquired from the USGS Renton gage Station # 12119000. February stream temperatures averaged 6.1° C in 2012, slightly cooler than the average of 6.3°C in the 21-year data set, however median migration date was only one day later than the 21-year average median migration date (Table 4).

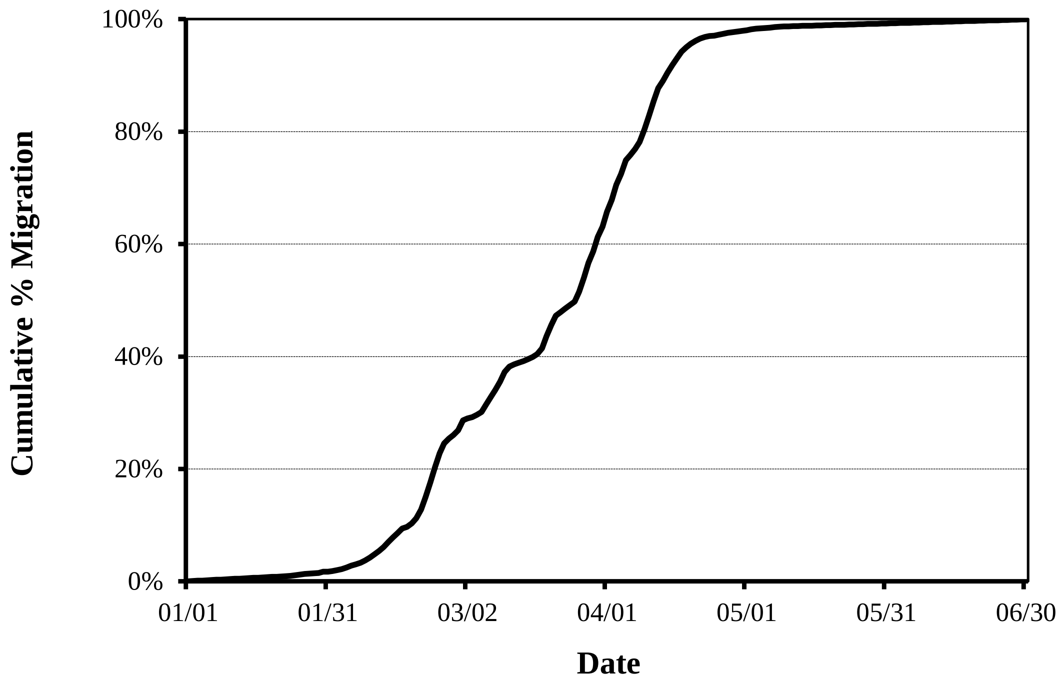

Figure 5. Cumulative migration of natural-origin sockeye fry from the Cedar River into Lake Washington in 2012.

Table 4. Median migration dates of natural-origin, hatchery, and total (combined) sockeye fry from the Cedar River for brood years 1991 to 2011. 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 i	Trap Year i+1	February Thermal Units	Median Migration Date			Difference (days) W-H
			Wild	Hatchery	Combined	
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	02/01	02/28	29
2005	2006	184	03/20	02/23	03/14	25
2006	2007	193	03/23	02/16	03/12	35
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	03/04	03/05	3
2010	2011	163	03/25	02/18	03/01	35
2011	2012	170	03/22	03/08	03/18	14
	Average		03/21	02/27	03/12	22

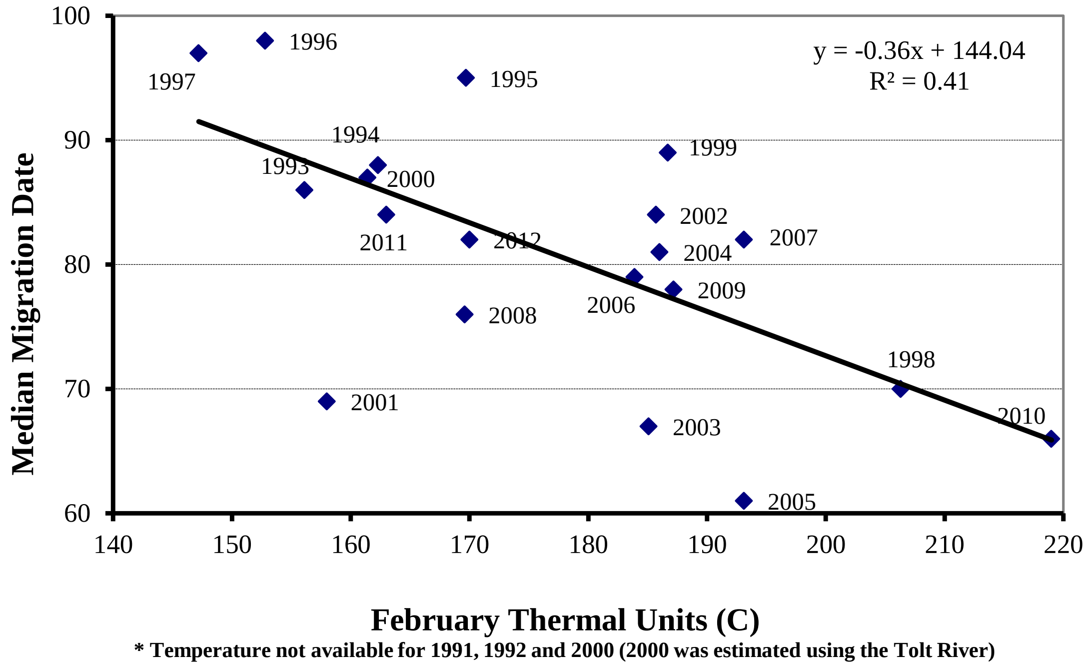

Figure 6. Median migration date (Julian Calendar day) for natural-origin sockeye fry in the Cedar River as a function of cumulative February thermal units (Celsius), migration years 1993-2012. Stream temperature data was measured at the USGS Renton gage Station #12119000.

Egg-to-Migrant Survival of Natural-Origin Fry

Egg-to-migrant survival of the 2011 brood Cedar River sockeye was estimated to be 37.6% (Table 5). Survival was based on 14.7 million natural-origin fry surviving from a potential 39.2 million eggs deposited by 11,827 females (A. Bosworth, Washington Department of Fish and Wildlife, personal communication). Average fecundity for the 2011 brood was 3,318 eggs per female sockeye (Cuthbertson 2012). This is the third highest egg-to-migrant survival observed since juvenile monitoring began in the Cedar River. Due to uncertainty in natural production on February 21, it is likely that survival is underestimated for the 2011 brood.

Analysis of the longer-term sockeye data set shows a negative correlation between egg-to-migrant survival and peak flow during the incubation period. (R^2 =0.39, Figure 7). The best fit model for this data series was a decreasing exponential equation ($y=be^{-ax}$). Higher peak flows during the egg incubation period, November 1 through January 31, have resulted in lower egg-to-migrant survival (Kiyohara and Zimmerman 2011). Below peak flow events of 5,000 cfs, survival has been highly variable with an average of 18.0% and a range between 5.0% and 56.6%. Above peak flows of 5,000 cfs, survival has been lower and less variable with an average of 4.7% and a ranged between 1.9% and 5.9%.

Table 5. 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 - 2011. 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)	Peak Incubation Flow 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

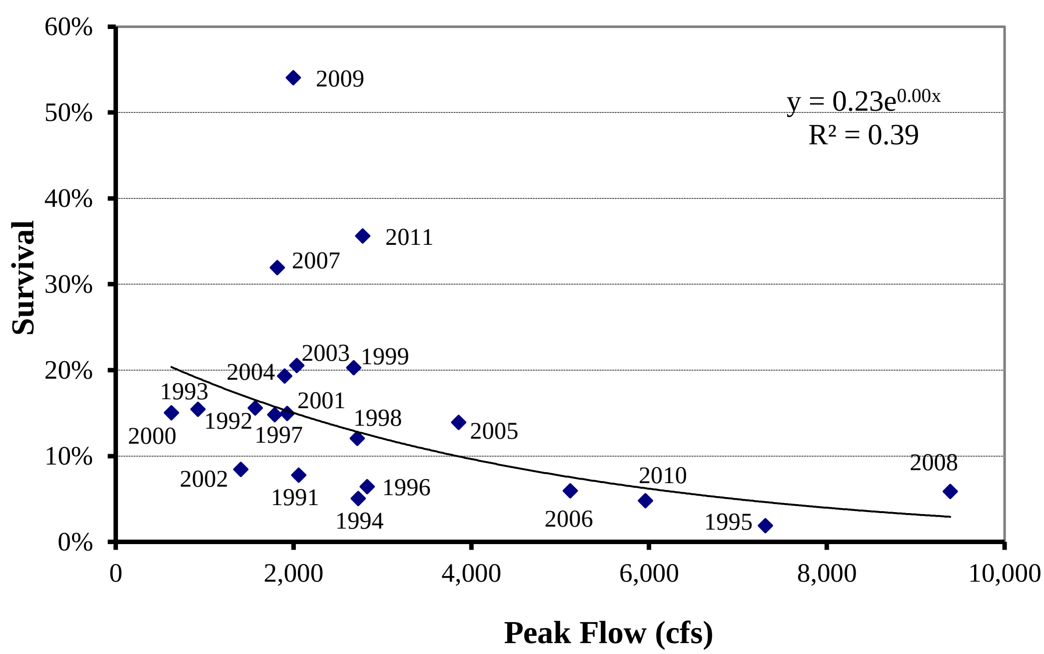

Figure 7. Egg-to-migrant survival of natural-origin sockeye in the Cedar River as a function of peak flow during the winter egg incubation period (November 1 through January 31). Survival for brood years 1991 to 2011 is fit with a decreasing exponential curve. Flow was measured at the USGS Renton gage, Station #12119000.

Chinook

Catch and Estimated Missed Catch

Inclined-Plane Trap

Total catch (actual and estimated missed) of natural-origin Chinook in the inclined-plane trap was estimated to be 16,993 sub yearlings. A total of 9,541 Chinook were captured and an estimated 7,452 additional fry would have been caught if the inclined-plane trap fished continuously (day and night) between January 22 and May 10. Day-to-night catch ratios used to calculate missed day catch ranged from 0.5% to 53.6%.

Screw Trap

Total catch (actual and estimated missed) of natural-origin Chinook in the screw trap was estimated to be 2,692 sub yearlings between May 11 and July 14, 2012. A total of 2,473 natural-origin (unmarked) and 11 hatchery (adipose fin clipped) Chinook were caught in the screw trap. Estimated catch for outage periods was 219 natural-origin Chinook and accounted for 8.1% of the total estimated catch. Production estimate was based on catches of natural-origin Chinook only.

Production Estimate

Inclined-Plane Trap

A total of 46 efficiency trials using sockeye (surrogates for Chinook) were conducted. Trials were aggregated into eighteen strata. Capture rates for the efficiency strata ranged from 0.50% to 11.48%.

Chinook migration was estimated to be 846,380 fry between January 22 and May 10, 2012 (Appendix B 2). A total of 17,215 Chinook fry were estimated to have migrated between January 1 and 21 (i.e., prior to inclined-plane trap operation). This extrapolation combined with the migration estimate during trap operation yields a total migration of 863,595 ± 165,774 (95% C.I.) Chinook fry through May 10 (Table 6).

From week 17 (beginning April 18) through 20 (ending May 10), both the inclined-plane and screw traps operated simultaneously. Inclined-plane trap migration catches and estimates were greater than screw trap catches and estimates for the entire overlap period. Inclined-plane trap catches allowed for larger efficiency trial groups and subsequently more confident capture rates and migration estimates. Due to low catches in the screw trap, efficiency trial groups were small and capture rates were low. Chinook production was estimated using inclined-plane trap estimates from the beginning of the season through May 10 and screw trap estimates from May 11 through the remainder of the season.

Screw Trap

A total of 29 efficiency trials, were conducted. Trials were aggregated into 4 final strata resulting in a recapture rate ranging from 5.08% to 38.82% (Appendix B3). Migration of natural-origin Chinook between May 11 and July 14 was estimated to be 38,001 ± 8,111 (±95% C.I.) parr (Table 6, Figure 9). A total of 918 Chinook parr were estimated to have migrated between July 15 and July 31 following the removal of the trap. Total parr migration is estimated at 38,919 ± 8,118 for the period between May 11 and July 31.

Table 6. Abundance of natural-origin juvenile migrant Chinook in the Cedar River in 2012. Data are total catch, abundance, 95% confidence intervals (C.I), and coefficient of variation (*CV*).

Gear	Period	Estimated		95% C.I.		*CV*
		Catch	Abundance	Low	High	
Pre-Trapping	January 1 - 21		17,215	9,168	25,263	23.85%
Inclined-Plane Trap	January 22-May 10	16,993	846,380	680,801	1,011,959	9.98%
Total Fry		**16,993**	**863,595**	**697,821**	**1,029,370**	**9.79%**
Screw Trap	May 11- July 14	2,692	38,001	29,890	46,112	10.89%
Post-Trapping	July 15 - July 31		918	577	1,259	18.95%
Total Parr		**2,692**	**38,919**	**30,801**	**47,037**	**10.64%**
	Season Total	**19,685**	**902,514**	**736,541**	**1,068,487**	**9.38%**

Combined Estimate

In total, 902,514 ± 165,973 (±95% C.I.) sub yearling Chinook are estimated to have migrated from the Cedar River into Lake Washington in 2012. This estimate is the combination of the Chinook production estimated from the extrapolated pre-trapping period, the inclined-plane trap from January 22 through May 10, the estimate from the screw trap for May 11 to July 14 (Table 6, Figure 8, Figure 9), and the extrapolated post-trapping period.

Migration Timing

Timing of the Chinook migration was bi-modal (Figure 8, Figure 9). Early migrants (fry) were estimated with inclined-plane trap estimates while late migrants (parr) were estimated with screw trap estimates. Juvenile Chinook emigrated mostly as fry, which represented 93% of the total migration (Table 6). Migration was 25%, 50%, and 75% complete by roughly February 21, February 23, and March 20 respectively (Figure 8, Figure 10). Chinook fry migration was estimated to be 1,440 Chinook on the first night of trapping, indicating migration had already begun. Migration climbed to over 5,000 fry per night through February. Fry migration peaked on February 21 when flows sharply increased; over 190,000 fry were estimated in a single night. Nights immediately following estimated between 20,000 and 87,000 fry moving a night. The remaining inclined-plane trap period continued to estimate migration between 1,400 to 14,000 fry per night until late April. Fry estimates declined to less than 1,400 fry per night for the remainder of the season. Daily parr migrations were low in abundance compared to inclined-plane trap migrations. Daily migrations were typically between 100 to 800 parr per day during screw trap operations. One broad prominent peak occurred between June 4 through June 11 when daily migrations ranged from 1,000 to 3,500 Chinook per day.

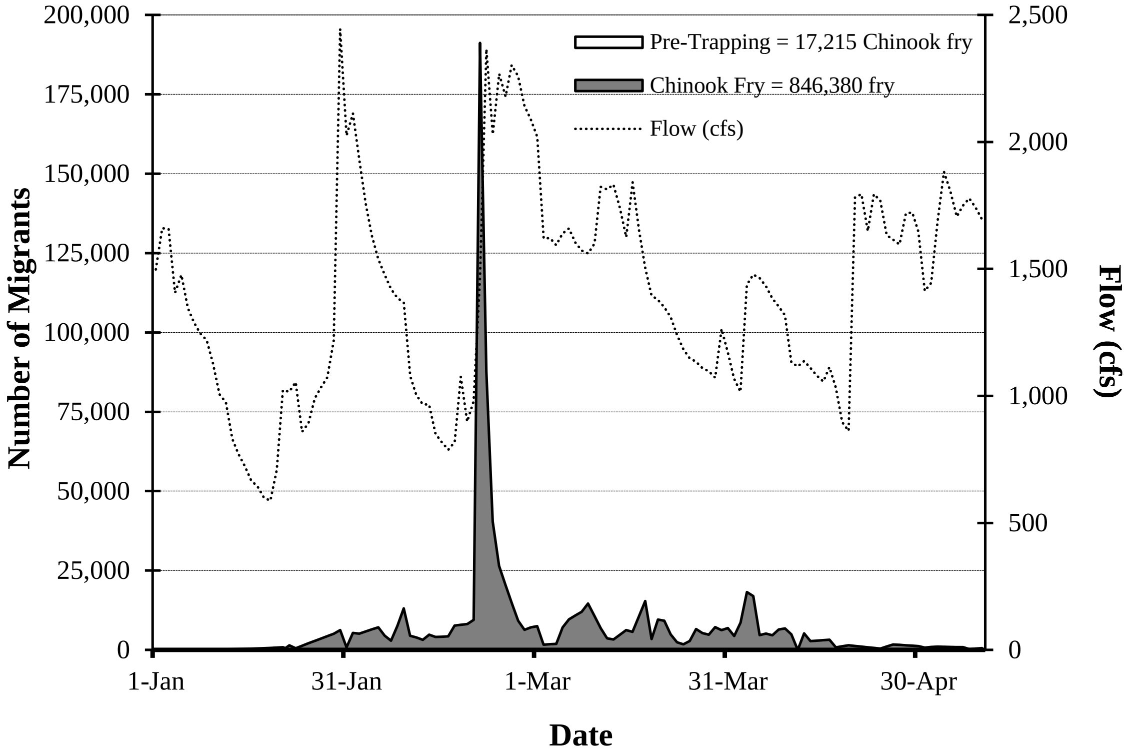

Figure 8**.** Estimated daily migration of Chinook fry from the Cedar River in 2012 based on inclined-plane trap estimates from January 21 to May 10. Graph includes mean daily flows during this time period (USGS Renton gage, Station #12119000) in 2012.

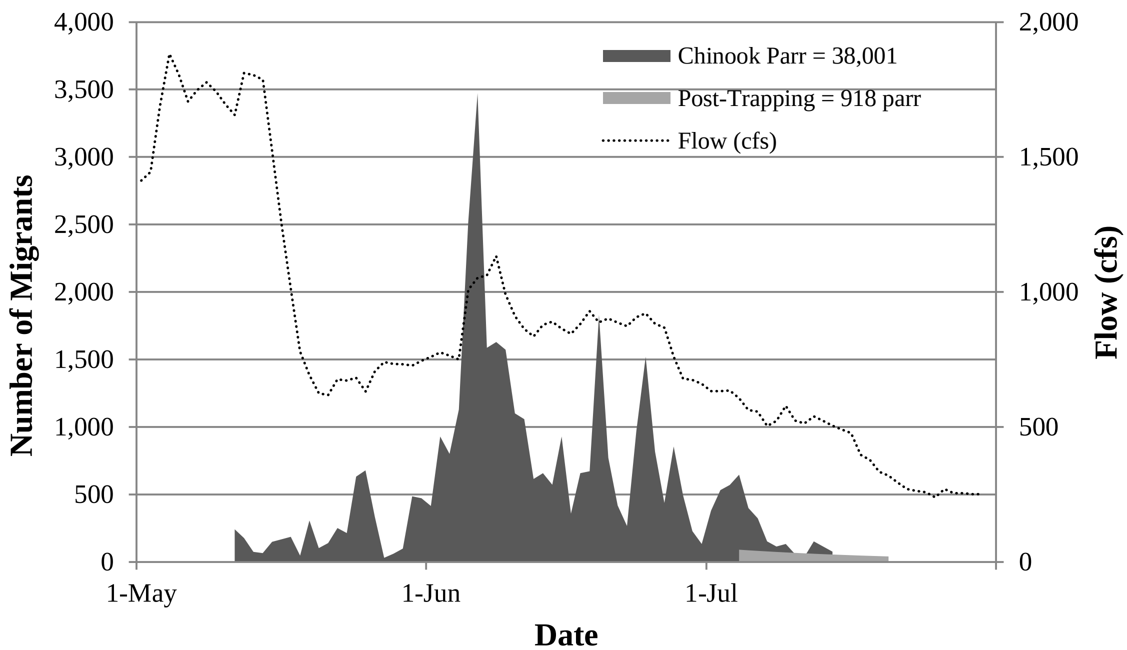

Figure 9. Estimated daily migration of Chinook parr from the Cedar River in 2012 based on screw trap estimates from May 11 to July 31. Graph includes mean daily flows during this time period (USGS Renton gage, Station #12119000) in 2012.

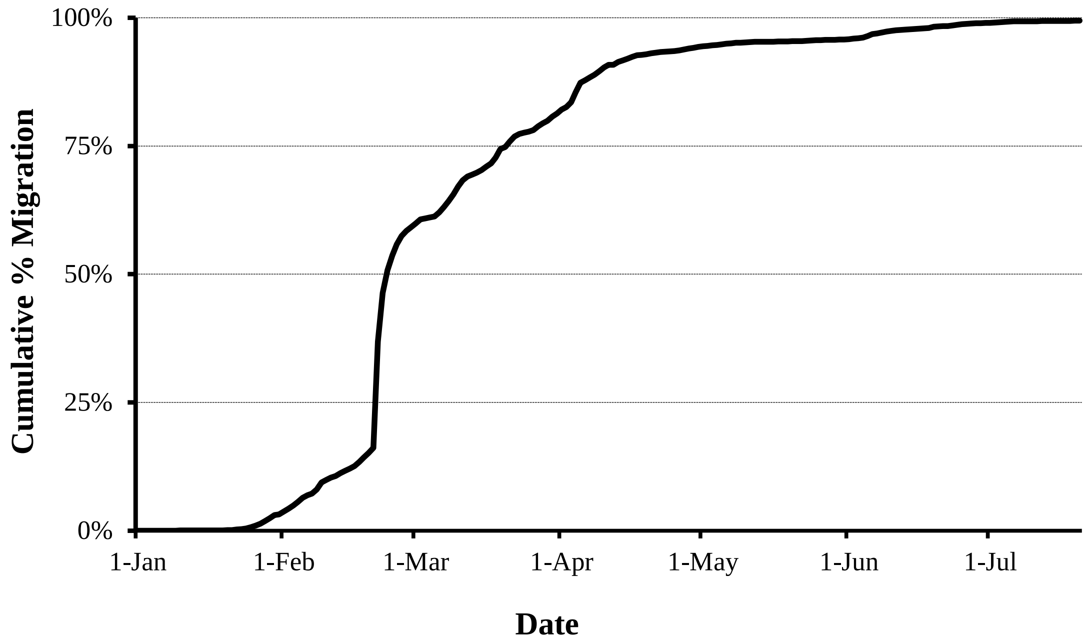

Figure 10. Cumulative percent migration of sub yearling Chinook from the Cedar River in 2012.

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2011 brood of Cedar River Chinook was estimated to be 61.8% (Table 6). Survival was based on 901,596 natural-origin sub yearlings surviving from a potential 1.4 million eggs deposited by 324 female spawners (Burton et al. 2012). Average fecundity for the 2011 brood was assumed to be 4,500 eggs per female.

Table 7. Abundance, productivity (juveniles per female), and survival of Chinook fry and parr among brood years. Fry migration was assumed to be January 1 to April 15. Parr migration was assumed to be April 16 through July 13. Egg-to-migrant survival was calculated from potential egg deposition (PED) for returning spawners. Data are Cedar River broods 1998 to 2011.

Brood	Juvenile Abundance			Percent Abundance		Est.	PED	Juvenile/Female			Survival		
Year	Fry	Parr	Total	Fry	Parr	Fem.		Fry	Parr	Total	Fry	Parr	Total
1998	67,293	12,811	80,104	84%	16%	173	778,500	389	74	463	8.6%	1.6%	10.3%
1999	45,906	18,817	64,723	71%	29%	182	810,000	252	103	356	5.6%	2.3%	7.9%
2000	10,994	21,157	32,151	34%	66%	53	238,500	207	399	607	4.6%	8.9%	13.5%
2001	79,813	39,326	119,139	67%	33%	398	1,791,000	201	99	299	4.5%	2.2%	6.7%
2002	194,135	41,262	235,397	82%	18%	281	1,264,500	691	147	838	15.4%	3.3%	18.6%
2003	65,875	54,929	120,804	55%	45%	337	1,516,500	195	163	358	4.3%	3.6%	8.0%
2004	74,292	60,006	134,298	55%	45%	511	2,299,500	145	117	263	3.2%	2.6%	5.8%
2005	98,085	19,474	117,559	83%	17%	339	1,525,500	289	57	347	6.4%	1.3%	7.7%
2006	107,796	14,613	122,409	88%	12%	587	2,641,500	184	25	209	4.1%	0.6%	4.7%
2007	691,216	75,746-81,404	766,962-772,620	89.5-90.1%	9.9-10.5%	899	4,045,500	769	84-90	856-862	17.2%	1.9-2.0%	19.1-19.2%
2008	124,655	14,883	139,538	89%	11%	599	2,695,500	208	25	233	4.6%	0.6%	5.2%
2009	115,474	36,916	152,390	76%	24%	285	1,282,500	405	130	535	9.0%	2.9%	11.9%
2010	153,126	34,680	187,806	82%	18%	266	1,197,000	576	130	706	12.8%	2.9%	15.7%
2011	836,886	64,710	901,596	93%	7%	324	1,458,000	2,583	200	2,783	57.4%	4.4%	61.8%

Size

Chinook fry caught in the inclined-plane trap had an average fork length (FL) of less than 50-mm between January and early April (Table 8, Figure 11). During screw trap operation, sizes ranged from 37-mm to 123-mm FL and averaged 82.2-mm FL. Chinook caught in the screw trap increased in size from a weekly average fork length of 48.5-mm in mid-April to 95.9-mm in July (Table 8). Chinook averaged more than 70-mm FL by mid-May. Both fry and parr lengths were near the median of the 12-year dataset (Table 9).

Table 8. Fork lengths (mm) of natural-origin juvenile Chinook caught in the Cedar River inclined-plane and screw traps in 2012. Data are mean, standard deviation (SD), range, sample size (n), and catch for each statistical week.

Statistical Week			Inclined-Plane Trap						Screw Trap					
Begin	End	No.	Avg.	SD	Range Min	Range Max	n	Catch	Avg.	SD	Range Min	Range Max	n	Catch
01/16	01/22	4	39.9	0.78	38	41	40	77						
01/23	01/29	5	40.6	1.20	36	42	79	166						
01/30	02/05	6	39.0	1.96	34	44	52	383						
02/06	02/12	7	40.9	1.32	37	43	119	636						
02/13	02/19	8	40.5	2.04	36	44	79	1,256						
02/20	02/26	9	40.1	2.02	36	48	76	1,056						
02/27	03/04	10	41.0	1.34	38	43	48	254						
03/05	03/11	11	42.0	2.23	36	46	50	774						
03/12	03/18	12	41.3	2.13	38	52	85	735						
03/19	03/25	13	42.6	3.45	38	55	90	904						
03/26	04/01	14	43.0	3.55	35	56	84	1,025						
04/02	04/08	15	43.3	3.86	38	55	63	1,251						
04/09	04/15	16	43.7	3.32	38	53	81	668						
04/16	04/22	17	46.6	2.31	42	54	58	221	48.5	7.44	40	59	10	13
04/23	04/29	18	44.8	2.20	42	52	46	60	57.2	6.76	47	64	5	6
04/30	05/06	19	49.8	6.45	41	68	48	48	59.8	10.51	37	80	33	61
05/07	05/13	20	54.7	7.26	44	71	23	27	66.0	9.42	48	84	51	77
05/14	05/20	21							70.9	10.14	47	92	86	110
05/21	05/27	22							76.3	8.69	55	97	156	254
05/28	06/03	23							78.3	8.81	60	97	131	248
06/04	06/10	24							81.9	7.62	65	107	507	741
06/11	06/17	25							82.5	7.11	65	101	259	335
06/18	06/24	26							86.3	7.55	69	115	273	379
06/25	07/01	27							89.1	7.83	68	123	186	191
07/02	07/08	28							94.6	7.90	69	118	130	144
07/09	07/15	29							95.9	10.46	75	120	28	30
Season Totals			42.5	4.15	34	71	1,121	9,541	82.2	10.94	37	123	1,861	2,589

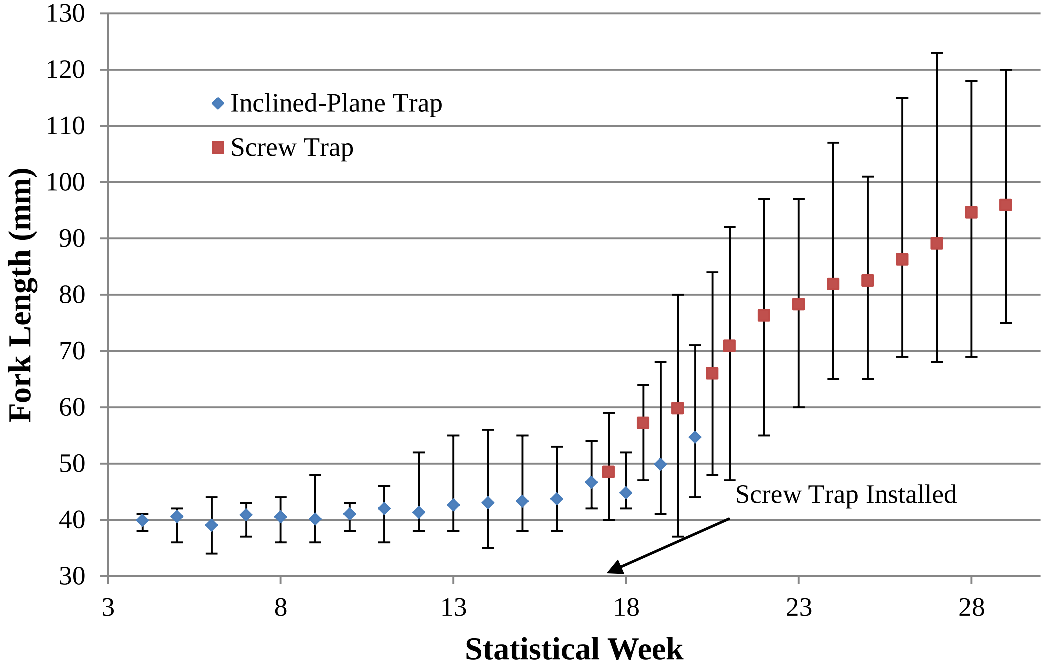

Figure 11. Fork lengths of natural-origin juvenile Chinook sampled from the Cedar River, 2012. Graph shows average, minimum, and maximum lengths by statistical week.

Table 9. Fork lengths (mm) of natural-origin juvenile Chinook measured over twelve years (brood years 2000-2011) at the Cedar River inclined-plane and screw traps.

Brood	Inclined-Plane Trap						Screw Trap					
Year	Avg	SD	Min	Max	n	Catch	Avg	SD	Min	Max	n	Catch
2000	40.3	4.18	34	75	287	687	81.3	14.91	40	121	379	2,872
2001	41.3	7.47	32	92	634	3,781	78.1	21.19	32	131	997	2,592
2002	44.3	10.79	34	90	563	7,186	91.0	13.69	42	128	1,782	3,675
2003	41.9	7.09	34	91	629	2,918	87.4	13.82	42	126	812	6,156
2004	44.7	9.00	36	110	416	4,640	95.7	10.80	42	138	2,260	4,524
2005	45.0	10.70	34	82	496	1,975	82.8	10.92	38	116	701	879
2006	41.8	6.20	34	85	568	2,714	91.7	10.10	45	125	803	878
2007	42.1	5.79	34	95	1,585	21,000	73.6	12.26	37	121	1,153	1,651
2008	44.7	10.20	32	90	1,102	4,561	84.9	13.6	41	116	781	1,093
2009	45.5	10.10	34	89	944	5,084	82.9	11.28	45	127	2,591	3,287
2010	41.5	5.98	30	91	623	2,961	84.3	12.48	40	118	708	832
2011	42.5	4.15	34	71	1,121	9,541	82.2	10.94	37	123	1,861	2,589

Coho

Catch and Estimated Missed Catch

A total catch (actual and estimated missed) in the screw trap was estimated to be 2,912 coho smolts. This included 2,804 natural-origin coho caught in the screw trap between April 18 and July 14 and 108 coho smolts that would have been caught had the trap fished continuously.

Production Estimate

A total of 27 efficiency trials were conducted. Efficiency trials were aggregated into three strata. Capture rates for these strata ranged between 3.4% and 11.34% (Appendix B 4). Total coho production was estimated to be 48,168 ± 9,675 (±95% C.I.) smolts for the period the trap was operating with a coefficient of variation of 10.25% (Table 10, Appendix B 4).

Table 10. Catch and abundance of Cedar River juvenile coho migrants for brood years 1997-2010. Gaps in data for brood years 1998 and 2006 prevented calculation of CV.

Year		Catch		Trapping Dates		Est'd	95% CI		CV
Brood	Trap	Actual	Est'd	Start	End	Production	Low	High	
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	n/a
1999	2001	5,927	335	04/08	07/22	82,462	60,293	104,661	13.70%
2000	2002	3,406	310	04/01	07/22	60,513	50,286	70,740	8.60%
2001	2003	3,763	201	04/10	07/12	74,507	58,947	90,067	10.70%
2002	2004	2,668	140	04/14	07/20	70,044	46,735	93,353	17.00%
2003	2005	2,889	29	04/01	07/28	72,643	42,725	102,561	21.40%
2004	2006	795	0	04/01	07/16	38,023	16,416	59,629	28.90%
2005	2007	482	0	04/01	07/20	33,994	8,291	59,697	40.80%
2006	2008	315	0	04/14	07/19	13,322	3,392	23,372	n/a
2007	2009	5,549	256	04/21	07/18	52,691	45,600	49,781	6.87%
2008	2010	6,321	207	04/22	07/04	83,060	70,049	96,071	7.99%
2009	2011	4,910	20	04/27	07/16	52,458	44,645	60,271	7.60%
2010	2012	2,804	108	04/18	07/14	48,168	38,493	57,843	10.25%

Migration Timing

Migration of coho smolts was already under way when the screw trap began operating. Migration continued to climb and came to two abrupt peaks on May 4 of 3,196 coho and on May 15 of 3,233 (Figure 12). Migration declined thereafter with one additional notable peak on June 4 of 1,711 smolts. Migration during the trapping period was 25%, 50%, and 75% complete by May 4, May 11, and May 15, 2012, respectively. Nearly 80% of the season's migration occurred prior to May 16. Daily migrations dropped sharply following the May 15 peak and averaged 162 coho per day through the remainder of the season.

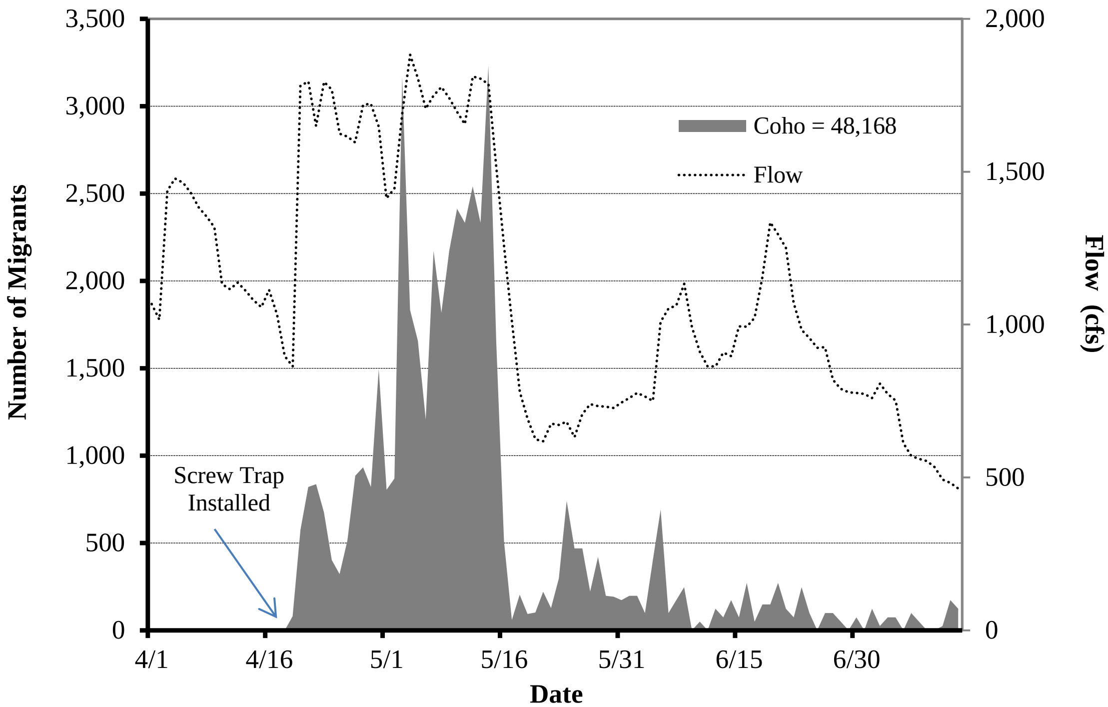

Figure 12. Daily coho migration and daily average flow (USGS Renton gage Station #12119000) at the Cedar River screw trap, 2012.

Size

Average fork length of all measured coho migrants was 107.6-mm FL; weekly averages ranged from 102.2-mm to 110.2-mm FL. Individual migrants ranged from 80-mm to 137-mm FL (Table 11, Figure 13).

Table 11. Fork length (mm) of coho migrants from the Cedar River screw trap in 2012. Data are mean, standard deviation (SD), range, sample size (n), and catch for each statistical week.

Statistical Week			Avg.	SD	Range		n	Catch
Begin	End	No.			Min	Max		
04/16	04/22	17	102.2	7.04	91	120	22	56
04/23	04/29	18	108.0	9.14	84	133	113	242
04/30	05/06	19	107.8	8.94	90	134	122	662
05/07	05/13	20	107.4	9.48	80	137	116	911
05/14	05/20	21	107.4	7.42	91	130	148	551
05/21	05/27	22	109.3	8.90	90	132	121	156
05/28	06/03	23	110.2	8.88	84	130	44	57
06/04	06/10	24	106.3	9.36	90	130	29	53
06/11	06/17	25	102.4	13.97	83	122	9	31
06/18	06/24	26	102.2	9.93	82	118	18	37
06/25	07/01	27	104.0	7.48	89	116	9	17
07/02	07/08	28	105.1	9.04	91	114	7	16
07/09	07/15	29	105.0	3.16	100	108	5	15
Season Totals			107.6	8.90	80	137	763	2,804

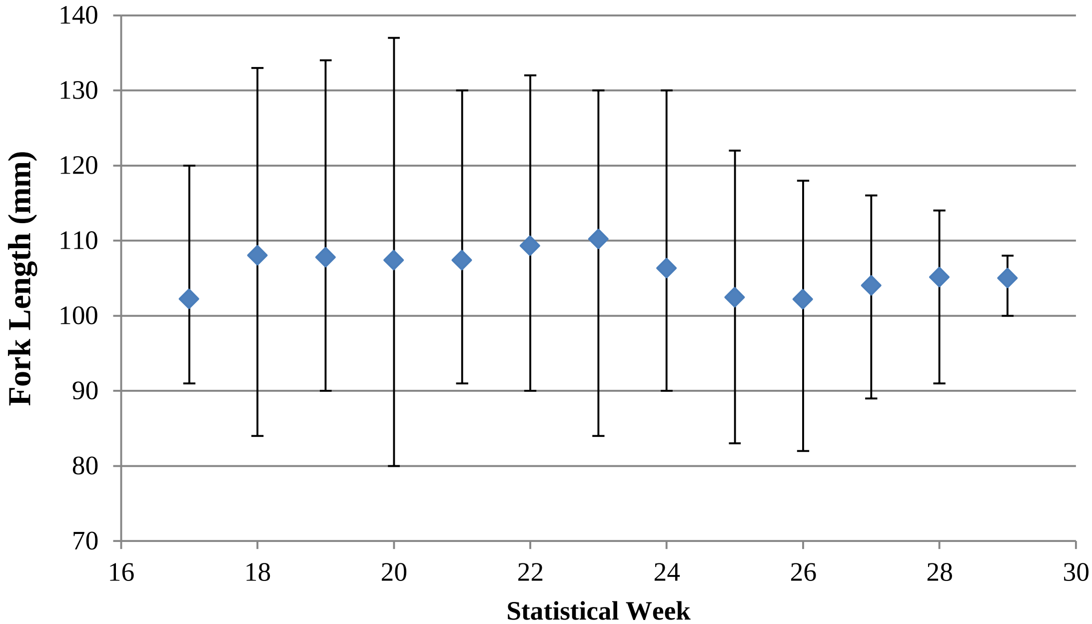

Figure 13. Fork lengths for coho migrants captured in the Cedar River screw trap in 2012. Data are mean, minimum, and maximum lengths.

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). Cutthroat-rainbow hybrids are included and indistinguishable in these numbers. Furthermore, it is difficult to determine whether juvenile *O. mykiss* have adopted the anadromous life form. The juvenile anadromous life history strategy, or "smolt," was assigned to steelhead trout that had a silver coloration upon capture. Those that did not display smolt-like characteristics were assigned as rainbow trout.

A total of 4 steelhead migrants and 103 cutthroat trout were captured in the screw trap. No rainbow trout were caught. Catches were too few to develop migration estimates. *O. mykiss* fork lengths ranged from 196-mm to 210-mm FL and averaged 204.7-mm FL. Cutthroat fork lengths ranged from 103-mm to 237-mm FL, and averaged 155.3-mm FL.

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 from May 10 through July 13, 2012; therefore, only the Chinook parr migrants were represented in the tag groups. 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. Over the season, a total of 1,678 natural-origin Chinook parr were PIT tagged at the Cedar River screw trap (Table 12). This tag group comprised 4.3% of the estimated Chinook parr production from the Cedar River in 2012.

A total of 212 Chinook PIT tags (12.6%) were detected as they moved through the smolt flumes at the Chittenden Locks while exiting Lake Washington. The first Chinook was detected on May 29, 2012 and the last on September 14, 2012. Median migration date of Chinook detected at the Locks was July 9, 2012. Individual travel times averaged 30 days (SD = 10.6). Although first detections of Chinook at the Locks were similar to 2010 and 2011, the last detection date and median detection date was 2 to 4 weeks later (Table 13).The percentage of tagged fish detected at the Locks was also the least of all three years.

Table 12. Natural-origin Chinook parr PIT tagged from the Cedar River screw trap in 2012.

Statistical Week			# Tagged	Length (mm)			Portion of Parr Migration	# Detected @ Locks	% of Tags Detected
Begin	End	No.		Avg	Min	Max			
05/07	05/13	20	26	73.9	65	84	3.63%	5	19.23%
05/14	05/20	21	37	76.4	65	86	2.54%	7	18.92%
05/21	05/27	22	115	78.3	64	97	1.14%	19	16.52%
05/28	06/03	23	105	77.9	65	96	0.80%	19	18.10%
06/04	06/10	24	504	81.8	65	107	0.20%	72	14.29%
06/11	06/17	25	282	82.5	65	101	0.54%	39	13.83%
06/18	06/24	26	266	86.0	69	115	0.40%	33	12.41%
06/25	07/01	27	176	89.2	71	123	0.77%	7	3.98%
07/02	07/08	28	140	94.5	69	118	0.92%	11	7.86%
07/09	07/15	29	27	97.7	75	120	4.56%	1	3.70%
Season Total			**1,678**	**84.0**	**64**	**123**	**4.29%**	**212**	**12.63%**

Table 13. Biological and migration timing data of PIT tagged natural-origin Chinook released from the Cedar River screw trap, tag years 2010 to 2012. 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	2,250	84.2	65	127	6.10%	504	22.40%	29.9	05/24	08/25	06/24
2011	579	87.3	65	118	5.80%	113	19.50%	19.3	05/26	08/27	06/07
2012	1,678	84.0	64	123	4.29%	212	12.63%	30.0	05/29	09/14	07/08

Mortality

One hundred and twenty three sockeye fry and three Chinook fry mortalities occurred while operating the inclined-plane trap.

During screw trap operations, two Chinook parr mortalities occurred due to PIT tagging, and 53 coho mortalities resulted from trapping or holding fish for releases.

Incidental Catch

Incidental catches in the inclined-plane trap included 7 coho fry, 190 coho smolts, 2 chum fry, and 5 cutthroat smolts. Other species caught included three-spine stickleback (*Gasterosteus aculeatus*), unspecified sculpin species (*Cottus* spp.), lamprey (*Lampetra* spp.), and largescale sucker (*Catostomus macrocheilus*).

Other salmonids caught in the screw trap include 10 ad-marked hatchery Chinook parr, 1 sockeye smolt, 19 coho 0+, 2,068 sockeye fry, and 29 trout fry. Other species caught included three-spine stickleback, unspecified sculpin species, large-scale suckers, peamouth (*Mylocheilus caurinus*), speckled dace (*Rhinichthys osculus*), lamprey, goldfish (*Carassius auratus)*, and brown bullhead catfish (*Ameiurus nebulosus*).

Bear Creek Results

Sockeye

Catch and Estimated Missed Catch

An estimated 24,494 sockeye fry would have been caught had the screw trap fished the entire period. From January 24 to July 14, sockeye catch totaled 19,651 sockeye and an additional 4,843 fry were estimated for the 18 nights not fished and 2 nights when the trap was stopped due to heavy debris.

Production Estimate

Sixteen efficiency trials using sockeye fry were conducted during the season and aggregated into eight final strata, with capture rates ranging from 2.4% and 16.9% (Appendix C 1). Catches were low and the first efficiency group was not released until March 1. Efficiency releases continued nearly twice or more weekly until April 18 when catches declined near the end of migration.

A total of 266,899 ± 62,030 (±95% C.I.) sockeye fry were estimated to have migrated from Bear Creek in 2012 (Table 14). Due to low catch at the beginning of the season, there was no pre-trapping catch estimated. As a result of operating a single gear type for the entirety of the sockeye migration (screw trap), it was unnecessary to estimate a migration following the trapping period as done in the past when multiple gear types were used.

Migration Timing

The first sockeye was not caught until after the first week of trapping. Catches were low and migration averaged less than 500 fish per day until February 19. Thereafter, migration continued to average less than 1,000 fish per day until March 22 when migration finally increased to tens of thousands per night. Migration peaked on March 29 with over 47,000 sockeye estimated to have migrated. The migration remained strong until April 17 when it began to taper off to less than 300 fish per night (Figure 14). Migration was 25%, 50%, and 75% completed by March 24, March 28, and April 1, 2012, respectively. Nearly 75% of the sockeye migration occurred between March 13 and March 31.

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2011 brood of Bear Creek sockeye was estimated to be 17.7% (Table 15). Survival was based on 266,899 fry migrants and a PED of 1,509,690 million eggs. PED was estimated based on 455 females in 2011 (A. Bosworth, Washington Department of Fish and Wildlife, personal communication) and an average fecundity of 3,318 eggs per female (Cuthbertson 2012).

Table 14. Abundance of sockeye fry migrants from Bear Creek in 2012. Table includes abundance of fry migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*).

Period	Dates	Total Estimated Catch	Fry Abundance	*CV*	95% C.I. Low	95% C.I. High
Screw Trap	Jan 24-July 14	24,494	266,899	11.9%	204,870	328,929

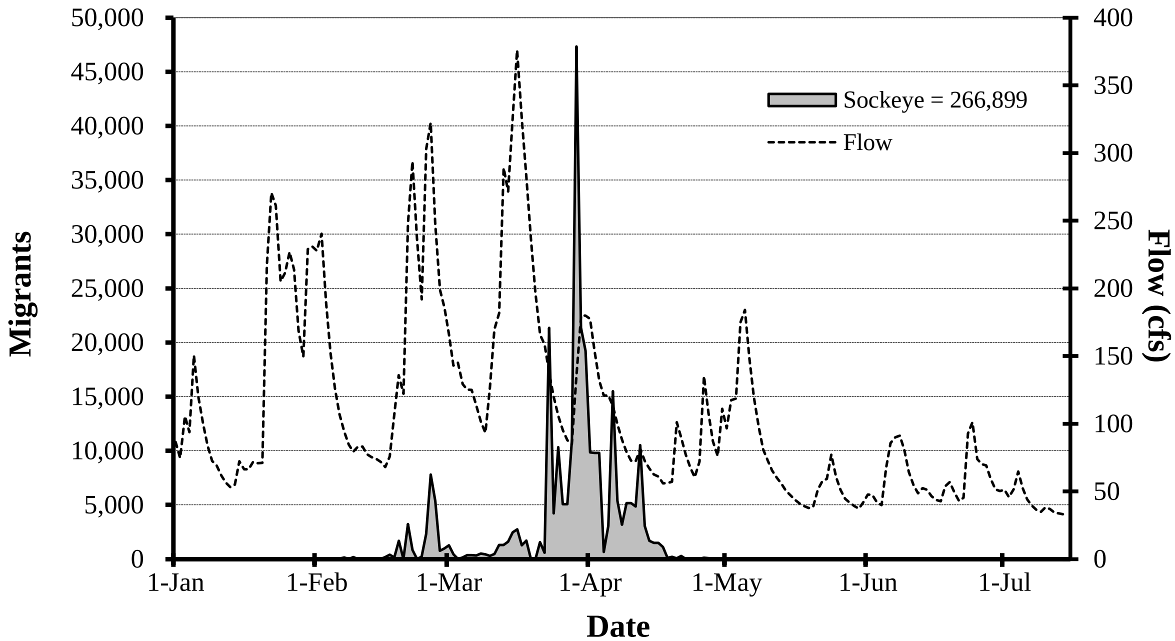

Figure 14. Estimated daily migration of sockeye fry from Bear Creek and daily average flow measured by the King County gage 02a at Union Hill Road in 2012 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Table 15. Egg-to-migrant survival of Bear Creek sockeye by brood year. Potential egg deposition (PED) was based on fecundity of sockeye brood stock 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

Chinook

Catch and Estimated Missed Catch

A total of 6,229 Chinook should have been caught had the screw trap operated continuously. A total of 6,091 Chinook were caught throughout the season and an estimated 138 Chinook were missed during the 8 outages periods when debris stopped the trap or 37 periods when the trap was not fished due to lack of staffing.

Production Estimate

For the period between January 24 and May 4, sockeye trap efficiencies were used to estimate Chinook fry abundance because catches were too low to form efficiency trials. From May 5 forward, a total of 30 efficiency trials were conducted with Chinook subyearlings. Trials were aggregated into fourteen strata; capture rates of these strata ranged between 2.4% and 55.0%. Chinook migration during screw trap operation was estimated to be 22,197 ± 2,304 (±95% C.I.) (Table 16, Appendix C3).

Table 16. Abundance of natural-origin juvenile Chinook emigrating from Bear Creek in 2012. Table includes abundance of juvenile migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*).

Gear	Period	Estimated		95% C.I.		*CV*
		Catch	Abundance	Low	High	
Screw Trap	January 24 - July 14	6,229	22,197	19,893	24,500	5.29%

Table 17. Abundance, productivity (juveniles per female), and egg-to-migrant survival 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 2011 brood years.

Brood	Juvenile Abundance			% Abundance		Est.	PED	Juveniles/Female			Survival		
Year	Fry	Parr	Total	Fry	Parr	Females		Fry	Parr	Total	Fry	Parr	Total
2000	419	10,087	10,506	4.0%	96.0%	133	598,500	3	76	79	0.1%	1.7%	1.8%
2001	5,427	15,891	21,318	25.5%	74.5%	138	621,000	39	115	154	0.9%	2.6%	3.4%
2002	645	16,636	17,281	3.7%	96.3%	127	571,500	5	131	136	0.1%	2.9%	3.0%
2003	2,089	21,558	23,647	8.8%	91.2%	147	661,500	14	147	161	0.3%	3.3%	3.6%
2004	1,178	8,092	9,270	12.7%	87.3%	121	544,500	10	67	77	0.2%	1.5%	1.7%
2005	5,764	16,598	22,362	25.8%	74.2%	122	549,000	47	136	183	1.0%	3.0%	4.1%
2006	3,452	13,077	16,529	20.9%	79.1%	131	589,500	26	100	126	0.6%	2.2%	2.8%
2007	1,163	11,543	12,706	9.2%	90.8%	89	400,500	4	143	147	0.3%	2.9%	3.2%
2008	14,243	50,959	65,202	21.8%	78.2%	132	594,000	108	386	494	2.4%	8.6%	11.0%
2009	1,530	7,655	9,185	16.7%	83.3%	48	216,000	32	159	191	0.7%	3.5%	4.3%
2010	901	16,862	17,763	5.1%	94.9%	60	270,000	15	281	296	0.6%	6.1%	6.7%
2011	4,000	18,197	22,197	18.0%	82.0%	55	247,500	73	331	404	1.6%	7.4%	9.0%

Migration Timing

Chinook migration was bi-modal with 18.0% of the migration emigrating as fry and 82.0% emigrating as parr (Figure 15, Table 17). Peak migration occurred on May 24 with an estimated 1,688 Chinook passing the trap in one day. Migration was 25%, 50%, and 75% complete by April 27, May 15, and May 30, respectively. The Chinook fry migration was small in magnitude and had one prominent peak on March 27 of 685 Chinook. Chinook parr daily migrations were larger than fry migrations with over 50% of the Chinook migration occurring between May 13 and June 13. One prominent peak occurred on May 24 of 1,688 Chinook parr.

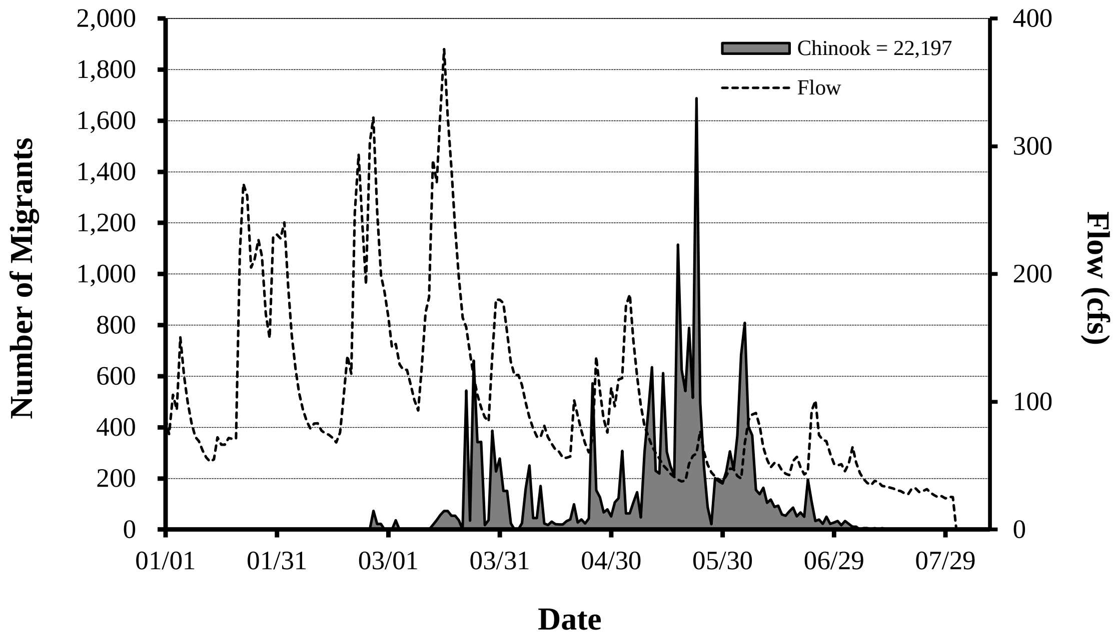

Figure 15. Daily migration of sub yearling Chinook and daily average flow from Bear Creek, 2012. Daily mean flows were measured at King County gage 02a at Union Hill Road in 2012 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2011 brood of Bear Creek Chinook was estimated to be 9.0% (Table 17). Survival was based on 22,197 sub yearling migrants and a PED of 247,500 eggs. The PED was estimated based on 55 female spawners (A. Bosworth, Washington Department of Fish and Wildlife, personal communication) and an assumed fecundity of 4,500 eggs per female.

Size

From early February through mid- April, weekly averages of Chinook fry ranged from 38-mm FL to 55.4-mm FL (Table 18). By late April Chinook grew to a weekly average 63.1-mm FL and continued to grow to average 82.1-mm FL by late June (Table 18, Figure 16). Although average FL increased quickly, some Chinook migrants were still measuring less than 65-mm FL in mid-June. The average length of fry was the second largest yet parr length in 2012 was the third smallest observed in the previous eleven years (Table 19).

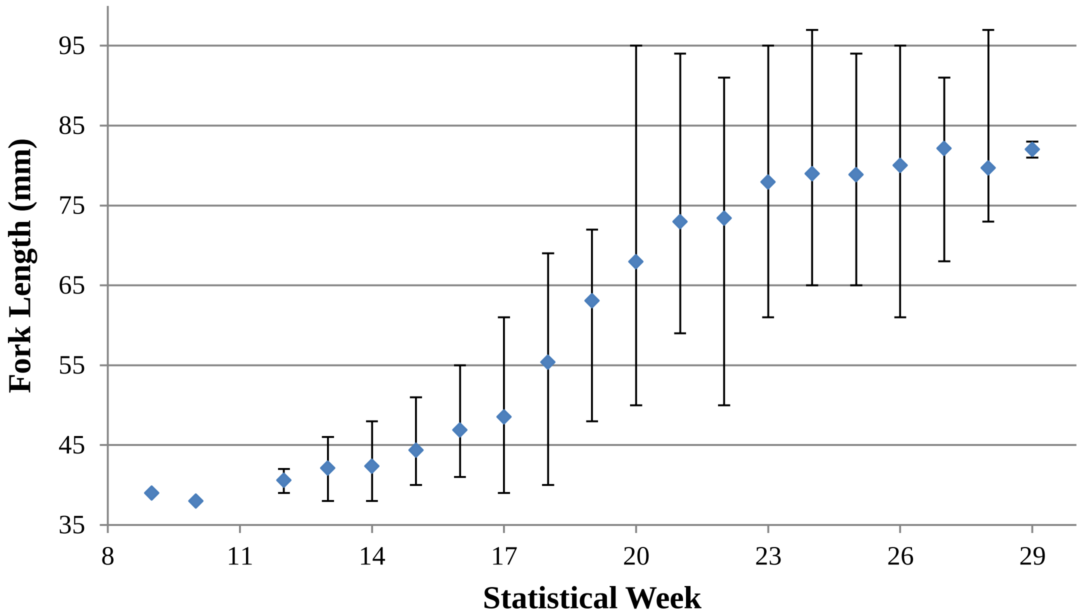

Figure 16. Fork lengths of sub yearling Chinook sampled from Bear Creek in 2012. Data are mean, minimum, and maximum lengths for each statistical week.

Table 18. Fork lengths of juvenile Chinook and coho captured in the Bear Creek screw trap in 2012. Data are mean fork lengths (mm), standard deviation (SD), ranges, sample sizes (n), and catch.

Statistical Week			Chinook						Coho					
Begin	End	No.	Avg.	SD	Range Min	Range Max	n	Catch	Avg.	SD	Range Min	Range Max	n	Catch
01/23	01/29	5												
01/30	02/05	6												
02/06	02/12	7												
02/13	02/19	8												
02/20	02/26	9	39.0	0.00	39	39	2	2						4
02/27	03/04	10	38.0	n/a	38	38	1	1						
03/05	03/11	11												
03/12	03/18	12	40.6	1.14	39	42	5	5						
03/19	03/25	13	42.1	2.25	38	46	39	58	101.3	2.87	98	105	4	6
03/26	04/01	14	42.4	2.09	38	48	70	130	105.2	7.82	99	116	5	12
04/02	04/08	15	44.4	3.72	40	51	22	22	114.6	11.13	101	134	13	15
04/09	04/15	16	46.9	3.68	41	55	27	33	106.4	7.21	96	121	24	24
04/16	04/22	17	48.5	5.29	39	61	45	55	116.0	10.42	96	134	61	132
04/23	04/29	18	55.4	5.77	40	69	98	260	111.5	11.22	85	142	140	670
04/30	05/06	19	63.1	5.85	48	72	80	201	112.8	11.55	85	152	149	1,102
05/07	05/13	20	67.4	7.61	50	95	227	558	108.8	9.86	89	154	201	1,111
05/14	05/20	21	72.8	5.41	59	94	563	1,512	107.5	8.63	88	131	178	608
05/21	05/27	22	73.3	5.67	50	91	875	1,821	109.5	11.54	90	163	144	201
05/28	06/03	23	78.3	6.20	61	95	176	324	109.9	9.18	91	132	28	32
06/04	06/10	24	78.9	6.37	65	96	428	698	106.5	5.94	98	116	15	17
06/11	06/17	25	79.0	5.40	68	94	123	212	110.0	9.85	95	134	11	13
06/18	06/24	26	80.3	5.86	61	95	95	142						2
06/25	07/01	27	82.1	6.17	68	91	22	36	99.0	2.83	97	101	2	2
07/02	07/08	28	79.7	6.24	73	97	13	18						
07/09	07/15	29	82.0	1.41	81	83	2	3						
Season Totals			**71.5**	**10.86**	**38**	**97**	**2,913**	**6,091**	**110.1**	**10.56**	**85**	**163**	**975**	**3,951**

Table 19. Fork lengths of natural-origin Chinook fry and parr measured over twelve years (brood years 2000-2011) at the Bear Creek juvenile migrant traps. Fry are assumed to have migrated between February 1 and April 8. Parr are assumed to have migrated between April 9 and June 30.

Brood	Fry						Parr					
Year	Avg	SD	Min	Max	n	Catch	Avg	SD	Min	Max	n	Catch
2000	41.1	1.97	34	47	39	63	73.4	11.60	38	105	622	5,131
2001	38.9	3.80	34	52	70	278	81.5	10.83	42	110	885	6,880
2002	40.9	3.20	34	54	78	86	75.9	11.20	35	106	709	8,182
2003	41.6	4.99	38	60	70	102	73.6	11.52	40	107	874	10,613
2004	40.6	2.29	38	47	46	102	78.7	7.06	40	102	1,766	4,612
2005	41.4	4.10	37	64	117	264	76.0	8.82	44	100	907	8,180
2006	41.7	3.30	38	55	75	106	79.8	6.80	40	118	2,978	5,320
2007	41.0	2.01	36	46	52	57	71.1	8.95	37	116	1,748	2,774
2008	43.4	4.57	32	61	227	1,014	67.3	11.85	38	99	921	8,613
2009	41.2	3.59	34	52	51	54	75.3	8.94	48	99	952	1,267
2010	42.3	3.27	38	54	48	49	79.3	7.39	42	107	2,714	4,434
2011	42.5	2.60	38	51	139	218	72.9	8.91	39	97	2,774	5,873

Coho

Catch

A total of 3,951 coho smolts were caught in the screw trap over the 80-day trapping season. If the trap had fished without interruptions, a total of 3,989 coho are estimated to have been caught during the season.

Production Estimate

Abundance of coho smolts was based on total catch and 35 efficiency trials, which were aggregated into three strata. Capture rates of efficiency strata ranged from 20.4% to 29.9%. Coho production was estimated to be 16,059 ± 1,325 (±95% C.I.) smolts (Figure 17, Appendix C 3).

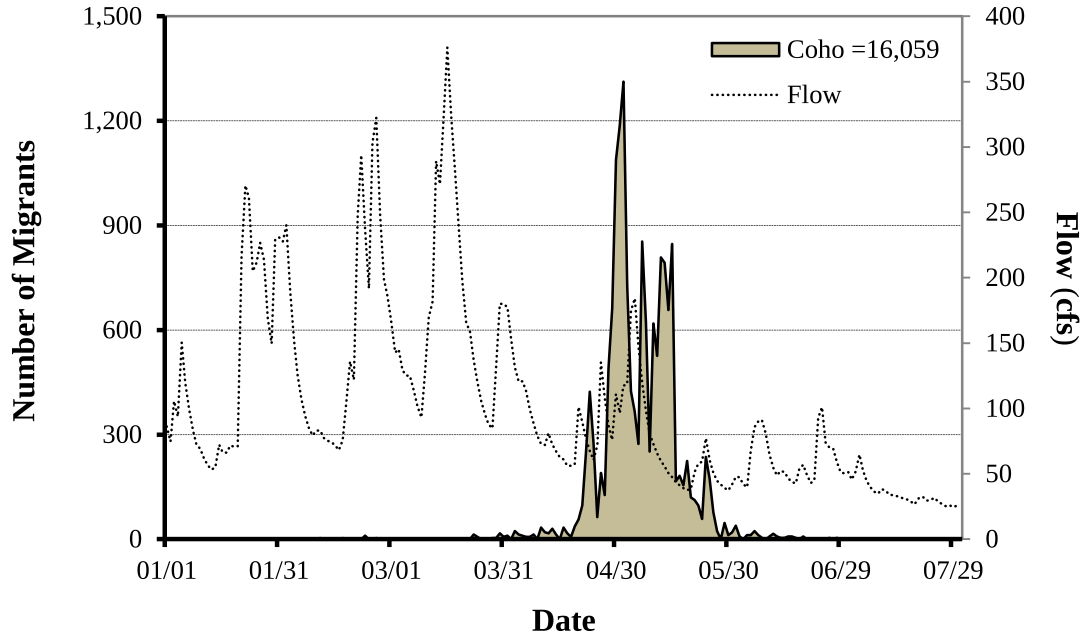

Figure 17. Daily migration of coho smolts in Bear Creek from January 24 to July 14, 2012. Graph also shows mean daily flows during this period. Flow data were measured at King County gage 02a at Union Hill Road in 2012 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Table 20. Catch and abundance of Bear Creek juvenile coho migrants, brood years 1997-2010.

Year		Catch		Trapping Dates		Est'd	95% CI		CV
Brood	Trap	Actual	Est'd	Start	End	Production	Low	High	
1997	1999	14,896	38	02/23	07/13	62,970	50,645	75,295	10.00%
1998	2000	7,737	0	01/24	07/13	28,142	26,133	30,151	3.64%
1999	2001	6,617	0	04/10	07/12	21,665	18,947	24,383	6.40%
2000	2002	17,366	15	04/12	07/15	58,212	52,791	63,633	4.80%
2001	2003	15,048	0	04/09	07/08	48,561	42,304	54,818	6.60%
2002	2004	9,111	0	04/05	06/26	21,085	18,641	23,529	5.90%
2003	2005	16,191	0	04/08	07/14	43,725	43,638	43,813	0.10%
2004	2006	11,439	0	04/08	06/29	46,987	44658	49316	9.70%
2005	2007	2,802	0	04/15	07/11	25,143	20,220	30,066	9.90%
2006	2008	1,572	0	04/16	07/09	12,208	9,807	14,609	9.90%
2007	2009	3,822	104	04/22	06/30	33,395	26,840	39,951	10.02%
2008	2010	1,895	59	04/22	07/04	13,100	11,427	14,773	6.52%
2009	2011	4,628	243	04/27	07/16	34,513	25,700	43,326	13.03%
2010	2012	3,951	38	01/25	07/14	16,059	14,734	17,384	4.21%

Migration Timing

Coho migration occurred in a very contracted period of time with 25%, 50%, and 75% of the migration completed by April 30, May 5, and May 12, 2012, respectively (Figure 17). Over 70%

of the migration moved between a two week period, April 30 and May 14. Migration peaked on May 2 with 1,312 coho smolts estimated to have migrated passed the trap.

Size

Over the trapping period, fork lengths ranged from 85-mm to 166-mm FL and averaged 110.1-mm FL (Figure 18). Weekly mean lengths ranged from 99.0-mm to 116-mm FL during trap operation (Table 18). Similar to Bear Creek Chinook, average coho length was near the second smallest observed in previous years of study (Table 21).

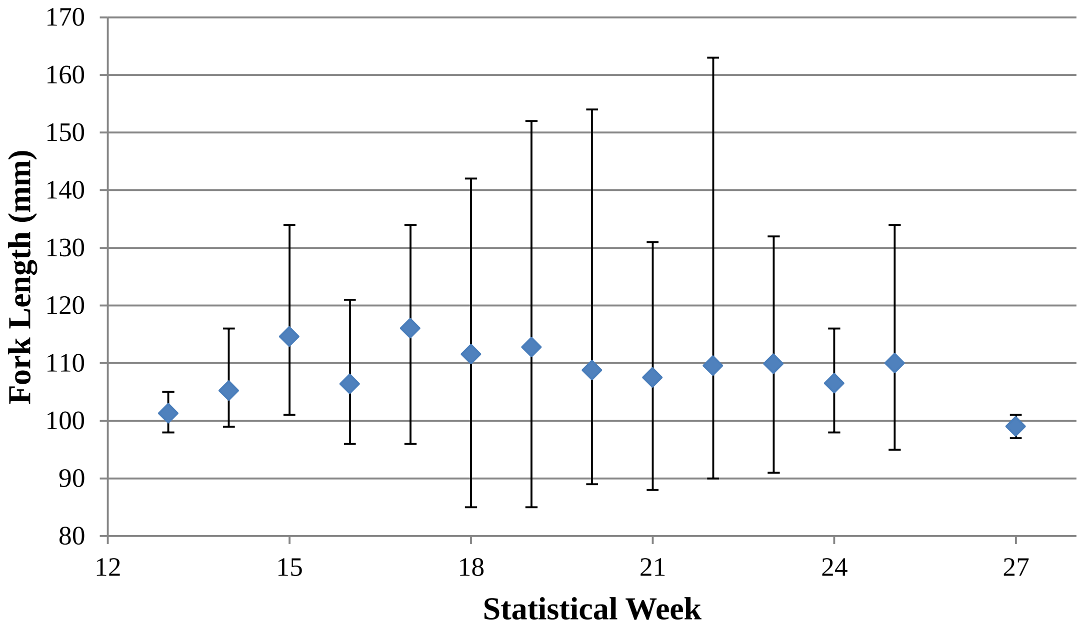

Figure 18. Fork lengths of migrating coho smolts caught at the Bear Creek screw trap in 2012. Data are statistical week mean, minimum, and maximum lengths.

Table 21. Fork lengths of natural-origin coho smolts in Bear Creek over migration years (2002-2012).

Migration	Screw Trap					
Year	Avg	SD	Min	Max	n	Catch
2002	119.9	13.80	75	209	461	17,366
2003	116.3	12.40	86	191	2,425	15,048
2004	111.9	14.40	80	198	610	9,111
2005	110.9	12.10	81	220	1,752	16,191
2006	113.8	13.98	80	184	857	11,439
2007	117.3	11.30	90	203	615	2,802
2008	114.3	13.03	89	168	582	1,573
2009	110.0	12.67	70	162	507	3,822
2010	113.3	12.86	83	163	853	1,921
2011	114.5	10.61	80	161	1,793	4,628
2012	110.1	10.56	85	163	975	3,951

Trout

The identification of trout in Bear Creek poses the same difficulties discussed earlier in the Cedar River section. Based on available visual identification, trout are referred to as cutthroat trout or steelhead/rainbow migrants. 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 cutthroat production.

Catch and Production Estimate

No steelhead were captured during the entire 2012 trapping season in Bear Creek.

A total of 1,116 cutthroat trout were captured in the screw trap in 2012. Results from Marshall et al. (2006), suggest that some Bear Creek fish identified by phenotype to be cutthroat trout may be rainbow-cutthroat hybrids. Movement was already occurring when trapping began January 24. Movement increased quickly and experienced one moderate peak of 355 cutthroat on February 11 and 12. Movement slowed to below 200 migrants per day until late April when migration increased and peaked twice with over 500 cutthroat on two separate days (April 29 and May 14).

Eighteen different efficiency trials of cutthroat were conducted over the season. Trials were aggregated into two strata with a capture rate of 6.7% and 30.8%. Migration was estimated to be 16,284 ± 6,822 (±95% C.I.) cutthroat, with a coefficient of variation of 21.4% (Figure 19, Appendix C 4) for the trapping period. During the 2000 season, the last time the screw trap operated from January through June on Bear Creek, 35% of the cutthroat migration occurred prior to April. In 2012, nearly 48% of the total migration moved passed the trap by early April.

Cutthroat trout fork lengths averaged 147.4-mm FL and ranged between 64-mm and 247-mm FL throughout the trapping season (Table 22). Average fork lengths showed no consistent trend across weeks.

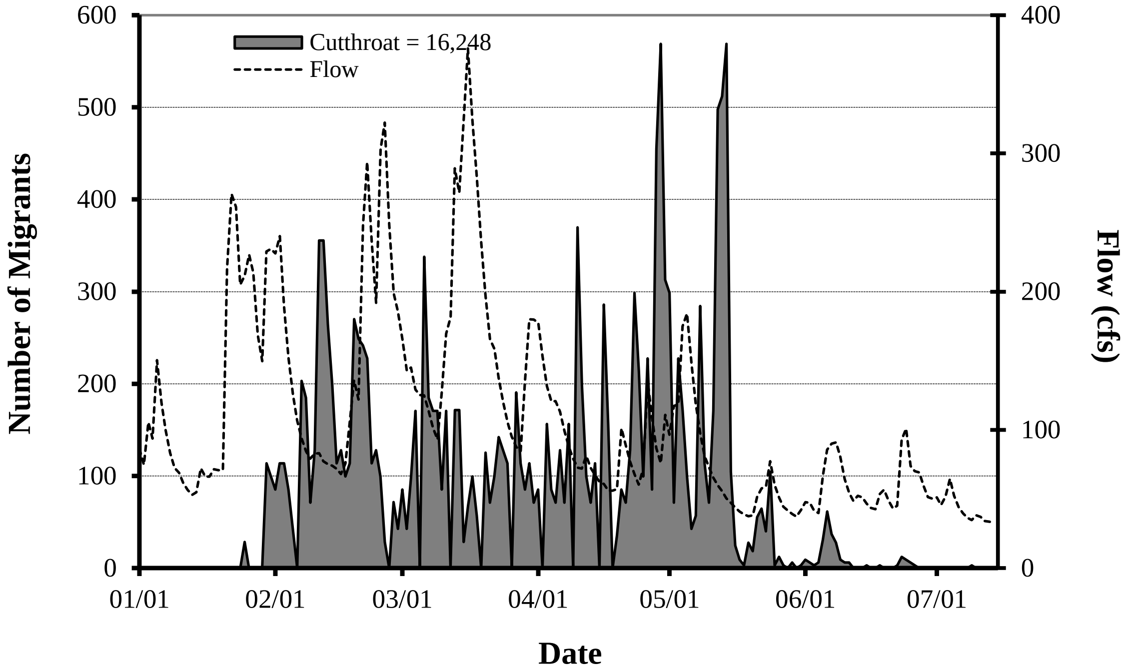

Figure 19. Daily migration of cutthroat trout passing the Bear Creek screw trap in 2012. Flow data were measured at the King County gaging station at Union Hill Road.

Table 22. Cutthroat fork length (mm), standard deviation (SD), range, sample size (n), and catch by statistical week in the Bear Creek screw trap, 2012.

Statistical Week			**Avg.**	**SD**	**Range**		**n**	**Catch**
Begin	**End**	**No.**			**Min**	**Max**		
01/23	01/29	5	150.0	14.14	140	160	2	2
01/30	02/05	6	144.2	26.86	84	211	46	46
02/06	02/12	7	126.3	27.53	64	188	75	77
02/13	02/19	8	125.9	26.08	82	195	61	65
02/20	02/26	9	130.8	29.83	91	214	35	35
02/27	03/04	10	143.6	29.05	91	191	31	31
03/05	03/11	11	143.9	28.34	91	201	55	55
03/12	03/18	12	159.4	31.94	91	203	16	16
03/19	03/25	13	157.8	29.79	98	214	39	39
03/26	04/01	14	145.8	31.82	91	208	33	33
04/02	04/08	15	154.2	30.37	107	221	27	36
04/09	04/15	16	146.1	37.56	96	211	31	34
04/16	04/22	17	165.4	31.81	104	216	29	31
04/23	04/29	18	168.9	24.96	110	232	75	137
04/30	05/06	19	159.2	26.25	108	247	60	86
05/07	05/13	20	158.6	23.79	96	210	76	120
05/14	05/20	21	147.9	13.90	123	189	60	101
05/21	05/27	22	142.8	17.41	104	195	73	92
05/28	06/03	23	138.6	5.19	132	145	7	9
06/04	06/10	24	145.7	17.63	108	192	46	58
06/11	06/17	25	145.3	9.45	138	156	3	3
06/18	06/24	26	140.5	18.41	118	163	4	6
06/25	07/01	27	160.3	42.19	134	209	3	3
07/02	07/08	28	n/a					
07/09	07/15	29	n/a					1
		Season Totals	**147.4**	**28.73**	**64**	**247**	**887**	**1,116**

PIT Tagging

As part of an ongoing multi-agency monitoring of Chinook migrating from the Lake Washington system, Chinook in Bear Creek were PIT tagged and released in 2012. Tagging began on May 8 and occurred two to three times a week through July 5. Fish were often held overnight to increase the number tagged per day. Over the season, 2,724 natural-origin Chinook were PIT tagged. A total of 314 Bear Creek PIT tagged Chinook (11.53%) were detected moving through the smolt flumes at the Chittenden Locks (Table 23). This tag group comprised 12.2% of the estimated Chinook parr production. The first fish was detected on May 22 and the last on July 15, 2012. Median migration date of fish detected at the Locks was June 16, 2012. Individual travel times averaged 31.1 days (SD = 8.8). Although more Chinook were PIT tagged at Bear Creek than previous years, the proportion of tagged Chinook detected at the Locks was the lowest of all years. Chinook average size was also the smallest.

Table 23. Natural-origin Chinook parr PIT tagged and released from Bear Creek screw trap in 2012.

Statistical Week			# Tagged	Length (mm)			Portion of Parr Migration	# Detected @ Locks	% of Tags Detected
Begin	End	No.		Avg	Min	Max			
05/07	05/13	20	220	71.8	65	95	11.4%	38	17.27%
05/14	05/20	21	623	73.1	62	94	18.7%	121	19.42%
05/21	05/27	22	964	73.6	63	91	22.1%	100	10.37%
05/28	06/03	23	159	78.3	65	92	11.7%	15	9.43%
06/04	06/10	24	486	78.9	65	96	16.6%	36	7.41%
06/11	06/17	25	155	78.8	65	91	22.8%	5	3.23%
06/18	06/24	26	111	80.2	72	94	17.6%	2	1.80%
06/25	07/01	27	4	82.0	74	88	1.8%		
07/02	07/08	28	2	90.5	84	97	2.0%		
Season Total			**2,724**	**75.2**	**62**	**97**	**12.2%**	**317**	**11.64%**

Table 24. Biological and migration timing data of PIT tagged natural-origin Chinook released from the Bear Creek screw trap, tag years 2010 to 2012. 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	7.80%	103	17.50%	26.1	06/06	07/07	06/23
2011	2,316	79.9	65	102	26.30%	336	14.50%	15.1	05/23	07/29	06/05
2012	2,724	75.2	62	97	12.2%	317	11.53%	31.3	05/22	08/13	06/21

Mortality

Six Chinook parr mortalities occurred in the screw trap as a result of heavy debris in the live box. An additional five Chinook mortalities resulted from PIT tagging.

Incidental Species

In addition to target species, the screw trap captured 8 trout fry, 2 hatchery trout plants from Cottage Lake and 18 cutthroat adults. Other species caught included lamprey (*Lampetra* spp.), pumpkinseed (*Lepomis gibbosus)*, 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*), and brown bullhead catfish (*Ameriurus nebulosus*).

Discussion

The 2012 out-migration season provided an opportunity to continue to validate assumptions associated with mark recapture population estimates of juvenile salmon in Cedar River and Bear Creek. Although catches of some species at either location limited repeated testing, they did provide insight relative to previous years. Cedar River sockeye and Chinook both experienced extremely high survival from egg deposition to migration, 37.6% and 61.8% respectively. Cedar River Chinook abundance was also the largest estimated since trapping began. These larger catches of Chinook also provided an opportunity to continue evaluation of the use of sockeye as surrogates for estimating Chinook inclined plane trap efficiencies. During the 2012 out-migration, the Cedar River inclined plane trap fished through ten hatchery sockeye releases conducted above the trap, allowing for further evaluation of hatchery abundance and survival estimation methods. This season was also a trial year to assess a new method of estimating hatchery sockeye abundance and survival from releases upstream of the Cedar River trap using calcein dye to identify hatchery sockeye in trap catches.

In 2012 Bear Creek sockeye and Chinook experienced conditions leading to relatively good survival as well. Bear Creek juvenile salmon production was assessed via a screw trap for the entire duration of the migration, a change from previous years. This changed provided an opportunity to increase fishing time and confidence in estimates by capturing the full extent of the sockeye, coho, and cutthroat migrations, as well as an opportunity to assess predation of sockeye in Bear Creek.

Bear Creek Screw Trap

From the 1999 to 2011, the evaluation of juvenile salmon migrants in Bear Creek was assessed using an inclined-plane trap to evaluate fry movement from January to mid-April and a screw trap that replaced the inclined-plane trap for the remainder of the season to assess the larger migrant component. During the 2012 out-migration, a screw trap was operated for the entire out-migration period, from January to July, in an effort to provide a more complete assessment of the sockeye and coho migration, and to increase confidence in abundance estimates by increasing fishing time. In addition, predation of sockeye was also examined and the cutthroat migration was fully assessed providing an opportunity to reevaluate the assumption that 35% of the cutthroat migration occurred prior to the installation of the screw trap.

Operating one gear type throughout the entire juvenile salmon out-migration increases the precision of abundance, survival and timing estimates. In prior years, once the screw trap was installed it was not calibrated for sockeye, and the remaining sockeye migration was estimated using linear regression through the end of April. In 2012, total migration that occurred following April 15 was estimated to be 6,923, only 2.6% of the total migration. The last sockeye was captured on June 12, notably later than the assumed migration end of April 30. Applying previous assumptions about the sockeye migration pattern, total sockeye, estimated using linear extrapolation, between April 15 and April 30 is 45,663 sockeye, considerably more than the actual sockeye migration estimated using actual catch for the same time period. Because an inclined-plane trap is not efficient at capturing and retaining coho migrants, it was difficult to assess the true beginning of the coho migration until the screw trap was installed. In 2012 the first coho was captured on February 11, with only 266 coho estimated to have migrated prior to April 15. Linear extrapolation was previously used to estimate coho missed prior to screw trap operation and would have estimated only 170 coho to have migrated prior to April 15. A greater number of coho moved prior to the assumed migration start than would have been expected by using the assumed migration pattern. Prior to 2012, 35% of the cutthroat migration was assumed to have migrated prior to the installation of the screw trap (assumed April 15). However in 2012, nearly 48% of the cutthroat movement occurred prior to April 15. Operating a screw trap for the entire season has shown that assumptions about migration patterns would overestimate the sockeye migration, and underestimate the coho and cutthroat migrations in 2012. A screw trap more accurately reflects the seasonal fluctuations in migration timing and abundance during periods when assumed migration patterns were applied.

In addition to increasing confidence in abundance estimates through more fully evaluating the sockeye and coho migrations, precision was also improved by increasing the number of night and day periods fished resulting from the operation of a less labor-intensive screw trap. Inclined-plane traps require extensive labor with continual monitoring and two-hour checks to remove fish and debris from the live box. During inclined-plane trapping efforts, day periods were fished no more than twice a month and only four night periods per week were fished. The remaining unfished time was estimated, increasing variance and reducing confidence in estimates. The screw trap is less demanding of staff time which allows for trapping more day and night periods. During 2012, fishing time was increased to include five night periods and six day periods per week, estimating only two night periods and one day period, and decreasing the uncertainty associated with day movement of salmonids and in nightly variations of migration patterns of all species. This change has decreased variance around estimates and increased confidence in abundance estimates.

Although screw traps are used on most other systems in the Puget Sound to evaluate entire out-migration periods (January through July) of all salmon species, an inclined plane trap was historically used in Bear Creek to reduce trout predation of sockeye fry that is thought to occur at a higher rate in the live box due to greater catches of trout compared to other systems. Nearly all juvenile salmon traps have some degree of predation of fry by larger fish; however total predation has not been documented due to difficulties determining the origin and timing of consumption of stomach contents of predators captured in the trap. To assess the potential impacts on sockeye and Chinook fry with changing gear types, we gather stomach content information on predators captured in the screw trap. Gastric lavage was conducted on predator species which were identified as any species that was larger than a fry except for lamprey due to their anatomy which makes it difficult to lavage. Interrogation was conducted between January 24 and April 14 on all predators captured in the trap. Fork lengths of all predators were recorded and stomach contents were best identified as salmon fry, insects, or worms. If contents were identified as a salmon fry, species was determined based on size and any visible markings. It was also noted if a fry appeared to be brown in color, indicating it may have been a Bismarck Brown marked fish used for efficiency trials. Due to the difficulty of identifying whether prey were consumed inside the trap live box or prior to capture, this information simply reflects predation of sockeye fry by predators captured in the trap, not specifically predation that occurs in the live box.

A total of 519 predator stomachs were lavaged from January 24 to April 14. Species that were lavaged included cutthroat, sculpin, coho parr/smolts, rainbow trout and pumpkinseed. Stomach contents included worms, small lamprey, insects, salmon fry, and sculpin. Total sockeye extracted from predator stomachs (1,681 sockeye) constituted 8.5% of the total sockeye catch for the season. During the period lavage was conducted, only 7 Chinook were identified in stomach contents out of a total trap catch of 251 Chinook. Cutthroat interrogated ranged in size from 71-mm to 380-mm FL. Cutthroat had the highest predation rate of all species, 3.6 sockeye per cutthroat. Sculpin had the second highest predation rate and nearly half that of cutthroat, with a rate of 1.9 sockeye per sculpin. Sculpin sampled ranged in size from 48-mm to 198-mm total length.

There does not appear to be any correlation between predator fork length and predation rate (R^2=0.05). Water temperature and timing appear to have some influence on sockeye fry consumption by predators. As water temperature increases and as migration proceeds, predation rates of sockeye appear to increase (R^2 = 0.20 and R^2 = 0.40, respectively) (Figure 20, Figure 21).

Although both water temperature and timing appear to have weak correlations with predation rates, it is unclear if they are drivers of predation or simply correlated with predation due to the onset of spring which typically brings warmer water temperatures which drives sockeye emergence. Although initial impressions pointed to temperature and temporal influences driving some component of predation, it appears that possibly the availability of sockeye for consumption is the main driver of predation rates, with some evidence for predator satiation provided by the asymptotic relationship (Figure 22).

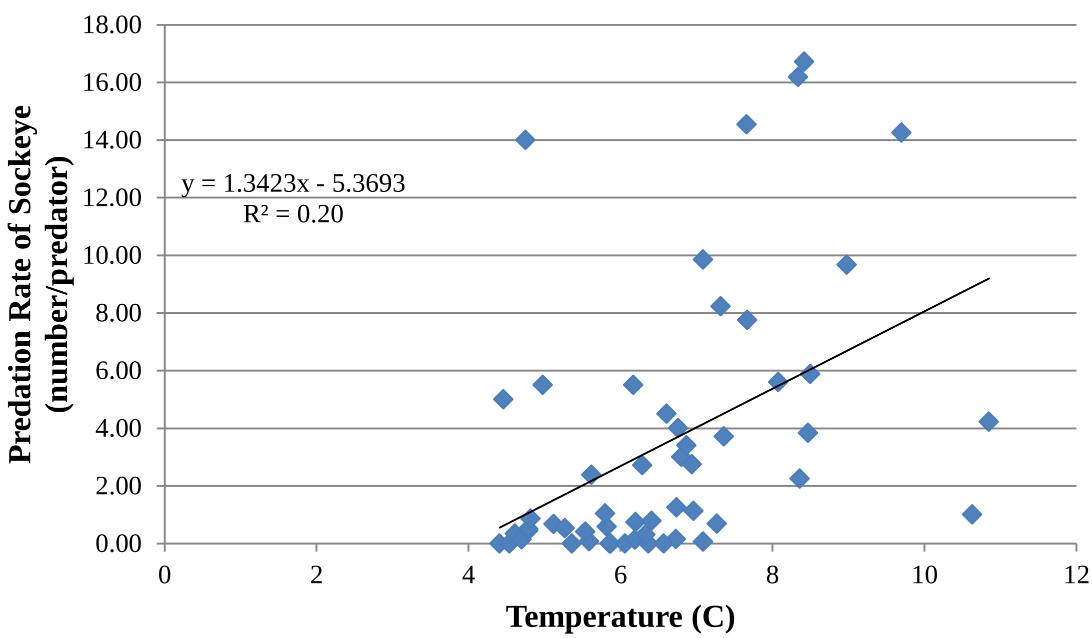

Figure 20. Predation rates of sockeye at stream temperatures (Celsius) in Bear Creek during the 2012 sockeye migration. Predators examined include cutthroat trout and sculpin captured in the Bear Creek Screw Trap.

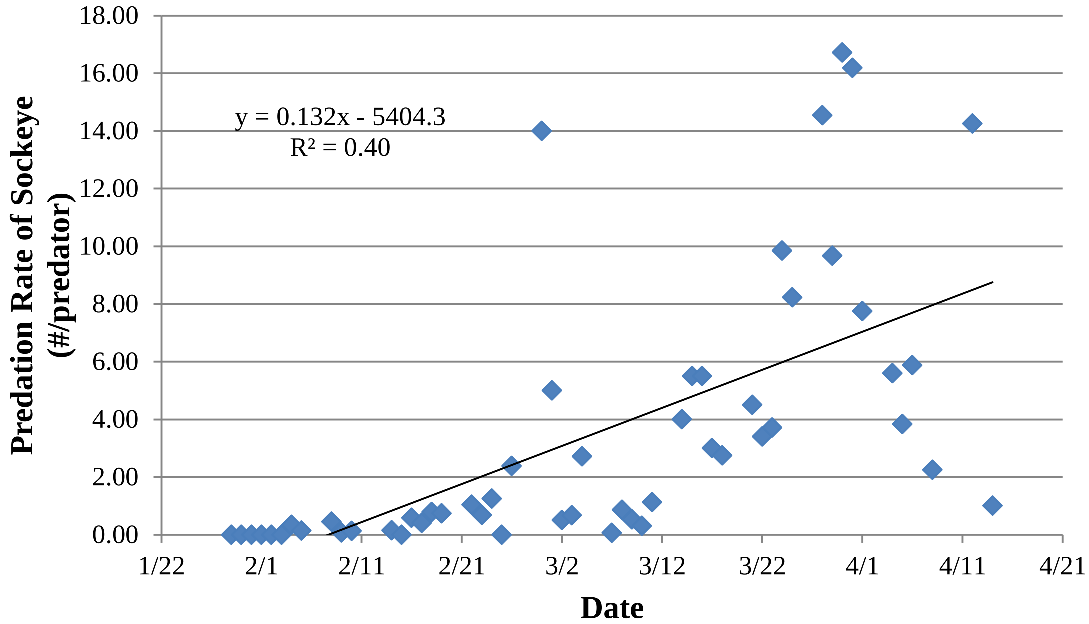

Figure 21. Predation rates of sockeye over the 2012 sockeye migration period. Predators include cutthroat and rainbow trout, sculpin, and coho parr captured in the Bear Creek screw trap.

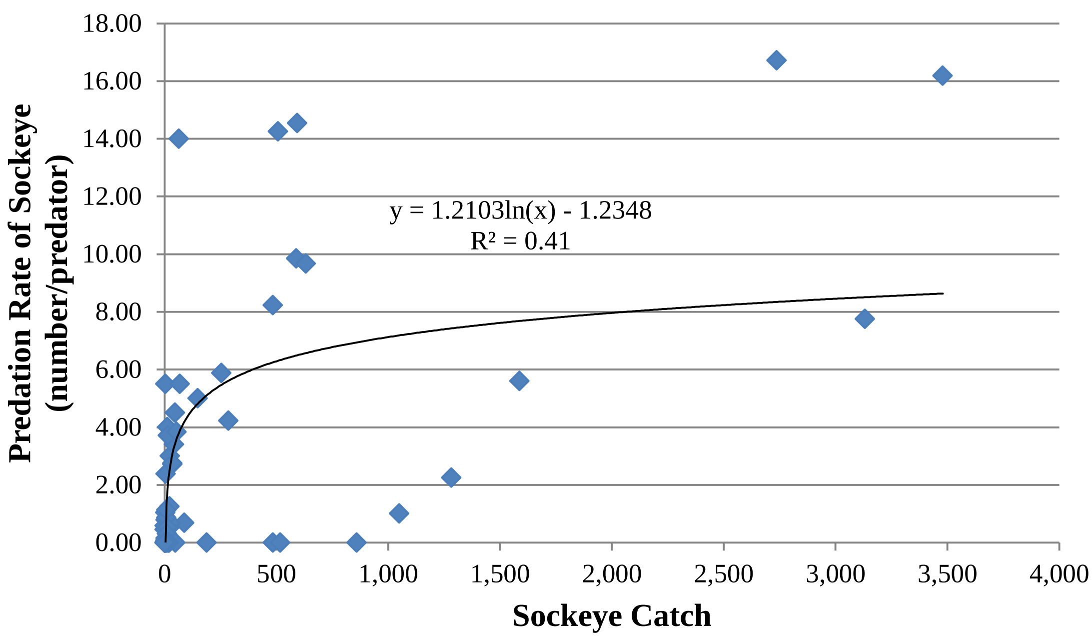

Figure 22. Sockeye predation rates of predators captured in the Bear Creek screw trap in 2012, corresponding to daily sockeye catches. Predators include cutthroat and rainbow trout, sculpin, and coho parr.

There are six assumptions that must be met for a valid mark recapture study: the population is closed geographically and demographically, all fish have equal probability of being caught, marking does not affect catchability, marked and unmarked fish are randomly mixed in the second sample, no marks are lost, and all marks are detected. The change from an inclined-plane trap to screw trap and any increased predation in the live box may lead to violation of two of these assumptions: that the mark does not affect catchability and that all marks are recovered. If one or both of the assumptions is violated post capture due to predation in the live box, abundance would be impacted by lowering recapture rates. By creating a situation that increases the time which predators and prey mingle in the live box for long periods, it is imperative to assess the consumption of marked sockeye to be sure that marked fish were not being consumed at a higher rate than unmarked fish. If marked sockeye are consumed at a greater rate than unmarked sockeye, abundance would be overestimated. Ratios of marked and unmarked fish present in the live box were compared to marked and unmarked fish present in stomach contents using a G-test. Between March 1 and April 18, sixteen efficiency trials of marked fish were released. On seven of those nights 27 marked sockeye were retrieved from stomach contents. There was no significant difference between ratios of marked and unmarked fish that were captured in the screw trap and those that were retrieved from stomach contents (P = 0.71), implying that there is no reason to believe that any assumptions concerning marks were violated, by potential predation in the live box.

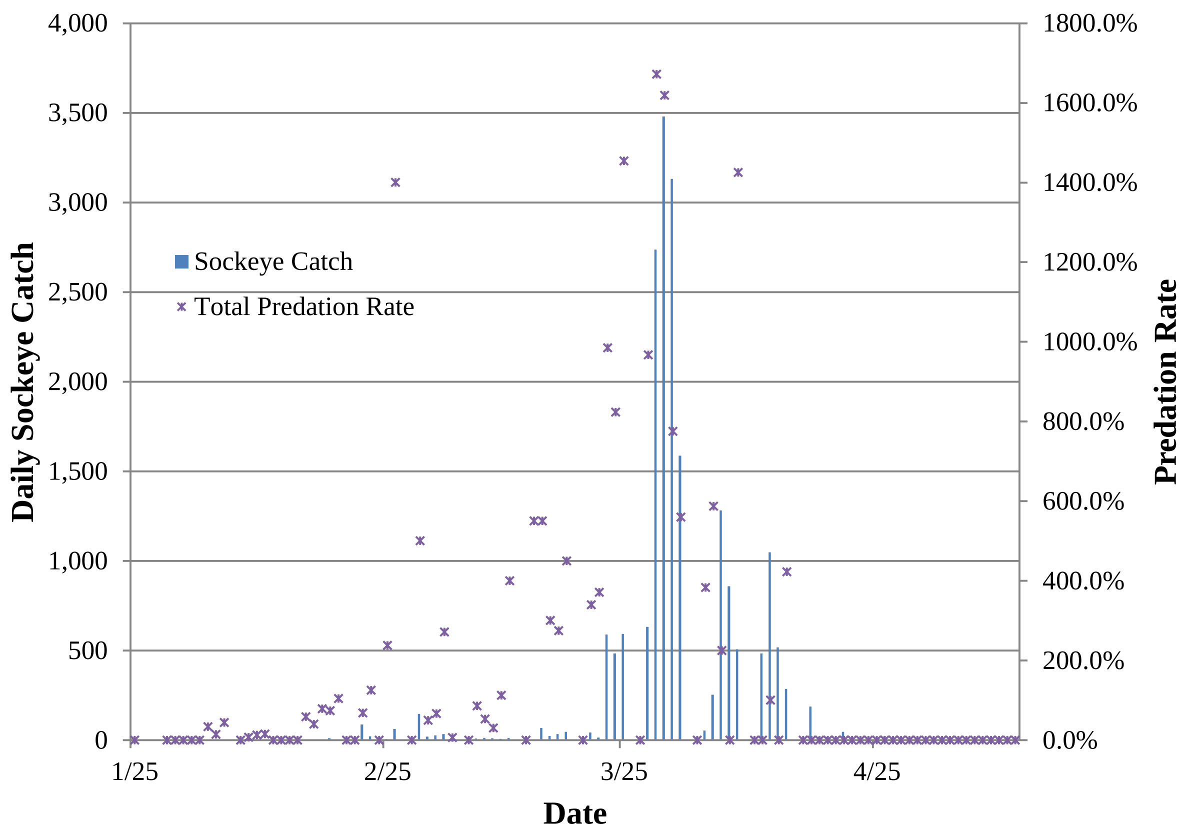

Figure 23. Daily sockeye catches and predation rates of sockeye measured from predators captured in the Bear Creek screw trap from late January to early May 2012.

In an effort to reduce predation in the live box and ensure that screw trapping was a feasible means of assessing juvenile salmonid abundance without inducing additional harm to salmonid populations in Bear Creek, various modifications of the screw trap live box and other portable structures were developed to provide protected areas for small fry to take cover from predators. Initially the trap live box was modified to add an additional 2 square feet of space on both sides of the live box. This area was screened off from the main live box with small mesh to allow sockeye to reside while keeping larger predators out. Similar mesh was used to create boxes that were anchored near the bottom of the trap and floating in the middle of the trap. These boxes provided cover near the bottom and space mid-water column for fry to occupy. Because the live box is covered to keep fish from jumping out and larger mammals from preying on fish, it was difficult to determine what proportion of fish used the provided covered areas and to what frequency they were occupied, however it was visually noted that sockeye fry did occupy these provided spaces nearly each time the live box was checked. Since it is difficult to distinguish whether a fry was consumed prior to entering the live box or after capture, we cannot make any assessment concerning changes in predation with addition of protected areas. Further structures will be constructed to test in future years.

Cedar River

Natural-Origin and Hatchery-Origin Sockeye Catch Composition

Throughout the 2012 Cedar River sockeye fry migration, ten hatchery sockeye groups were released above the inclined-plane trap in the Cedar River, resulting in an unknown portion of hatchery and natural-origin sockeye in the catch. In previous years, various methods have been used to partition both origins as appropriately as possible, these include the collection of otoliths (hatchery sockeye otoliths are thermally marked); a flow regression model based on historical otolith analysis; interpolation of natural-origin catch; and assessing the nightly migration timing of natural-origin fish to partition natural-origin fish during hours when hatchery fish inundate the trap (Kiyohara and Volkhardt 2008). Of these methods, otolith sampling is the only direct method, and deemed the most reliable method, to estimate hatchery and natural-origin sockeye in nightly catch. Although otoliths were collected in 2012, otolith sampling was found to be biased, so all releases were evaluated using indirect methods listed above.

The nightly timing method estimated more reasonable survivals (estimates between 0% and 100%) than all methods and was the chosen method for determining abundance and survival of the 2012 releases. Although the survival of the March 18 release was estimated greater than 100% (survival = 105.38%), the 95% confidence intervals on the abundance estimate suggests that survival could range from 58.4% to 152.4%. This method examines the natural-origin nightly migration distribution on nights surround the release and assumes migration distribution on hatchery release nights to be similar (hourly proportion contribution). Fish in excess of the expected hourly catch are considered hatchery catch. This assumes that nightly migration timing of naturally produced fish is consistent over several days. Aware that delayed migration of hatchery sockeye occurs, only the night prior to a release was used to assess natural migration timing on hatchery release nights. This ensured that the timing was not skewed by additional hatchery fish migrating on nights following a release.

In previous years, interpolation has been identified as the most reliable indirect method to assess hatchery abundance and survival. With this approach, the catch of natural-origin sockeye fry is estimated as intermediate between the preceding and following nights of a release, and catch of hatchery sockeye fry is the difference between total catch and natural-origin estimated catch. Although this method is the same approach that is used to estimate entire nights catch when the trap is not operating, it did not provide reasonable estimates for three of ten hatchery releases in 2012. Seven of the survival estimates calculated using the interpolation approach were similar to those estimated using the nightly timing approach and, with the exception of March 1 and March 25 releases, are within the 95% confidence intervals around the estimates calculated by nightly timing approach. The March 1 and March 25 releases are within less than 1% of the lower bound of the 95% confidence intervals of the nightly timing survival estimate. This may in part be due to inaccurate counts of fry released from the hatchery or more natural-origin sockeye migrating on hatchery release nights than expected, violating the assumption that natural-origin sockeye migrations are similar to nights prior to and following a hatchery release night or a night that the trap did not operate. This method seems to perform poorly when flows are variable from night to night and especially when flows change dramatically during a trapping period. It is likely there is more nightly variation in sockeye migrations than previously expected, or delayed migration of hatchery sockeye on nights following hatchery releases artificially inflated catch that was assumed to be natural-origin. The trap did not fish on night's surrounding the April 19 hatchery release leaving us unable to provide an estimate using the nightly timing method. Interpolation was rendered the next most reliable method for estimating hatchery abundance and survival and was the applied method to estimate the April 19 release (Table 25).

Neither interpolation nor nightly migration timing methods provided reasonable estimates for survival of hatchery sockeye released on February 21, 2012, and therefore separate hatchery and natural-origin estimates were not made. High flow and heavy debris prevented the trap from fishing the entire night of the release. Beginning at midnight, the trap only operated ten minutes of each hour. Due to dramatically increasing flows, debris, and uncertainties in estimating hatchery catches we believe that none of the methods provide an accurate assessment of hatchery abundance and survival for this date.

A flow-based regression model used to estimate survival in previous seasons (2004, 2005, and 2006) was considered in 2012 but did not yield reasonable estimates for three releases. Due to high flows during most of the fry migration, the flow regression model estimated the highest survival of all methods, rendering some releases unreasonable as expected catches were greater than actual catch or survival was greater than 100%. This method was previously developed using unfed hatchery fry released from Cedar River Sockeye Hatchery and may not be appropriate to use in 2012 because all fish released were fed prior to release and two releases occurred at R.M. 13.5 (Seiler et al. 2005). In 2007, this model was also dismissed as a useful tool to estimate hatchery survival as it yielded unreasonable estimates. In both 2007 and 2011, hatchery fish were fed before release and released downstream of the hatchery. Differences in the fish condition and release site location may both be reasons why this model did not perform well.

One additional piece of data that may introduce further uncertainty in the sockeye estimates, and thus contributing to the wide range of survival estimates, is the use of natural-origin sockeye fry for trap efficiency calibration and the assumption that capture rates of natural-origin sockeye are similar to those of hatchery-origin sockeye. In prior years paired releases of hatchery and natural-origin efficiency trials verified that hatchery fish are adequate surrogates for natural-origin sockeye. However, in 2011, hatchery practices changed to allow for feeding fish for potentially a week longer than previously. An increased feeding time may increase or decrease hatchery-origin capture rates compared to natural-origin sockeye capture rates. This could impact estimates of both natural and hatchery-origin abundance and survival. If hatchery sockeye are larger, they may possess a greater ability to maneuver in the river and may migrate on following nights, like observed in 2012. Trap operators observed this anecdotally.

Table 25. Cedar River hatchery sockeye release survival estimates comparing methods of interpolation, nightly timing, and flow regression model, 2012.

Date	Flow (cfs)	Release Location	Method to Estimate Hatchery Survival		
			Interpolation	Nightly Timing	Flow Regression
2/21/2012	1,466	Upper	357.14%	154.88%	91.30%
2/27/2012	2,260	Middle	109.68%	87.28%	110.40%
3/1/2012	2,021	Upper	11.96%	15.81%	105.46%
3/5/2012	1,639	Middle	62.09%	65.04%	96.23%
3/8/2012	1,572	Combo U and M	86.36%	86.82%	94.40%
3/18/2012	1,507	Upper	110.43%	105.38%	92.53%
3/22/2012	1,311	Middle	63.18%	47.43%	86.36%
3/25/2012	1,148	Upper	47.71%	57.92%	80.54%
3/29/2012	1,072	Middle	36.84%	37.52%	77.52%
4/19/2012	863	Upper	49.43%		67.93%

Based on these observations, the indirect methods used to allot sockeye fry catch into hatchery and natural-origin has added additional uncertainty to the final estimates. Specifically, estimates of hatchery migration and survival are likely to be low and estimates of natural-origin sockeye fry abundance are likely to be high on hatchery release nights. Both methods used to estimate hatchery catch assume migration patterns of natural-origin sockeye are consistent on nights previous and following a release. Observations of delayed migration by hatchery fish complicate estimates if they are included in the following night's natural-origin total catch. If hatchery sockeye are larger, they may possess a greater ability to maneuver in the river, and hold and migrate on following nights, like observed in 2012. Currently, only catch on nights of hatchery releases are partitioned in to separate origins. We do not account for the possibility of hatchery fish migrating on subsequent nights. Any hatchery fish that migrate beyond the trapping efforts for a given night are counted as natural-origin sockeye, inflating the natural-origin production estimate and decreasing hatchery estimates.

To gain more certainty in hatchery and natural-origin catch composition, direct measures of hatchery proportions in nightly catches following hatchery releases are needed. One potential option is to apply an external mark that would identify hatchery fish, such as a dye or paint mark, or to improve subsampling methods to unbiasedly collect otolith samples.

Calcein Pilot Study

The Cedar River Sockeye Hatchery releases sockeye into the Cedar River upstream of the Cedar River inclined-plane trap throughout the natural out-migration period. These fish are externally unidentifiable as hatchery fish, which contributes to uncertainty in natural and hatchery proportions of catches on nights of and periods following a hatchery release. In past years, estimating hatchery and natural-origin components on hatchery release nights involves multiple approaches throughout the season, as mentioned above in the previous section. Although hatchery fish are not externally marked, their otoliths have been thermally marked, and upon lethal sampling, the origin of fish can be identified, providing a method to estimate abundance and in-river survival of hatchery reared sockeye. However, otoliths have not been collected from sockeye catches at the trap since 2007.

In previous years the only direct method used to partition hatchery and natural-origin components was otolith sampling on hatchery release nights. Otolith analysis can be expensive especially with large sample sizes as needed for statistical confidence and, during small release years, lethal sampling is frowned upon due to its impacts on rebounding populations. In 2012, in an effort to improve hatchery and natural-origin abundance estimates, a pilot study was developed to assess the logistical feasibility of using calcein as an external mark to identify hatchery sockeye at the inclined-plane trap.

Due to its intensive dying process and scheduling conflicts, only two releases (March 18 and March 25) were identified as reasonable opportunities to test calcein. All hatchery fish in both releases were dyed with calcien. Calcein dye is a bright green dye that adheres to calcified structures, most visible under UV light on fin rays and bones. Hatchery dying protocols are described in Cuthbertson 2012. On nights of releases, the trap began fishing prior to the release, and fished continuously for nearly 36 hours to assess delayed migration of hatchery fish during the day and following night periods. Catches from the hatchery release nights were held in a large garbage can modified to provide fresh water and appropriate drainage for evaluation the following morning. Day catches, and subsequent night's catches, were held separately to determine the portion of hatchery catch for the initial release night separate from those that migrate later. Fish were removed from the tub using a large dip net and placed in a small 5 quart wash tub in the darkened trap house for processing in smaller batches. Fish were dip netted out of the 5 quart wash tub with flat nets or other flat trial containers to provide a surface for a single layer of fish for interrogation. A UV light with special filters was used to detect marked fry, which glowed bright green upon exposure to the light.

Total marked fish were counted and recorded for each night and day period. All calcein marked sockeye were assumed to be hatchery fish and all remaining unmarked fish were assumed to be natural-origin sockeye. Abundance was estimated for each origin using respective night's efficiency trials to expand catch into abundance and survival. A subsample of 500 sockeye from both release nights were taken from the total catch, interrogated for a calcein mark, then submitted for otolith analysis to the WDFW Otoltih Lab. Otolith marks were used to verify calcein counts and provide a viewer detection rate to correct for missed or over-counted marks.

On March 18, 356,400 calcein marked hatchery sockeye were released from the Cedar River Sockeye Hatchery at Landsburg. Flows were moderately high (1,500 cfs). Total catch for the release night was 12,751 sockeye. After correcting for viewer detection rate (105%) 5,088 sockeye were identified as calcein marked. Abundance was estimated at 271,168 and survival at 76.1%. The hatchery released 495,000 calcein marked sockeye from its Landsburg facility on March 25 at river flows of 1,150 cfs. After correcting for viewer detection rate of 98.7%, a total of 7,183 calcein marked sockeye were recovered from a total catch of 21,208. Survival was estimated at 31.7% (Table 26). Delayed migration of hatchery fish did occur on both releases but appeared to be a minor portion of the total estimated hatchery migration. For the March 18 release, 5.63% of the total estimated hatchery migration passed the trap on nights or days following the initial release night. For the March 25 release, 8.48% of the total estimated hatchery migration moved passed the trap on nights following the initial release (Table 27).

Contributions to total migrations were similar during the first day period following the release night, and the first night following the release.

Table 26. Catch, abundance, and survival of two sockeye hatchery releases from the Cedar River Sockeye Hatchery. Abundance and survival were estimated using two methods: total catch of calcein dyed hatchery sockeye and otolith samples obtained from Cedar River inclined-plane catches, for comparison.

Date	Total Night's Catch	Calcein Catch	Calcein Abundance	Calcein Survival	Otolith Total in Subsample	Otolith Abundance	Otolith Survival
Mar 18	11,844	5,088	271,168	76.10%	285	359,793	100.95%
Mar 25	21,208	7,183	156,709	31.70%	240	222,099	44.87%

Table 27. Estimated hatchery sockeye catch, abundance, and survival of two calcein marked hatchery sockeye releases. Data obtained from catches at the Cedar River inclined-plane trap. Catches are separated by fishing period to assess delayed migration of hatchery releases.

Hatchery Release of 356,000					
Date	Total Catch	Total Calcein Marks	Estimated Hatchery Migration	Cumulative Estimated Survival	% of Total Estimated Hatchery Migration
Mar 18	11,844	5,088	271,168	76.09%	92.72%
Mar 19 AM	709	165	8,818	78.56%	3.02%
Mar 19 PM	7,133	222	11,808	81.87%	4.04%
Mar 20	5,904	12	659	82.06%	0.23%
Total	**25,590**	**5,488**	**292,452**	**82.06%**	

Hatchery Release of 495,000					
Date	Total Catch	Total Calcein Marks	Estimated Hatchery Migration	Cumulative Estimated Survival	% of Total Estimated Hatchery Migration
Mar 25	21,208	7,183	156,709	31.66%	92.67%
Mar 26 AM	1,091	368	8,019	33.28%	4.74%
Mar 26 PM	15,297	287	6,252	34.54%	3.70%
Mar 27	15,809	17	376	34.62%	0.22%
Total	**53,405**	**7,854**	**171,355**	**34.62%**	

In previous years when otoliths were taken, hatchery and natural-origin catch proportions on hatchery release nights were determined by proportions of each origin in a sample taken for otolith analysis. Otolith analysis allows proportions of hatchery and natural origin fish to be determined in samples and total catch if samples are unbiased and provide a true representation of the total catch. Until 2012, we had no method to verify that our sampling provided an accurate representation of the entire catch. Calcein provided an external mark allowing comparison of proportions of hatchery and natural-origin fish in the sample and the whole night's catch to determine if the sampling is unbiased. After both calcein marked hatchery releases, a sample of 500 sockeye were removed from the total night's catch, examined for calcein marks, and placed in a jar of alcohol for later otolith analysis to verify mark retention and identification.

Otolith analysis of the sample taken on March 18 estimated abundance at 359,793 and survival at 100.95%. Based on total calcein marked sockeye in trap catches on March 18, hatchery survival was estimated at 76.1%. Otolith analysis of the sample taken on March 25 estimated hatchery abundance of 222,099 hatchery sockeye with a survival of 44.87%. Total calcein marked sockeye in trap catches on March 25 estimated hatchery sockeye survival at 31.7%. This substantial difference in survival between the sample (otolith sample) and total catch (calcein) suggested that hatchery fish were over represented in the sample. Further statistical evaluation was conducted comparing expected and actual proportion of hatchery and natural-origin fish in the subsample using a G-test. A significant difference was detected (March 18 P=1.84E-6, March 25 P= 6.19E-10), pointing to either biased sampling or error in identifying and counting marks. We do not believe that identifying marks was a concern as we were able to correct for potential over or under counting by comparing total calcein marked fish in each otolith subsample and verifying with otolith analysis. Because every hatchery fish is otolith marked and both releases were fully marked with calcein, every fish identified as a hatchery fish by otolith, should have also been calcein marked. Both otolith samples estimated hatchery survival greater than calcein estimates, indicating that otolith samples were biased toward hatchery fish (Table 26).

Behavioral differences between natural-origin and hatchery sockeye may contribute to biased subsamples. Observations while interrogating the entire night's catch indicated that stratification of hatchery and natural-origin sockeye may have occurred in the holding container. The majority of the hatchery sockeye were present in the first half of the fish interrogated, while nearly all of the unmarked fish (natural-origin sockeye) appeared in the latter half of the fish interrogated for marks. We believe this stratification may be due to different behavioral tendencies of each origin. Hatchery fish, which have no predators in their hatchery environment and are fed during the day, may have a tendency to reside in the upper half of the water column for food. Natural-origin fish are typically taking cover during daylight to avoid predation, and would be expected to be found near the bottom of the trough. As fish were processed, scoops of fish were netted off the top first, explaining the noted division of marked (hatchery) and unmarked (natural-origin) fish at the time of processing. If adequate mixing of natural-origin and hatchery sockeye did not occur, then a biased subsample may result, as experienced in 2012.

Although there is a significant discrepancy in the 2012 samples, we do not believe that this finding impacts previous years' sampling efforts when otoliths were used to estimate survival. Although we cannot be certain, in past years, the sample was composed of fish that were sampled at hourly checks, rather than the entire nights catch in one trough, as done in 2012. The holding trough in 2012 was constructed differently, allowing areas for fish to embed themselves and resist mixing upon sampling. In previous years, small containers such as buckets were used for holding hourly checks and did not provide areas for fish to hold in. We believe that the larger container and greater abundance of sockeye to sample lead to errors in sampling. In previous years, smaller containers and catches may have led to better mixing and the potential for an unbiased sample.

Calcein marking proved to be a promising option for assessing origins of fish, provided validation of assumptions associated with mark-recapture estimates. This pilot study was formed to assess its logistical feasibility concerning marking technique and demands of the interrogation processes. It was not designed to test all the assumptions of a mark recapture study to adequately make confident survival estimates. Therefore, abundance and survival estimates from this pilot study should be viewed with caution. Assumptions not tested in 2012 include ensuring equal probability of marked and unmarked fish being caught, that the mark does not affect catchability, and that no marks are lost. Only one paired efficiency trial was conducted, releasing 976 calcein marked and Bismarck Brown marked sockeye from the Logan Street Bridge. No significant difference was detected (P= 0.34). This is only one trial under specific environmental circumstances and does not necessarily provide evidence for a more general conclusion that the calcein mark does not affect catchability. Distance traveled from Logan Street Bridge is much shorter than the distance that calcein marked sockeye traveled on hatchery release nights providing greater opportunity for predation or delayed mortality related to calcein and the dying process to occur. Additional assumption testing is necessary to make any determinations concerning these and the other assumptions listed above.

Cedar River Sockeye Survival Estimates

Egg-to-migrant survival for years prior to BY 2011 were estimated incorrectly due to incorrect adult abundance data. Adult abundance data used prior to BY 2011 was the total AUC estimate for the Cedar River and did not discount the sockeye removed from the population that were used for brood stock collection. As a result adult abundance was reported as greater than the actual naturally spawning population, and artificially deflated the egg-to-migrant survival for most years. Change in survival was minimal, ranging from -0.5% to 0.5% (Table 28). The corrected adult abundance and corresponding survival estimates are reflected in Table 5. All other analysis involving egg-to-migrant sockeye survival estimates have been adjusted and changes are reflected in the Results section of this report.

Table 28. Corrected adult abundance and egg-to-migrant survival estimates for Cedar River sockeye brood year 1991 to 2010.

Brood Year	Data Listed Prior to BY 2011		Corrected		Change in Survival
	Spawner Abundance	Egg-to-Migrant Survival	Spawner Abundance	Corrected Egg-to-Migrant Survival	
1991	77,000	7.76%	76,592	7.80%	0.04%
1992	100,000	15.62%	99,849	15.64%	0.02%
1993	76,000	15.39%	74,677	15.67%	0.27%
1994	109,000	5.03%	107,767	5.08%	0.06%
1995	22,000	1.91%	21,443	1.96%	0.05%
1996	230,000	6.43%	228,391	6.48%	0.05%
1997	104,000	14.81%	102,581	15.01%	0.20%
1998	49,588	12.06%	48,385	12.36%	0.30%
1999	22,138	20.27%	21,755	20.63%	0.36%
2000	148,225	15.03%	146,060	15.26%	0.22%
2001	119,000	14.92%	117,225	15.15%	0.23%
2002	194,640	8.43%	192,395	8.53%	0.10%
2003	110,404	20.54%	109,164	20.77%	0.23%
2004	116,978	19.32%	114,839	19.68%	0.36%
2005	50,887	13.90%	49,846	14.22%	0.32%
2006	106,961	5.90%	105,055	6.05%	0.15%
2007	45,489	31.95%	45,066	32.25%	0.30%
2008	15,995	6.50%	17,300	6.01%	-0.49%
2009	12,501	56.58%	12,501	56.58%	0.00%
2010	66,910	4.39%	59,795	4.91%	0.52%

Cedar River Sockeye Median Migration Data

Dataset Analysis

The Cedar River sockeye brood year 2000 survival has historically been considered an outlier in the long term data set due to extremely low flows during the out-migration period and a landslide that may have impeded migration and caused high mortality. This brood year has been excluded from some datasets, such as temperatures' effect on median migration date, because of its apparent negative influence on the correlation between median migration date and February water temperature. Although there is a notable negative influence when included (change in R^2 from 0.55 to 0.40), there appears to be little evidence statistically to justify removing the 2000 brood year from the dataset.

A residual analysis was conducted and neither Cook's distance nor influence, both measures of the influence of one data point on the entire dataset, provide any evidence to exclude brood year 2000. Although Cook's distance shows that the 2000 brood may be greater than other points, in conjunction with influence, the 2000 brood does not appear to have any more impact on the dataset than any other year. In fact, the 2004 brood appears to have more influence than the 2000 brood (Figure 24). Therefore beginning with the 2012 out-migration report, the 2000 brood will be included in further analysis.

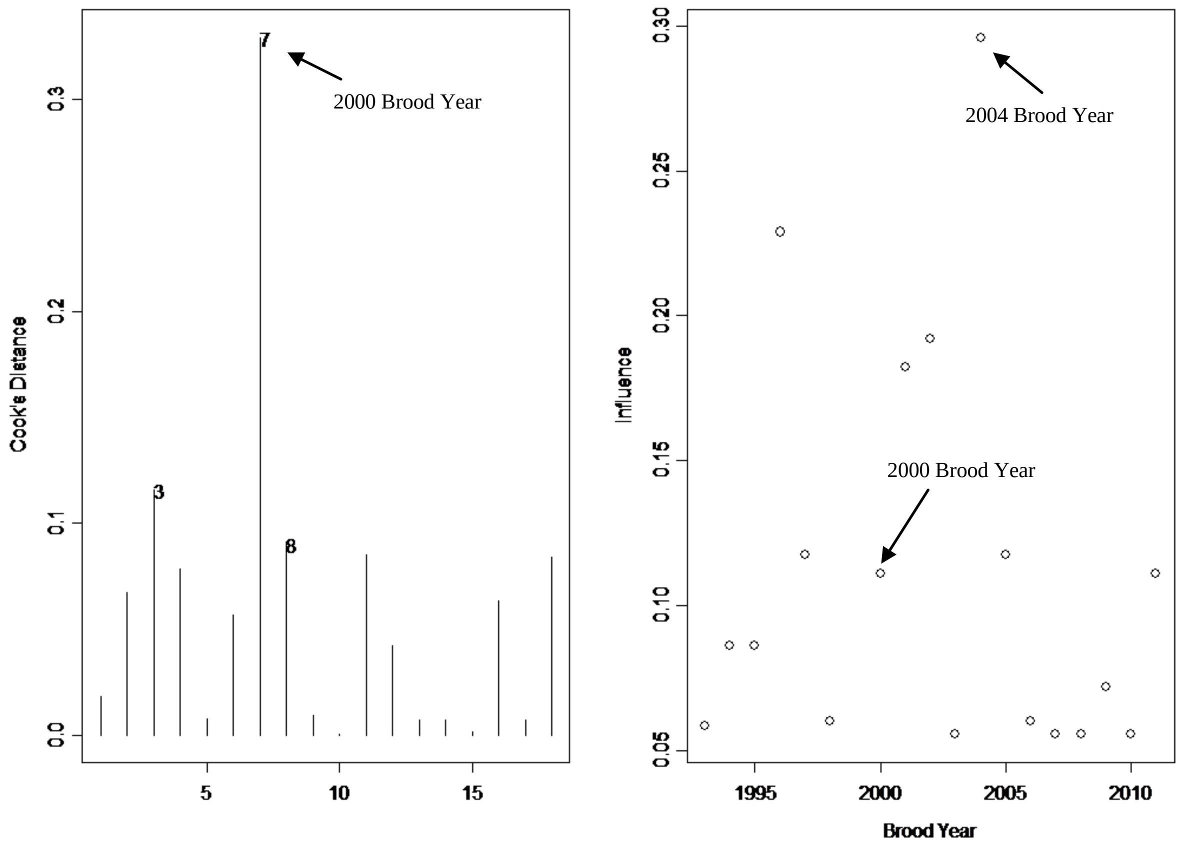

Figure 24. Cook's distance and influence assessment of Cedar River sockeye median migration date as it relates to February stream temperatures, brood years 1993 to 2011.

Median Migration Date Predictor

One goal of this long-term monitoring plan is to identify environmental variables that drive migration patterns of natural-origin sockeye. In previous reports, total thermal units during the month of February have been identified as a good predictor of sockeye median migration date (Figure 6, R^2 = 0.40). Recently, average water temperature from November through January has been identified as a better predictor of median migration date (R^2 = 0.52, Figure 24). With the recent completion of the new Cedar River Sockeye Hatchery and the implementation of the Cedar River Adaptive Management Plan, which calls for the hatchery population to pattern the natural component in all life stages, using temperatures prior to releases for predicting natural migration patterns can inform hatchery operations. Because these months occur earlier in the season, they should be useful for making management decisions such as release timing of hatchery sockeye in order to mimic the natural migration. Most sockeye spawning has been completed and majority of the eggs have been deposited in the gravel prior to November. If temperatures are warmer during the incubation period, from November to January, then sockeye may emerge earlier. Brood years 1999 and 2005 were not included because November and December temperatures were not available.

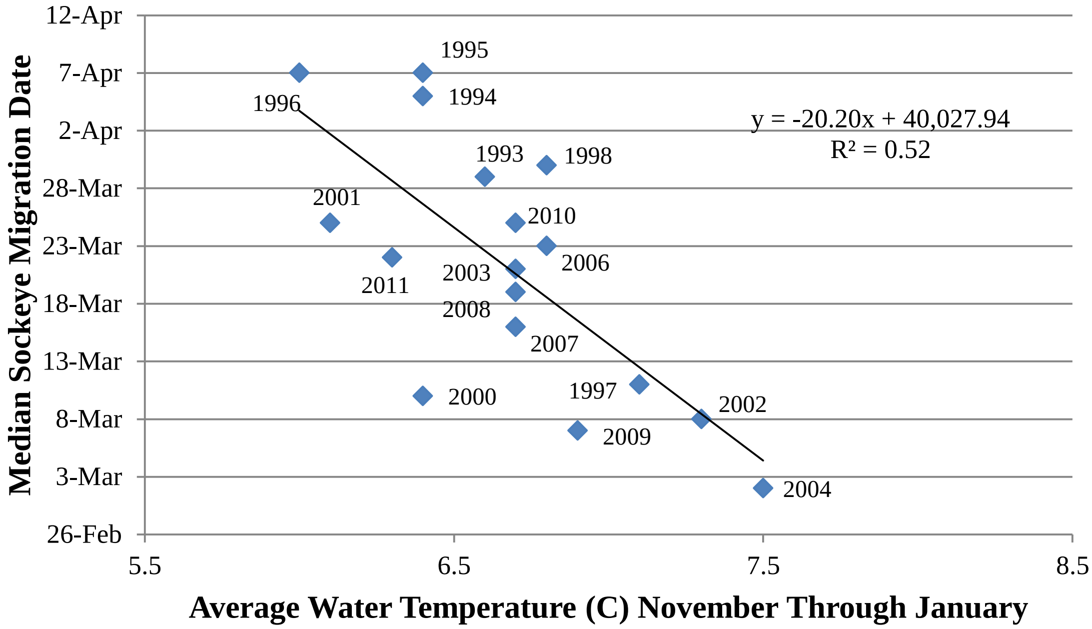

Figure 25. Median migration date for brood years 1993-2011 sockeye as a function of average November through January water temperatures in the Cedar River as measured at the USGS Renton Gage #12119000. Brood years 1999 and 2005 were not included as temperature data was not available.

Cedar River Chinook Abundance and Survival

The 2011 Chinook brood in the Cedar River experienced favorable conditions that resulted in the highest abundance (over 900,000) and egg-to-migrant survival (61.8%) observed since trapping began. This is a surprisingly large abundance and high survival rate compared to other years in the Cedar River and other Puget Sound basins. The Cedar River Chinook migration in 2012 was primarily composed of fry (93%) that migrated between January and April. During this timeframe there was one period that appears to be the largest contributor to abundance and survival. From February 21 through March 1, estimated abundance (379,160 Chinook) accounted for nearly 45% of the entire fry migration, and 42% of the entire fry and parr migration. Due to this period's large contribution to the total Chinook abundance, alternative approaches to estimating abundance for this period was examined.

The large emigration between February 21 and March 1, 2012 was driven by high catches and low trap efficiencies concurrent with high flows. On February 21, flow on the Cedar River (USGS gage 1211900) increase nearly 1,000 cfs and ranged from 2,021 cfs to 2,365 cfs, between February 21 and March 1. During trap operations on the evening of February 21, trap efficiency, calculated by dividing 14 recaptured marked sockeye by the 4,018 released, was measured at 0.35%. Furthermore, three additional efficiency trials were conducted through March 1 under a similar flow regime. These trials resulted in trap efficiencies ranging from 0.87% to 1.16% (Table 29), similar to that conducted on February 21, which further verified low trap efficiencies during the high flow period. Flow earlier in the season was similarly high and trap efficiency was also similarly low. On January 31, daily average flow in Renton was 2,025 with trap efficiency at

0.9%, and on February 2 trap efficiency was 1.09% at 1,929 cfs. Flow was lower during periods prior to and following this event, and subsequently trap efficiencies were also greater.

Table 29. Actual, estimated, and total Chinook catch (actual plus estimated catch), sockeye efficiency trial data, and flow for February 20, 2012 to March 2, 2012 on the Cedar River. Catch was estimated for entire night periods, day periods, and partially fish night periods due high flow and heavy debris. The trap was not fished on March 22, 25, and 29.

Date	Daily Average Flow (cfs)	Actual Chinook Catch	Est. Chinook Catch	Total Catch	# Released	# Recovered	Trap Efficiency	Strata
2/20/2012	899	172	23	195	290	5	1.72%	4
2/21/2012	979	551	446	997	4018	14	0.35%	5
2/22/2012	1,466	0	290	290				
2/23/2012	2,365	165	46	211	717	7	0.98%	5
2/24/2012	2,030	108	30	138	172	2	1.16%	5
2/25/2012	2,268	0	107	107				
2/26/2012	2,179	60	17	77				
2/27/2012	2,303	48	0	48	462	4	0.87%	5
2/28/2012	2,260	25	8	33				
2/29/2012	2,142	0	37	37				
3/1/2012	2,089	30	9	39				
3/2/2012	2,021	70	22	92	1146	63	5.50%	6

An additional factor contributing to large abundance during this period was high Chinook catches, specifically on February 21 when catch peaked for the season at an estimated 997 Chinook. Actual catch totaled 551 Chinook. Due to heavy debris, the trap was only operated for 10 minute periods out of each hour from 1:00am to 8:00 am on February 22. The remaining 446 Chinook accounted for those that were estimated to have migrated during the remaining 50 minute period of each hour and the expected day catch. Subsequent night's catches were not nearly as abundant however flows were more stable following the sharp increase on February 21 (Table 29, Figure 26). It is not uncommon to see a large movement of fish on sharply increasing and decreasing flows but stable catches when flows are stable, even while during a period of high flows.

Due to their similarity and significant difference to surrounding dates when trap efficiency was measured, the efficiency trials conducted during the period between February 21 and March 1, during high flows, were grouped together into one stratum for estimating abundance using the G-test (Table 29, Appendix B2). Although trap efficiencies were not deemed significantly different using (alpha=0.5) additional analysis was conducted to assess how total abundance would be affected if efficiency trials were applied differently.

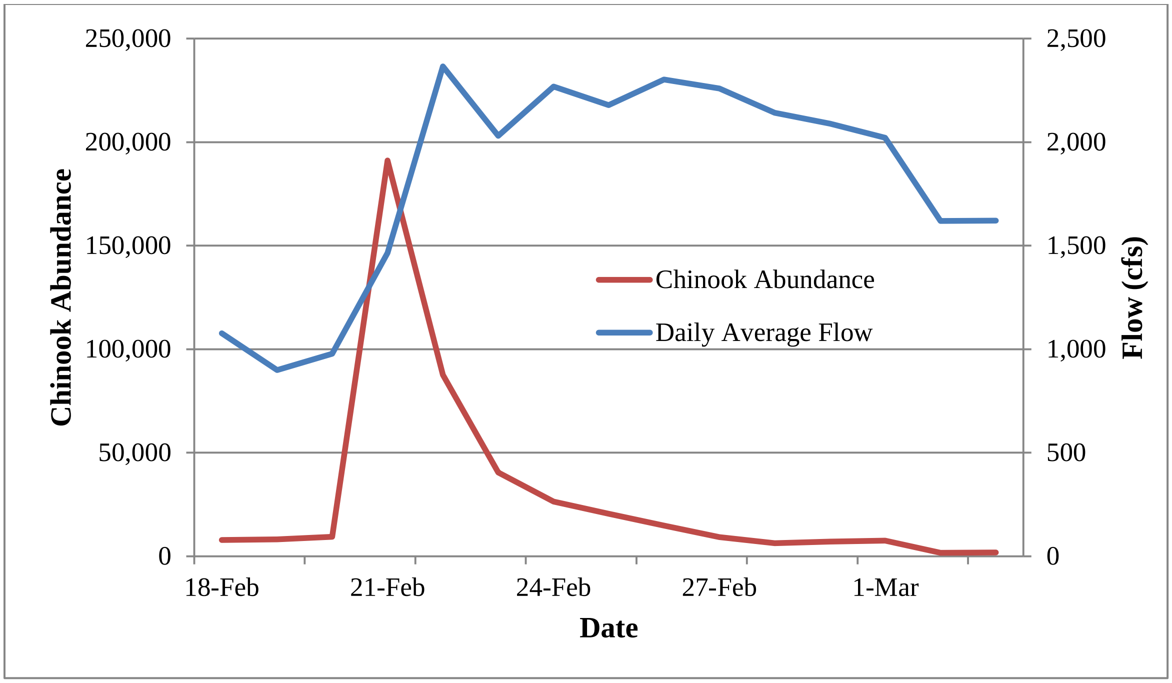

Figure 26. Cedar River Chinook fry abundance and river discharge (cfs) from February 18 to March 3, 2012.

Since flow sharply increased during the night of February 21, it could be argued that the measured trap efficiency should be applied only to that night's catch since trap efficiency was nearly one-third of the other measured trap efficiencies on subsequent days. The remaining efficiency trials during that period would then be grouped and applied to their respective catch. If this approach is taken, total abundance for the period between February 21 and March 1 would only decreased by 17,390 Chinook. Another potential option for estimating abundance for this period would be to disregard the application of statistics and changes in environmental conditions to determine strata and combined the prior and following efficiency trials to create one stratum. This stratum would entail the period between February 17 and March 4 and would estimate abundance at 244,666 Chinook, nearly 134,500 Chinook less if this approach was applied. One last approach would apply measured trap efficiencies to their respective catches rather than stratifying. For nights when trap efficiency was not measured, measured efficiency was applied to nights following an efficiency trial until the next trial was conducted. This approach for the period of February 21 to March 1 estimates 406,566 Chinook migrants, over 27,000 more Chinook than our current estimate. All potential options for estimating abundance during this period provide total abundance estimates that are within the confidence intervals of the abundance estimated by applying the current G-test method.

Regardless of the exact analytical techniques used, the late February high flow period consistently observed large catches of Chinook and low trap efficiencies. Our Chinook abundance estimates are based, in large part, on the assumption that the fry trap captures Chinook and sockeye at the same rate. Unfortunately, we encounter too few Chinook salmon for statistically robust mark groups of Chinook released throughout the season. Given this constraint, our estimates utilize the best analytical techniques available at this point in time. Paired releases of Chinook and sockeye have shown that sockeye tend to have a higher capture rate than Chinook, but this difference is not statistically significant (Table 30, see next section for detailed discussion). We are working towards using these paired releases groups to develop a Chinook specific trap efficiency in an effort to improve our Chinook abundance estimates.

It is clear that a large number of Chinook fry, nearly half of the entire migration, were flushed from the Cedar River early in the migration period. This earlier migration date would tend to inflate survival values relative to years with a later migration date because mortality is cumulative. In other words, the time period over which we measured survival in 2012 was shortened by the early migration, which provided less time for mortality to accumulate relative to other years. These early late February migrants were likely forced from the system by high flows. Although they survived to migrate downstream, they may have been unprepared for entry into Lake Washington. It is possible that high mortality in Lake Washington will offset the high survival observed in the river, but we have no method of testing this hypothesis.

Although this survival appears high compared to previous years and other Puget Sound Chinook populations, survival rates greater than 61% have been documented in other systems outside of the Puget Sound. In the Yakima River, WA, spring Chinook egg-to-fry survival has been documented to range from 21.9% to 90% on individual redds and annually averaging 59.6% and 62.4% over two years (Fast et al. 1991). Other studies using egg boxes and artificial redds in rivers have also document high survival ranging from 60% to 87% in the Yakima River, WA during low to moderate flow conditions (Johnson 2012). Although these findings do not reflect environmental conditions confronting naturally spawned redds in the Cedar River, they are indicative of potential egg to fry survival values observed under favorable conditions.

It is important to determine the main driver(s) that contribute to such high survival rates in the Cedar River watershed. A two way ANOVA was conducted examining the interactions between Chinook survival, sockeye adult abundance, and spawning, incubation, and peak incubation flows. There appears to be little interaction between any of these factors and their influence on Chinook survival ($P = 0.98$ incubation flows, $P = 0.98$ peak incubation flows, $P = 0.43$ spawning flows). Perhaps other unknown combinations of environmental conditions are greater drivers of survival than those expected to have direct impact on production and survival. Although environmental effects are often considered to be the main contributor to survival, genetic effects can be just as influential. Johnson et al (2012) suggests that during years when environmental conditions such as flow are less variable, parental affects may become very pronounced as major contributors to Chinook survival in the Yakima River, Washington. Other studies have indicated that parental effects impact survival in both a hatchery and seminatural environment (Knudsen et al. 2008). Because we cannot separate the environmental and parental effects of each brood's survival, we cannot attribute the high survival of the 2011 brood to any particular factor.

Capture Rates of Cedar River Chinook Fry

In past years, catches of Cedar River Chinook fry have been too low to conduct efficiency trials during inclined-plane trap operations. Consequently, sockeye fry efficiencies had been used to estimate Chinook fry production. Sockeye fry capture rates were assumed to be a good surrogate for Chinook fry due to the similar body sizes of sockeye and Chinook fry. However, Chinook fry are slightly larger than sockeye and differences in the migration behavior of these two species are unknown. In recent years, Chinook catches have been abundant enough to conduct paired sockeye and Chinook efficiency trials. In 2010 and 2011, there was no significant difference detected between sockeye and Chinook efficiencies during river flows between 402 cfs and 1,032 cfs. However sockeye efficiencies appeared to be consistently higher than Chinook efficiencies. In 2012 Chinook catches allowed for ten paired releases. Efficiency trials were conducted in the same manner described in the Methods section for sockeye. Efficiency trial groups consisted of 100 and 401 of each species with an equal number of each species released over flows ranging from 797 cfs to 2,268 cfs.

Table 30. Paired efficiency trial releases of Chinook and sockeye at the Cedar River inclined-plane trap in 2012.

Date	Daily Average Flow (cfs)	Number Released	Recaptured		Efficiency		P Value
			Chinook	Sockeye	Chinook	Sockeye	
2/13/2012	966	166	6	7	3.64%	4.24%	1.00
2/14/2012	851	188	13	9	6.91%	4.79%	0.38
2/17/2012	891	200	9	7	4.50%	3.50%	0.80
2/20/2012	797	290	13	5	4.48%	1.72%	0.09
2/24/2012	2,268	172	3	2	1.74%	1.16%	1.00
3/12/2012	1,813	100	1	1	1.00%	1.00%	0.47
4/2/2012	1,068	186	10	5	5.38%	2.69%	0.29
4/3/2012	1,017	401	3	5	0.75%	1.25%	0.72
4/9/2012	1,318	172	8	5	4.65%	2.91%	0.57
4/10/2012	1,133	185	10	8	5.41%	4.32%	0.81

The *G*-test was used to compare each paired release in order to determine if the ratio of seen:unseen differed between species (Table 30). There was no significant difference detected between sockeye and Chinook recapture rates. However, further testing using a paired t-test, which has greater power to detect differences, shows that there is a significant difference with Chinook efficiencies consistently higher than sockeye efficiencies (t_9=2.79, P = 0.01) (Figure 27). This is opposite of what was observed in 2010 and 2011, when sockeye efficiencies were consistently higher than Chinook efficiencies. Differences may be a result of environmental or temporal factors. In 2012 river discharge ranged from 797 cfs to 2,268 cfs on nights paired releases were conducted, considerably higher flows than in 2010 and 2011. Compiling the 2010 through 2012 paired release data, sockeye appear to be adequate surrogates for Chinook when flows are less than 750 cfs, however, as flows increase, sockeye do not appear to be good surrogates for Chinook to estimate trap efficiency, as Chinook trap efficiencies appear to be consistently greater (Figure 28). This suggests that perhaps sockeye and Chinook behave similarly at lower flows, potentially occupying the water column and river habitat similarly, but as flows increase, they may behave differently, occupying different spaces in the river.

Further assessment shows that as the migration season progresses, capture rates of Chinook tend to be greater than sockeye. Chinook could be actively moving to acquire suitable habitat for rearing before exiting the river as they emerge from the gravel and begin to grow (Figure 29). Chinook may lose their mobility when velocities exceed a threshold, increasing their capture rate.

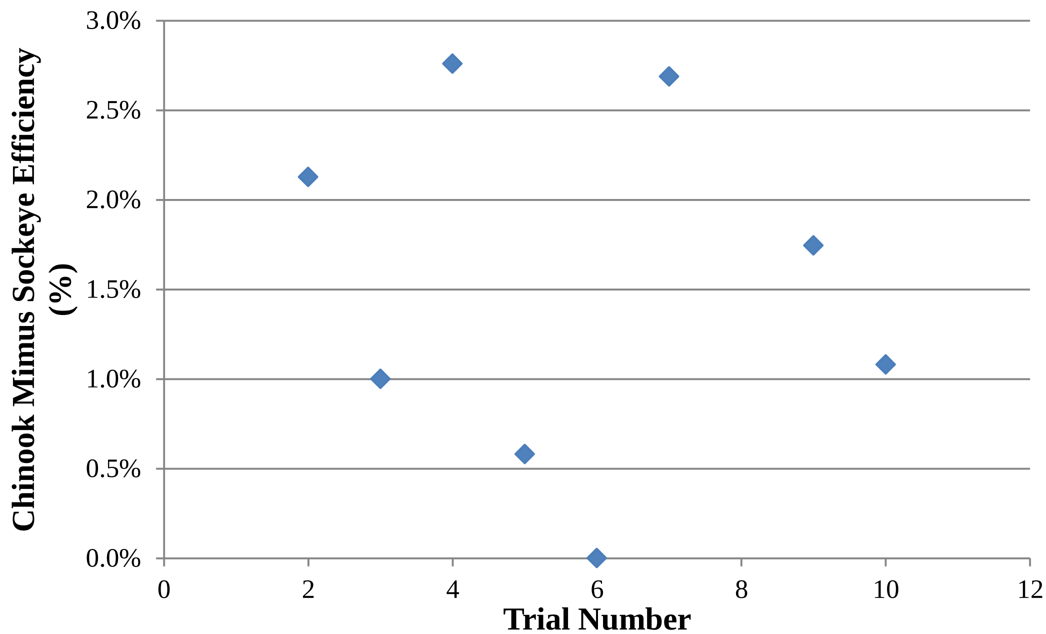

Figure 27. Difference between Chinook and sockeye capture rates at the Cedar River inclined-plane trap, 2012.

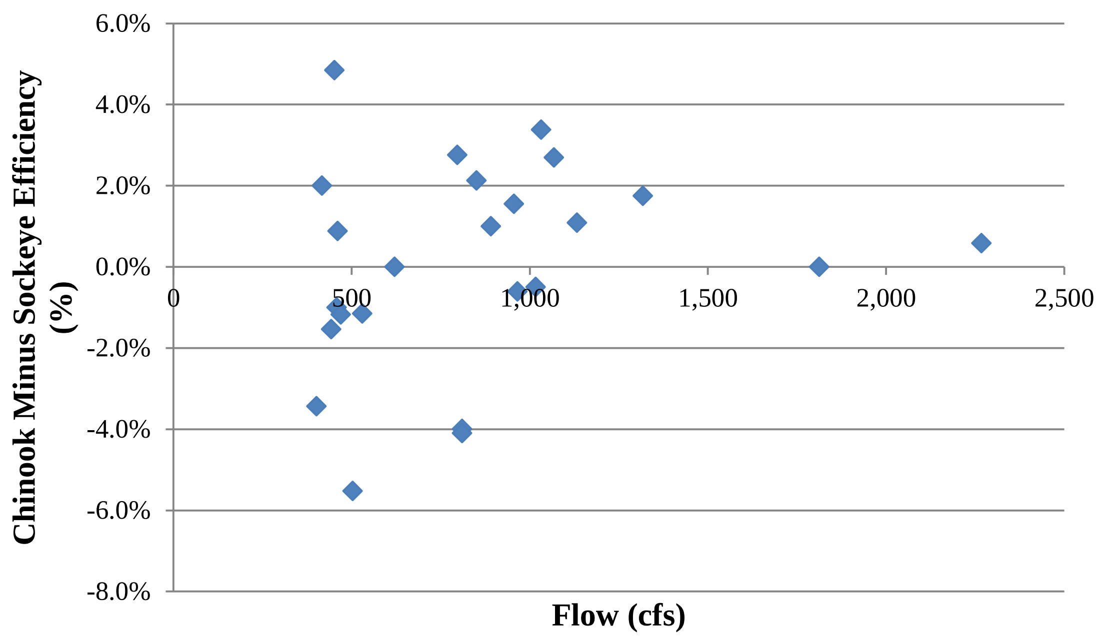

Figure 28. Difference between Chinook and sockeye trap efficiencies at various flows at the Cedar River inclined-plane trap, trap years 2010 through 2012.

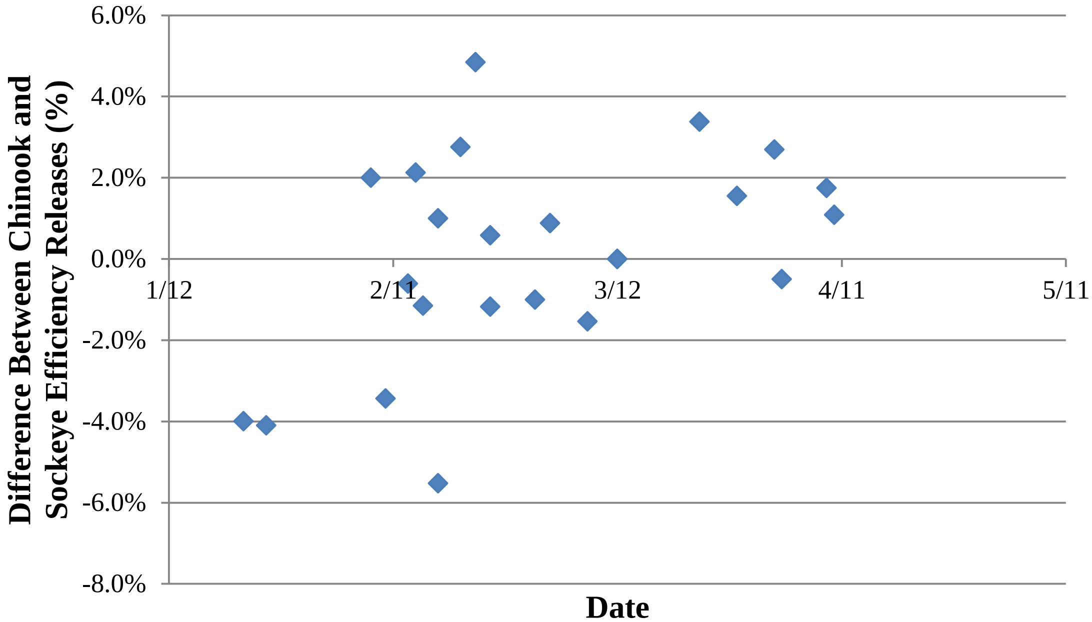

Figure 29. Difference between Chinook and sockeye trap efficiencies by date at the Cedar River inclined-plane trap, trap years 2010 through 2012.

Continued assessment of Chinook trap efficiencies over a larger range of flows is necessary to make any conclusive statements about the impacts of using sockeye trap efficiencies on estimating Chinook abundance. However, it is possible that under high flow conditions, applying sockeye trap efficiencies to Chinook catch may lead to overestimating Chinook abundance. Additional data may contribute to developing a correction factor that could be applied when Chinook catches are too low to conduct efficiency trials.

Difference in Chinook and sockeye recapture rates in the Cedar River are not transferable to Bear Creek because Chinook appear to have longer freshwater residency in Bear Creek with very few Chinook migrating as fry. Therefore differences in recapture rates of Chinook and sockeye may result from a difference in behavior rather than a difference in trap efficiency. In addition catch of Chinook fry in Bear Creek are not abundant enough to compare Chinook and sockeye capture efficiencies. Additional years of paired trials over a broader range of flows and species densities will further allow us to better assess Chinook fry capture rates as they compare to those of sockeye.

Recommendations

While evaluating the 2012 juvenile salmon migration data for both systems, the uncertainty of a number of assumptions associated with our estimates became apparent. In particular, concerns arose about methods used to evaluate hatchery sockeye abundance and survival in the Cedar River. We recommend additional assessment of various components associated with developing hatchery sockeye abundance and survival estimates, in particular, continued uses of a more direct method (calein dye) for improving estimates, develop methods of unbiased sampling for otoliths in catches on hatchery release nights, and begin a comparison of the trap efficiencies for hatchery sockeye and natural-origin sockeye in the Cedar River. Continued assessment of sockeye trap efficiencies as surrogates for Chinook efficiencies should be conduct. Annual validation of assumptions associated with mark recapture studies should be conducted as well. Pursuing these recommendations will improve the accuracy of abundance estimates each trap season and more confidently identify contributing factors that affect survival and productivity of salmon in each watershed.

Recommendation 1: Improve natural and hatchery origin catch composition on nights when hatchery releases occur above the Cedar River inclined-plane trap. Various historical methods used to estimate hatchery and natural-origin components of catch on release nights have indicated that there are flaws to some degree in the approaches that are taken to estimate migrations. In 2012, hatchery migration and survival was estimated for nine hatchery releases conducted above the trap using various methods. Estimated survival ranged from 15.81% to 105.38%. To reduce uncertainty and assess future hatchery fry migrations more concretely, continued assessment of calcein dye or other dyes to externally mark all hatchery released fry should be conducted. In addition, methods to collect unbiased otolith samples from catches on hatchery release nights are encouraged to develop protocols for future use.

Recommendation 2: Validate trap efficiency of hatchery and natural-origin sockeye: Hatchery practices have changed and fry are now fed for up to two weeks prior to release. Fed time varies as fish are able to volitionally move into feeding troughs upon emergence. The availability of food for longer or shorter periods of time creates variability in size of hatchery fish, and obvious physical differences compared to natural-origin sockeye. The physical size difference may be enough to cause differences in capture rates at the inclined-plane trap. Trap operators noted behavioral differences between hatchery and natural-origin fish in holding totes in 2012 and in 2011. Such differences imply that it is not valid to use natural-origin sockeye trap efficiencies for estimating hatchery abundance and survival on hatchery release nights. This may also indicate that it is not valid to use hatchery sockeye trap efficiencies to estimate natural-origin abundance on nights and years when sockeye are too few to form efficiency trial groups.

Recommendation 3: Test the assumption that sockeye are adequate surrogates for estimating Chinook fry capture rates of the Cedar River inclined-plane trap. This assumption has been made based on the similar physical states (i.e., recently emerged fry) of each species. Chinook fry movement has been assumed to be comparable to that of sockeye fry. As a result, the abundance of Chinook fry migrants was derived based on sockeye capture rates. In part, this strategy was developed to minimize handling of the natural-origin Chinook fry, which are listed under the ESA as threatened. However, until recently (2010), there have not been enough Chinook fry captured to conduct efficiency trials. During the 2010, 2011 and 2012 trapping seasons, this assumption was tested when Chinook fry abundance was large enough to form adequate size release groups. Flows were variable between years but similar within each year. Species-specific comparisons of capture rates are needed over a range of flows in order to justify (or not) approaches taken to re-evaluate historical juvenile migrant data for Cedar River Chinook. In 2012, flows were consistently high but catches were abundant enough to form ten paired releases, providing further insight to potential behavioral and temporal differences of each species under certain environmental conditions.

Recommendation 4: Test assumptions affiliated with mark-recapture studies. A variety of tests should be conducted to assess the quality of our production estimates by validating assumptions. These assumptions include verifying that all fish have equal probability of being captured and recaptured, marks do not affect the ability of a fish to be captured and marks are retained from point of release to recapture. Continued testing will reveal areas of uncertainty in juvenile production estimates. In particular, the release site used for Bear Creek trap will be examined in order to better address whether marked and unmarked fish are adequately mixing prior to recapture.

Appendix A

Variance of total unmarked out-migrant numbers, when the number of unmarked juvenile out-migrants is estimated.

Kristen Ryding
Statistician
Stock Assessment Unit
Science Division, Fish Program
WDFW

Appendix A. Variance of total unmarked out-migrant numbers, when the number of unmarked juvenile out-migrants is estimated. Kristen Ryding, WDFW Statistician.

The estimator for $\hat{U}_i$ is,

$$\hat{U}_i = \frac{\hat{u}_i\left(M_i+1\right)}{\left(m_i+1\right)}$$

the estimated variance of $\hat{U}_i$, $Var\left(U_i\right)$ is as follows,

$$Var\left(\hat{U}_i\right) = Var\left(\hat{u}_i\right)\left(\frac{\left(M_i+1\right)\left(M_i m_i+3M_i+2\right)}{\left(m_i+1\right)^2\left(m_i+2\right)}\right)+Var\left(\hat{U}_i\middle|E\left(\hat{u}\right)\right)$$

where

$$Var\left(\hat{U}_i\middle|E\left(\hat{u}\right)\right) = \frac{\left(M_i+1\right)\left(M_i-m_i\right)E\left(\hat{u}_i\right)\left(E\left(\hat{u}_i\right)+m_i+1\right)}{\left(m_i+1\right)^2\left(m_i+2\right)},$$

$E\left(\hat{u}_i\right)$ = the expected value of $\hat{u}_i$ either in terms of the estimator (equation for $\hat{u}_i$) or just substitute in the estimated value and, $Var\left(\hat{u}_i\right)$ depends on the sampling method used to estimate $\hat{u}_i$.

Derivation:

Ignoring the subscript *i* for simplicity, the derivation of the variance estimator is based on the following unconditional variance expression,

$$Var\left(\hat{U}\right) = Var\left(E\left(\hat{U}|u\right)\right)+E\left(Var\left(\hat{U}|u\right)\right).$$

The expected value and variance $\hat{U}$ given u is as before, respectively,

$$E\left(\hat{U}_i|u\right) = \frac{u_i\left(M_i+1\right)}{\left(m_i+1\right)} \text{ and,}$$

$$Var\left(\hat{U}|u\right) = \frac{u\left(u+m+1\right)\left(M+1\right)\left(M-m\right)}{\left(m+1\right)^2\left(m+2\right)}.$$

Substituting in $\hat{u}$ for u gives the following,

$$Var\left(\hat{U}\right) = Var\left(\frac{\hat{u}\left(M+1\right)}{\left(m+1\right)}\right)+E\left[\frac{\left(M+1\right)\left(M-m\right)\hat{u}\left(\hat{u}+m+1\right)}{\left(m+1\right)^2\left(m+2\right)}\right]$$

$$Var\left(\hat{U}\right) = \left(\frac{\left(M+1\right)}{\left(m+1\right)}\right)^2 Var\left(\hat{u}\right)+\frac{\left(M+1\right)\left(M-m\right)}{\left(m+1\right)^2\left(m+2\right)}\left[E\left(\hat{u}^2\right)+E\left(\hat{u}\right)\left(m+1\right)\right]$$

Note that,

$$E\left(\hat{u}^2\right) = Var\left(\hat{u}\right) + \left(E\hat{u}\right)^2$$

Substituting in this value for $E\left(\hat{u}^2\right)$,

$$Var\left(\hat{U}\right) = \left(\frac{(M+1)}{(m+1)}\right)^2 Var\left(\hat{u}\right) + \frac{(M+1)(M-m)}{(m+1)^2(m+2)}\left[Var\left(\hat{u}\right) + \left(E\left(\hat{u}\right)\right)^2 + E\left(\hat{u}\right)(m+1)\right]$$

$$= \left(\frac{(M+1)}{(m+1)}\right)^2 Var\left(\hat{u}\right) + \frac{(M+1)(M-m)}{(m+1)^2(m+2)}\left[Var\left(\hat{u}\right) + E\left(\hat{u}\right)\left[E\left(\hat{u}\right) + m + 1\right]\right]$$

$$Var\left(\hat{U}\right) = \left(\frac{(M+1)}{(m+1)}\right)^2 Var\left(\hat{u}\right) + \frac{(M+1)(M-m)}{(m+1)^2(m+2)}Var\left(\hat{u}\right) + \frac{(M+1)(M-m)E\left(\hat{u}\right)\left[E\left(\hat{u}\right)+m+1\right]}{(m+1)^2(m+2)}$$

$$Var\left(\hat{U}\right) = Var\left(\hat{u}\right)\left(\frac{(M+1)^2}{(m+1)^2} + \frac{(M+1)(M-m)}{(m+1)^2(m+2)}\right) + \frac{(M+1)(M-m)E\left(\hat{u}\right)\left[E\left(\hat{u}\right)+m+1\right]}{(m+1)^2(m+2)}$$

$$Var\left(\hat{U}\right) = Var\left(\hat{u}\right)\left(\frac{(M+1)^2}{(m+1)^2} + \frac{(M+1)(M-m)}{(m+1)^2(m+2)}\right) + Var\left(\hat{U}\middle|E\left(\hat{u}\right)\right)$$

$$Var\left(\hat{U}\right) = \frac{(M+1)}{(m+1)^2}Var\left(\hat{u}\right)\left(\frac{(M+1)(m+2)}{(m+2)} + \frac{(M-m)}{(m+2)}\right) + Var\left(\hat{U}\middle|E\left(\hat{u}\right)\right)$$

$$Var\left(\hat{U}\right) = \frac{(M+1)}{(m+1)^2}Var\left(\hat{u}\right)\left(\frac{Mm + 2M + m + 2 + M - m}{(m+2)}\right) + Var\left(\hat{U}\middle|E\left(\hat{u}\right)\right)$$

$$Var\left(\hat{U}\right) = Var\left(\hat{u}\right)\left(\frac{(M+1)(Mm + 3M + 2)}{(m+1)^2(m+2)}\right) + Var\left(\hat{U}\middle|E\left(\hat{u}\right)\right)$$

Appendix B

Catch and Migration Estimates by Strata for Cedar River
Sockeye, Chinook, and Coho Salmon, 2012.

Appendix B 1. Catch and migration by strata for Cedar River natural-origin sockeye fry, 2012.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	1/22/2012	2/1/2012	7,484	6.10%	121,497	2.42E+08
2	2/1/2012	2/9/2012	6,285	1.68%	357,674	5.68E+09
3	2/10/2012	2/19/2012	47,551	4.72%	1,000,791	9.72E+09
4	2/20/2012	2/20/2012	4,403	1.72%	213,556	6.39E+09
5	2/21/2012	3/1/2012	12,387	0.50%	2,375,554	2.16E+11
6	3/2/2012	3/4/2012	8,886	5.50%	159,256	5.92E+08
7	3/5/2012	3/15/2012	25,898	1.87%	1,370,416	2.47E+10
8	3/16/2012	3/21/2012	38,298	2.72%	1,396,945	1.55E+10
9	3/22/2012	3/22/2012	13,795	4.84%	280,159	1.34E+09
10	3/23/2012	3/24/2012	21,061	11.48%	182,094	2.59E+08
11	3/25/2012	3/28/2012	58,721	4.55%	1,285,756	6.31E+09
12	3/29/2012	3/31/2012	27,301	2.67%	1,005,045	3.19E+10
13	4/1/2012	4/2/2012	32,043	4.66%	679,079	5.24E+09
14	4/3/2012	4/4/2012	9,382	1.25%	628,561	6.19E+10
15	4/5/2012	4/7/2012	23,313	4.96%	465,592	2.44E+09
16	4/8/2012	4/11/2012	44,408	3.19%	1,364,856	4.05E+10
17	4/12/2012	4/23/2012	64,038	4.78%	1,333,816	6.19E+09
18	4/24/2012	5/10/2012	4,635	1.81%	239,475	3.53E+09
		Total	**449,888**		**14,460,122**	**4.38E+11**

Appendix B 2. Catch and migration by strata for Cedar River natural-origin Chinook fry, 2012.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	1/22/2012	2/1/2012	1,742	6.10%	28,278	1.98E+07
2	2/1/2012	2/9/2012	1,018	1.68%	57,933	1.65E+08
3	2/10/2012	2/19/2012	2,498	4.72%	52,575	2.18E+07
4	2/20/2012	2/20/2012	195	1.72%	9,458	1.29E+07
5	2/21/2012	3/1/2012	1,977	0.50%	379,160	6.56E+09
6	3/2/2012	3/4/2012	298	5.50%	5,341	5.14E+05
7	3/5/2012	3/15/2012	1,695	1.87%	89,692	9.25E+07
8	3/16/2012	3/21/2012	1,475	2.72%	53,801	4.39E+07
9	3/22/2012	3/22/2012	241	4.84%	4,894	5.00E+05
10	3/23/2012	3/24/2012	483	11.48%	4,176	5.15E+05
11	3/25/2012	3/28/2012	889	4.55%	19,466	2.06E+06
12	3/29/2012	3/31/2012	551	2.67%	20,284	7.72E+06
13	4/1/2012	4/2/2012	613	4.66%	12,991	2.17E+06
14	4/3/2012	4/4/2012	525	1.25%	35,175	1.78E+08
15	4/5/2012	4/7/2012	722	4.96%	14,420	2.34E+06
16	4/8/2012	4/11/2012	588	3.19%	18,072	6.85E+06
17	4/12/2012	4/23/2012	1,166	4.78%	24,286	2.61E+06
18	4/24/2012	5/10/2012	317	1.81%	16,378	1.76E+07
		Total	**16,993**		**846,380**	**7.14E+09**

Appendix B 3. Catch and migration by strata for Cedar River natural-origin Chinook parr, 2012.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	5/11/2012	5/26/2012	405	10.19%	3,764	7.32E+05
2	5/27/2012	5/29/2012	75	38.82%	190	9.04E+02
3	5/30/2012	6/20/2012	1,695	6.86%	24,224	1.31E+07
4	6/21/2012	7/14/2012	517	5.08%	9,823	3.32E+06
Total			**2,692**		**38,001**	**1.71E+07**

Appendix B 4. Catch and migration by strata for Cedar River natural-origin coho migrants, 2012.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	4/18/2012	5/16/2012	201	6.16%	38565	1.52E+07
2	5/17/2012	5/24/2012	1674	11.34%	1611	1.07E+05
3	5/25/2012	7/14/2012	1013	3.40%	7992	9.02E+06
Total			**2,888**		**48,168**	**2.44E+07**

Appendix C

Catch and Migration Estimates by Strata for Bear Creek
Sockeye, Chinook, Coho Salmon, and Cutthroat Trout, 2012.

Appendix C 1. Catch and migration by strata for Bear Creek sockeye, 2012.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	1/24/2012	3/23/2012	1,851	2.42%	67,094	5.11E+08
2	3/24/2012	3/24/2012	484	11.29%	4,220	3.04E+05
3	3/25/2012	3/28/2012	2,388	5.51%	41,529	6.87E+07
4	3/29/2012	3/31/2012	9,349	16.08%	57,388	4.21E+07
5	4/1/2012	4/5/2012	3,518	8.20%	42,500	3.55E+08
6	4/6/2012	4/7/2012	2,142	15.86%	13,407	1.43E+06
7	4/8/2012	4/12/2012	3,071	9.75%	30,783	2.24E+07
8	4/12/2012	7/14/2012	1,692	16.90%	9,978	8.49E+05
		Total	**24,494**		**266,899**	**1.00E+09**

Appendix C 2. Catch and migration by strata for Bear Creek natural-origin Chinook, 2012.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	1/29/2012	3/23/2012	32	2.42%	1,162	1.91E+05
2	3/24/2012	3/24/2012	4	11.29%	35	2.83E+02
3	3/25/2012	3/28/2012	78	5.51%	1,363	5.13E+05
4	3/29/2012	3/31/2012	106	16.08%	651	8.66E+03
5	4/1/2012	4/5/2012	50	8.20%	604	7.49E+04
6	4/6/2012	4/7/2012	4	15.86%	25	1.35E+02
7	4/8/2012	4/12/2012	50	9.75%	501	1.50E+04
8	4/12/2012	4/18/2012	46	16.90%	270	2.05E+03
9	4/19/2012	5/12/2012	942	25.00%	3,718	1.95E+05
10	5/13/2012	5/15/2012	586	55.00%	1,061	5.35E+03
11	5/16/2012	5/26/2012	2,853	41.94%	6,782	1.54E+05
12	5/27/2012	6/13/2012	1,135	23.69%	4,756	1.78E+05
13	6/14/2012	6/20/2012	205	40.30%	503	3.40E+03
14	6/21/2012	7/14/2012	138	16.88%	766	4.13E+04
		Total	**6,229**		**22,197**	**1.38E+06**

Appendix C 3. Catch and migration by strata for Bear Creek natural-origin coho smolts, 2012.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	1/29/2012	4/29/2012	900	29.88%	2,998	4.98E+04
2	4/30/2012	5/6/2012	1,102	20.36%	5,377	2.05E+05
3	5/7/2012	7/14/2012	1,987	25.78%	7,684	2.03E+05
		Total	**3,989**		**16,059**	**4.57E+05**

Appendix C 4. Catch and migration by strata for Bear Creek cutthroat migrants, 2012.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	1/29/2012	5/14/2012	1,094	6.67%	15,558	1.21E+07
2	5/15/2012	7/14/2012	236	30.77%	726	2.68E+04
		Total	**1,330**		**16,284**	**1.21E+07**

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