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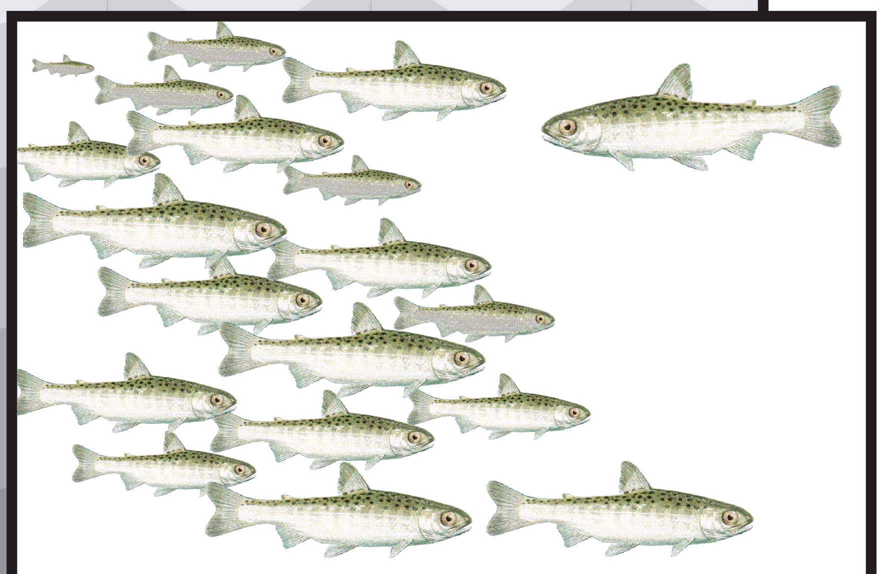
Evaluation of Juvenile Salmon Production in 2010 from the Cedar River and Bear Creek



by Kelly Kiyohara, and Mara Zimmerman

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

FPA 11-12

Evaluation of Juvenile Salmon Production in 2010 from the Cedar River and Bear Creek

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August 2011

Supported by
King County Department of Natural Resources and Parks
King Conservation District
Seattle City Public Utilities

Acknowledgements

Evaluations of 2010 juvenile salmon production in the Cedar River were made possible by City of Seattle Public Utilities (SPU), which funded operations of the inclined-plane trap. King Conservation District and King County Department of Natural Resources and Parks (DNRP) provided funding for trapping in Bear Creek, the Cedar River screw trap, and PIT tagging in both systems.

Success of these projects relied on the hard work of a number of dedicated Washington Department of Fish and Wildlife (WDFW) personnel. The WDFW Hatcheries Program successfully collected adult sockeye brood stock and incubated eggs, releasing over 4.54 million sockeye fry into the Cedar River. Escapement data were collected and estimates developed by individuals from several agencies: Steve Foley, Aaron Bosworth, Larry Lowe, Dan Estell, Lacey Jeroue, and Dave Smith from WDFW; Mike Leslie, Brian Footen, and Eric Warner from the Muckleshoot Tribe; Karl Burton from SPU; and Hans Berge, Mistie Hammer, 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 the traps, mark, identify, and count juvenile fish. WDFW biologists Mike Ackley and Pete Topping provided valuable experience and logistical support for the juvenile trapping operation. Project management was provided by Paul Faulds from SPU and Hans Berge from King County.

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

Cedar River

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

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

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

The United States Geological Survey provided continuous flow monitoring.

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

Bear Creek

Blockbuster Video provided electrical power.

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

King County Water and Land Resource Division provided continuous flow monitoring.

Table of Contents

List of Tables

List of Figures

Executive Summary

This report describes juvenile migrations of five salmonid species emigrating 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 basin, 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 production estimates to be derived for coho, steelhead, and cutthroat trout.

In 1997, WDFW initiated an evaluation of sockeye fry migrants in the Sammamish basin. 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, steelhead, and cutthroat trout.

The primary study goal of this program in 2010 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 2009 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 17 and May 2, 2010. A rotary screw trap was operated at R.M 1.6, just under the I-405 Bridge between April 15 and July 4, 2010. 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 2010 due to insufficient catch.

Production of natural-origin sockeye fry in the Cedar River was estimated to be 12.5 million ± 799,799 (95% C.I.). This estimate was based on a total catch of 804,648 between January 17 and May 2 and trap efficiencies ranged from 3.3% to 14.7%. Survival of sockeye fry from egg deposition to lake entry was calculated at 56.6%, based on an estimated deposition of 22.1 million eggs. Over the season, 4.5 million hatchery-origin sockeye fry were released into the Cedar River below the inclined-plane trap. If survival of the released hatchery fry is assumed to be 100%, an estimated 17.1 million combined natural and hatchery-origin sockeye fry entered Lake Washington from the Cedar River in 2010.

Median migration date for natural-origin sockeye fry was March 7, 2010, 14 days earlier than the long-term average and three days earlier than that of the hatchery fry release. The timing of sockeye outmigration was correlated with February stream temperatures (R^2=0.58) and the 2010 daily average temperatures (7.7°C) were warmer than the 19-year average of 6.4°C.

Production of natural-origin Chinook was estimated to be 152,390 ± 13,058 (95% C.I.) sub yearlings. This estimate was based on operation of both the inclined-plane and screw traps. Between January 1 and April 14, 2010, 115,474 ± 13,058 (95% C.I.) natural-origin Chinook were estimated to have passed the inclined-plane trap. This estimate was based on a total catch of 7,522 and trap efficiencies ranging from 3.3% to 14.7%. Between April 15 and July 4, 2010, 36,916 ± 5,374 (95% C.I.) natural-origin Chinook were estimated to have passed the screw trap. This estimate is based on a total catch of 3,567 natural-origin juvenile Chinook in the screw trap and trap efficiencies ranging of 8.9% and 11.2%. Egg-to-migrant survival of the 2009 brood year Chinook was estimated to be 11.9%, the fourth highest estimated since trapping began..

Weekly average lengths of sub yearling Chinook increased from 38.2 mm fork length (FL) in January to 95.6 mm FL by the end of the season. Migration timing was bi-modal. The small fry emigrated between January and mid-April and comprised 76% of all sub yearlings. The large parr emigrated between mid-April and July and comprised 24% of the total migration.

A total of 83,060 ± 13,011 (95% CI) natural-origin coho were estimated to have migrated passed the screw trap in 2010. This total included 1,091 coho estimated to have migrated before screw trapping began, 81,720 coho estimated during the trapped period, and 249 coho estimated to have migrated after trapping concluded. Steelhead/rainbow and cutthroat trout production were not estimated in 2010 due to low catches (8 steelhead/rainbow and 73 cutthroat).

Bear Creek

An inclined-plane trap was operated 100 yards downstream of the Redmond Way Bridge between January 31 and April 16, 2010. On April 17, a rotary screw trap replaced the inclined-plane trap and was fished until July 4, 2010. The abundance of natural-origin juvenile migrants was estimated for sockeye fry, sub yearling Chinook, coho, and cutthroat trout. No steelhead/rainbow were caught in the Bear Creek traps during the 2010 trapping season.

Sockeye fry migration in 2010 was estimated to be 129,903 ± 19,443 (95% C.I.). This estimate was based on a total catch of 8,881 sockeye fry and trap efficiencies ranging from 6.7% to 8.1%. An egg-to-migrant survival rate of 4.7% was based on an egg deposition of 2.8 million and was the lowest estimate of survival since trapping began in 1998.

Production of natural-origin Chinook was estimated to be 9,185 ± 2,408 (95% C.I.) sub yearlings. This estimate was based on catch in the inclined-plane and screw traps. A total of 1,554 ± 415 (95% C.I.) Chinook were estimated to have migrated passed the inclined-plane trap between January 31 and April 16. This estimate was based on a total catch of 104 Chinook and efficiencies ranging of 6.7% and 8.1%. A total of 7,631 ± 2,372 (95% C.I.) Chinook were estimated to have migrated passed the screw trap between April 17 and July 4. This estimate is based on a total catch of 1,316 Chinook and screw trap efficiencies ranging from 5.8% to 52.9%.

Egg-to-migrant survival of the 2009 brood year natural-origin Chinook was estimated to be 4.3%, the second highest survival measured.

Weekly average lengths of sub yearling Chinook migrants averaged 38.0 mm FL in February and increased to an average of 82.3 mm FL near the end of the season. Migration timing of sub yearling Chinook was bimodal. Small fry emigrated between February and April and comprised 16.7% of the total migration. Large parr migrants emigrated between May and July and represented 83.3% of total production in Bear Creek during 2010.

A total of 13,100 ± 1,673 (95% C.I.) natural-origin coho and 5,209 ± 769 (95% C.I.) cutthroat trout were estimated to have migrated from Bear Creek in 2010.

Introduction

This report describes the juvenile migrations of five salmonid species emigrating from two heavily spawned tributaries in the Lake Washington basin: 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 2010 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.

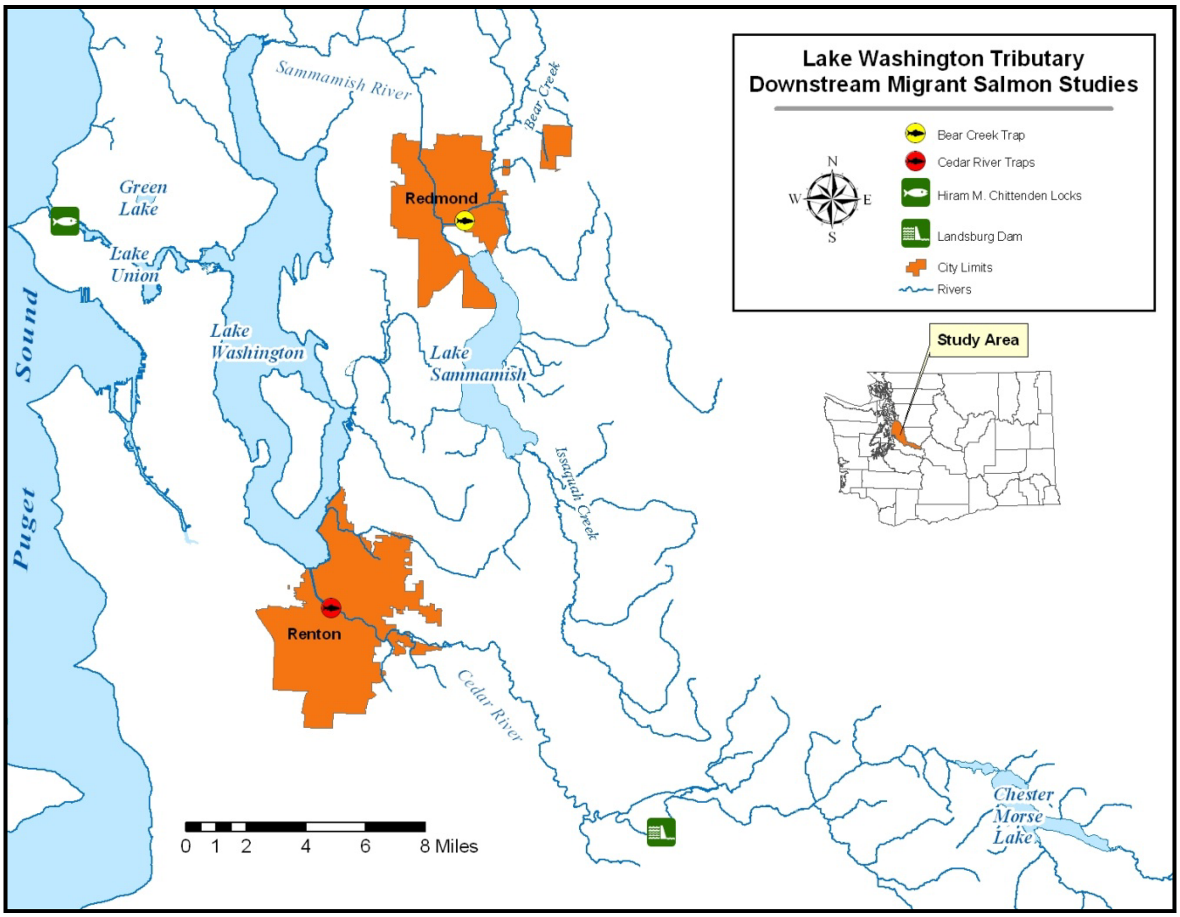

Figure 1. Map of Lake Washington trap sites used to monitor abundance of juvenile migrant salmonids in the Cedar River and Bear Creek, near Renton and Redmond, respectively.

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 90,042 spawners. Survival from egg deposition in the Cedar River to lake entry has ranged between 1.9% and 56.6%. When juvenile monitoring in the Sammamish watershed began in 1997, sockeye had returned to Bear Creek in excess of 50,000 spawners (1996 broodyear). Over the duration of the juvenile monitoring study, escapement has ranged from 577 to 60,000 spawners, with an average return of 13,944 sockeye. Survival from egg deposition to migration in Bear Creek has ranged between 3.0% and 36.2%.

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 Basins, but adult-to-adult survival provides little insight into life stage-specific survival in freshwater or marine habitats. 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 6 months and includes an early migration of newly emerged fry and a later migration of larger 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 later in the season. A rotary screw trap more effectively catches the late-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 19.1% 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 1.0% and 11.0% since 2000.

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. 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 outmigration 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 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 avoiding 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 19 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 in order to operate under suitable current velocities.

In 2010, the inclined-plane trap was positioned at RM 0.8, just downstream of the South Boeing Bridge (Figure 2). This trap fished off the east bank and was repositioned within eight feet of the shoreline in response to changing flows. Two scoop traps were fished in parallel throughout the season except on 4 nights when only one trap was operated due to high flows and debris loads.

The inclined-plane trap began operating on the night of January 17 was operated 71 nights between January 17 and May 2. During each night of operation, trapping began before dusk and continued past dawn. Trapping was also conducted during five day-time periods on a bi-weekly basis from the beginning of February through the end of March. Inclined-plane trap operations were suspended for a total of three hours and twenty minutes in one evening due to heavy debris. 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.

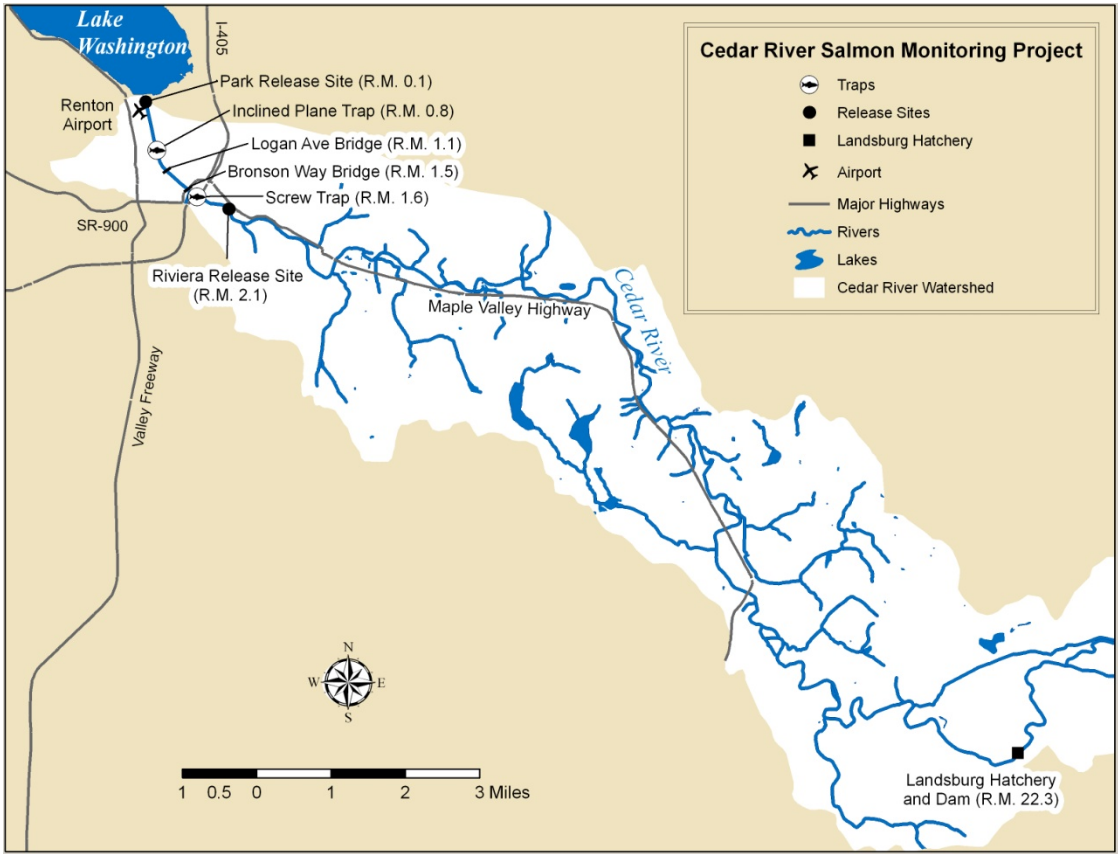

Figure 2. Site map of the lower Cedar River watershed depicting the inclined-plane and screw trap locations and hatchery sockeye release site for the 2010 trapping season.

In 2010, the screw trap was operated at R.M 1.6, just under the I-405 Bridge (Figure 2), between the evening of April 15 and July 4, except during 5 night outage periods (May 5, 6 and 29, and June 2 and 27) caused by high debris loads and 28 day periods when the 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

As with the Cedar River, juvenile migrants were captured using two traps in lower Bear Creek. An inclined-plane trap, identical to that employed in the Cedar River, was used to capture sockeye and Chinook fry early in the trapping season. This trap was replaced with a 5 ft diameter screw trap in mid April to capture Chinook, coho, steelhead/rainbow, and cutthroat.

The inclined-plane trap was operated between January 31 and April 16. A single scoop trap was suspended from a 30 x 12 ft steel pontoon barge positioned in the middle of the channel approximately 100 yards downstream of Redmond Way, below the railroad trestle (Figure 3). When the trap was operated, fishing began before dusk and continued past dawn. During trap operations, captured fish were removed from the trap and enumerated. Depending on catch rates, fish were removed from the trap every hour or every several hours. On April 16, 2010, the screw trap replaced the inclined-plane trap and fished for the remainder of the season.

The screw trap was operated between April 16 and the morning of July 4, except during three outage periods (May 10, 22, and June 30) caused by debris. Catches were identified to species and enumerated at dusk and in the early morning.

For both traps, fork lengths were randomly sampled on a weekly basis from all Chinook, coho, steelhead/rainbow, and cutthroat smolts.

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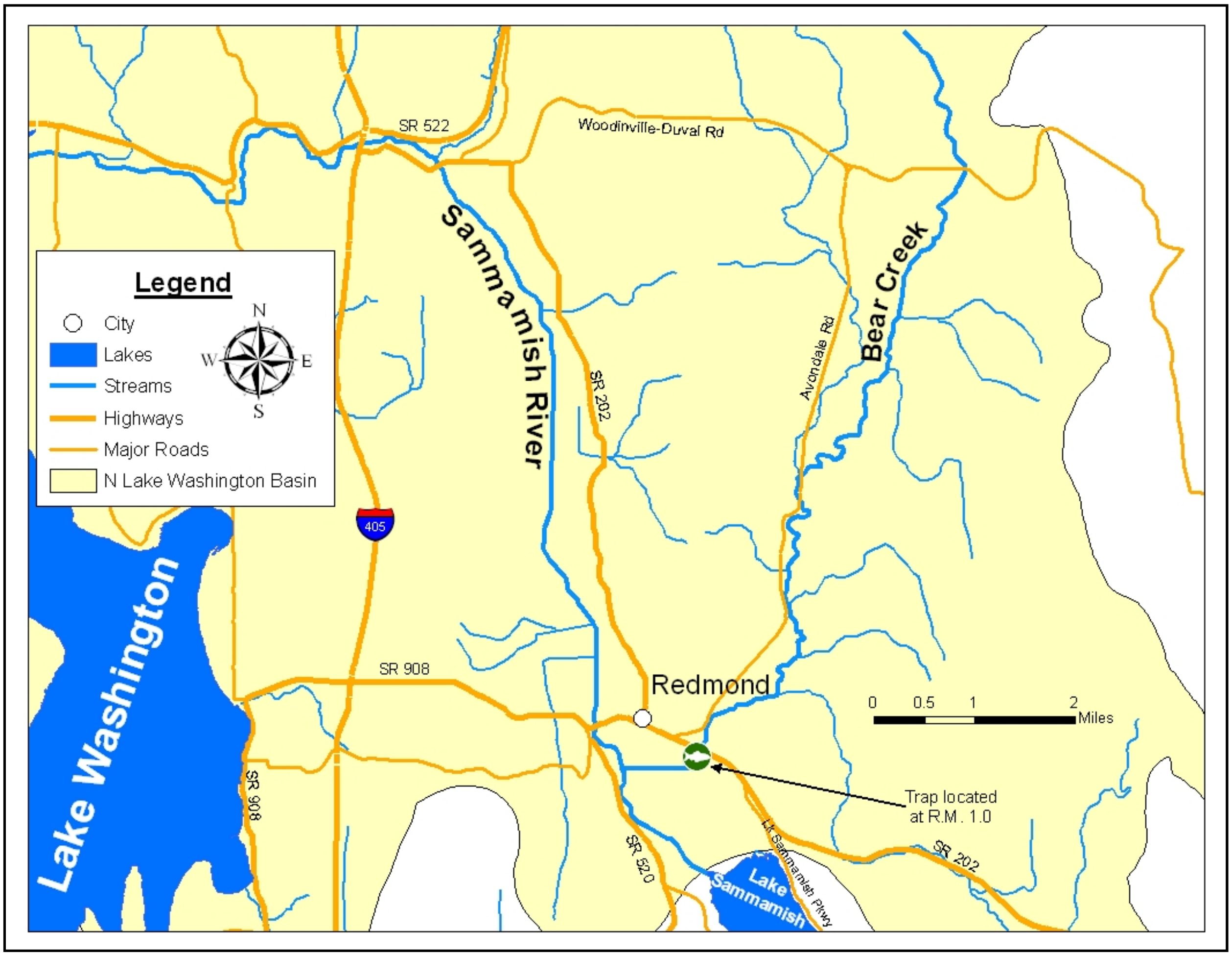

Figure 3. Site map of the Bear Creek watershed in the North Lake Washington Basin showing trap location for the 2010 trapping season.

PIT Tagging

During screw trap operation at both sites, a portion of Chinook migrants were tagged with Passively Integrated Transponder (PIT) tags. Tagging occurred two to three times a week, depending on catches, at the Cedar River screw trap between April 20 and June 30, 2010, and from May 5 through June 11, 2010 in Bear Creek. 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 larger 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). 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. Natural-origin sockeye fry 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 23 to 1,667 marked sockeye fry, were released at the Logan Street Bridge (R.M. 1.1) nearly every night the trap operated (71 nights) throughout the season. At the release location, marked fry were distributed across the middle of the channel. Catches were examined for marked fish and recaptures were noted during each trap check.

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 water flow. 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 1,200-yds upstream of the trap (Riviera release location). On a given night, releases varied from 1 to 155 juveniles of each species. Catches were examined for marks or tags and recaptures were noted during each trap check.

Beginning April 20, Chinook parr longer 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 release 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 of Chinook parr.

Bear Creek

Inclined-Plane Trap

Trap efficiencies for the Bear Creek inclined-plane trap were estimated from recaptures of marked sockeye fry released above the trap. Release groups ranged from 24 to 274 sockeye and were released approximately 100 yards upstream of the trap at the Redmond Way Bridge. Mark groups were smaller than previous years due to low catches of sockeye fry. Fry releases occurred on 28 nights throughout the season, when adequate numbers of fish were available. Fry captured in the early hours of the 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.

Screw Trap

Trap efficiencies for the Bear Creek screw trap were estimated for Chinook, coho, and cutthroat using the same approach described for the Cedar River screw trap. On a given night, groups of 3 to 73 individuals of each species were released from the Redmond Way Bridge.

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 recapture 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 estimated for entire night or entire day periods only applied to the inclined-plane trap when planned outages occurred for an entire diel period. Missed day catches were not estimated in Bear Creek because previous years' sampling has indicated that day migrations are minimal to none in this watershed.

Missed Catch for Entire Night Periods

When the inclined-plane trap was 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

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

Equation 2

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

where:

k = number of sample nights used in the interpolation,

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

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

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

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

Equation 3

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

Missed Catch for Partial Day and Night Periods

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

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

where:

T_i = Hours during non-fishing period *i*

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

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

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

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

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

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 are assigned to one strata and the significantly different trial is 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 two 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 and coho in both watersheds was January 1 to July 13.

Total Production

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

Equation 13

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

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

Egg-to-Migrant Survival

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 2010 abundance of juvenile migrants by the 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. The number of sockeye females was assumed using an even sex ratio. Cedar sockeye fecundity was the average number of eggs per female during 2009 sockeye brood stock collection for the Landsburg Hatchery on the Cedar River (Cuthbertson 2010). Fecundity of Cedar River sockeye was assumed to be the same as the fecundity of Bear Creek 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. 2010). Chinook fecundity was based on measured fecundities at the Soos Creek Hatchery (M. Wilson, Washington Department of Fish and Wildlife, personal communication).

Cedar River Results

Sockeye

Catch and Estimated Missed Catch

Total estimated catch (actual and missed) in the inclined-plane trap was 804,648 sockeye fry. A total of 554,503 natural-origin sockeye fry were caught in the inclined-plane trap during trap operations. An additional 234,220 sockeye fry should have been caught had the inclined-plane trap fished continuously at night between January 17 and May 2, 2010. Five day intervals were trapped to evaluate day-time migration: February 2, 16, and March 2, 17, 30. Flows on these days ranged from 456 cfs to 676 cfs at the Cedar River USGS gage (#12119000) and were representative of flows throughout the season. Day-to-night catch ratios ranged from 1.2% to 8.3%. An estimated 15,924 fry should have been caught had the trap fished during all day-time periods. Missed day-time catch represented 1.98% of the season's total catch.

Production Estimate

A total of 57 efficiency trials, ranging in size from 100 to 1,668 sockeye, were conducted in 2010. Trial data were aggregated into twenty-two strata. Recapture rates for these strata ranged from 3.3% to 14.7%.

An estimated 17.1 million sockeye fry entered Lake Washington from the Cedar River in 2010 (Table 1, Figure 4, Appendix B1). This migration included 12.5 million ± 799,779 (95% C.I.) natural-origin fry and 4.5 million hatchery fry. Pre-season migration, January 1 through January 16, was estimated to be 11,768 fry, and the post-season migration, May 3 through June 30, was estimated to be 91,107 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 3.3%.

Table 1. Abundance of natural-origin and hatchery sockeye fry entering Lake Washington from the Cedar River in 2010. Table includes abundance of fry migrants, 95% confidence intervals (C.I.), and coefficients of variation (*CV*).

Component	Period	Dates	Fry Abundance	95% C.I. Low	95% C.I. High	*CV*	Proportion of Total
Natural Origin	Pre Trapping	January 1 - 16	11,768	9,908	13,628	8.1%	0.1%
	During Trapping	January 17-May 2	12,416,385	11,616,606	13,216,163	3.3%	99.2%
	Post Trapping	May 3- June 30	91,107	85,711	96,503	3.0%	0.7%
		Subtotal	**12,519,260**	**11,719,460**	**13,319,059**	**3.3%**	
Hatchery	Below Trap	February 8 - April 12	4,543,000				
		Subtotal	**4,543,000**				
		Total	**17,062,260**				

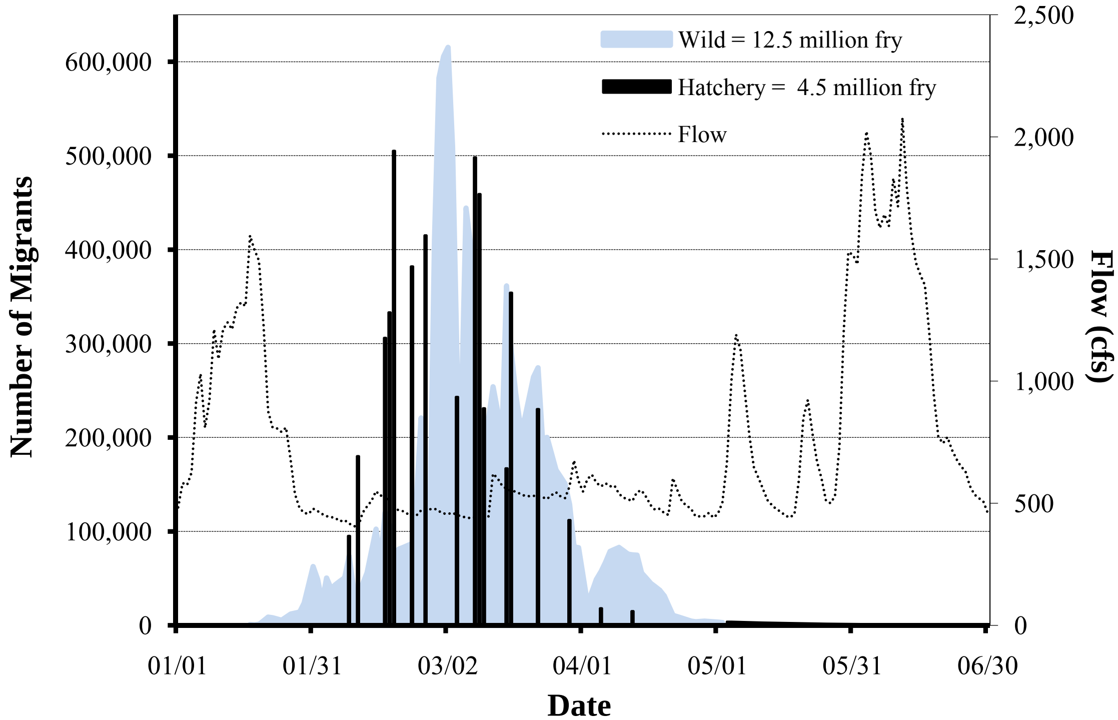

Figure 4. Daily migration of natural-origin and hatchery sockeye fry migrating from the Cedar River into Lake Washington between January 17 and May 2, 2010. Graph includes daily average flows during this period (USGS Renton gage Station #12119000).

Natural-Origin and Hatchery Timing

In 2010, hatchery sockeye were released downstream of the Cedar River inclined-plane trap. Releases of hatchery fry began on February 8 and continued through April 12 (Table 2, Figure 4). Median migration date for hatchery fry released downstream of the inclined-plane trap was March 4 (Table 3).

Migration of natural-origin fry was under way when trapping began on January 17. The number of natural-origin juvenile migrants increased moderately at the beginning of the season. Daily migrations averaged less than 100,000 sockeye per day until February 23. Between February 24 and March 29, the number of daily migrants averaged over 200,000 sockeye per day. Migration peaked on March 2 with 615,316 sockeye passing the trap on a single night (Figure 4). The median migration date for natural-origin fry occurred on March 7, three days later than the hatchery median migration date (Table 3). Natural origin migration was 25%, 50% and 75% completed by February 28, March 7, and March 21, respectively (Figure 5).

Stream temperatures were correlated with median migration date. 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 = 0.58, Figure 6). Temperature data was acquired from the USGS Renton gage Station # 12119000. February stream temperatures averaged 7.7° C in 2010, the warmest over the 19-year data set which averages 6.4°C. Median migration date was also earlier than the 19-year average median migration date (Table 3). The 2001 fry migration was not included in this analysis. This point was treated as an outlier due to extreme low flows throughout the outmigration and an earthquake on February 28. Low flows may have increased predation, and the earthquake triggered a landslide that temporarily blocked flow and likely caused significant mortality in the later-timed portion of the fry production.

Table 2. Hatchery sockeye fry released into the Cedar River in 2010 (Cuthbertson 2010)

Release Date	Number Released Below Trap (RM 0.1)
02/08/2010	95,000
02/10/2010	180,000
02/16/2010	306,000
02/17/2010	333,000
02/18/2010	505,000
02/22/2010	382,000
02/25/2010	415,000
03/04/2010	243,000
03/08/2010	498,000
03/09/2010	459,000
03/10/2010	231,000
03/15/2010	167,000
03/16/2010	354,000
03/22/2010	230,000
03/29/2010	112,000
04/05/2010	18,000
04/12/2010	15,000
Total	**4,543,000**

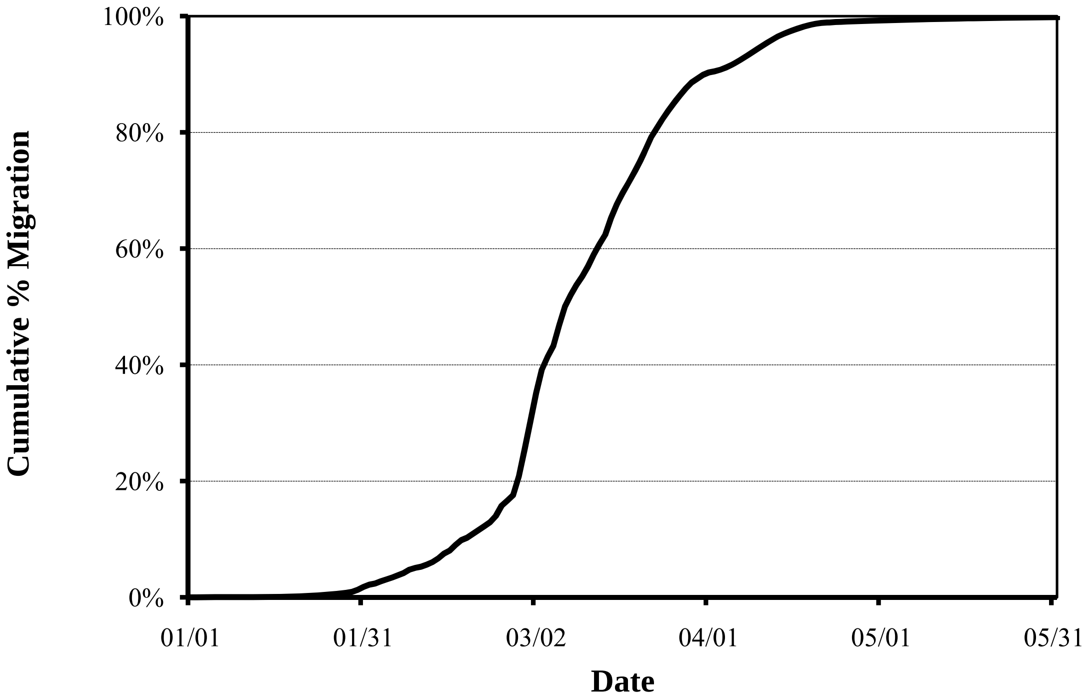

Figure 5. Cumulative migration of natural-origin sockeye fry from the Cedar River into Lake Washington in 2010.

Table 3. Median migration dates of natural-origin, hatchery, and total (combined) sockeye fry from the Cedar River for brood years 1991 to 2009. Total thermal units for February was measured in degrees Celsius at the USGS Renton gage Station #12119000. Temperature was not available for the 1991 brood year. Brood year 2000 was treated as an outlier and not included in this analysis.

Brood Year	Trap Year	February	Median Migration Date			Difference
i	i+1	Thermal Units	Wild	Hatchery	Combined	(days) W-H
1991	1992		03/18	02/28	03/12	19
1992	1993	156	03/27	03/07	03/25	20
1993	1994	162	03/29	03/21	03/26	8
1994	1995	170	04/05	03/17	03/29	19
1995	1996	153	04/07	02/26	02/28	41
1996	1997	147	04/07	02/20	03/16	46
1997	1998	206	03/11	02/23	03/06	16
1998	1999	187	03/30	03/03	03/15	27
1999	2000	161	03/27	02/23	03/20	32
2000	2001	158	03/10	02/23	03/08	15
2001	2002	186	03/25	03/04	03/19	21
2002	2003	185	03/08	02/24	03/03	12
2003	2004	186	03/21	02/23	03/15	26
2004	2005	193	03/02	02/01	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
	Average		03/21	02/27	03/13	22

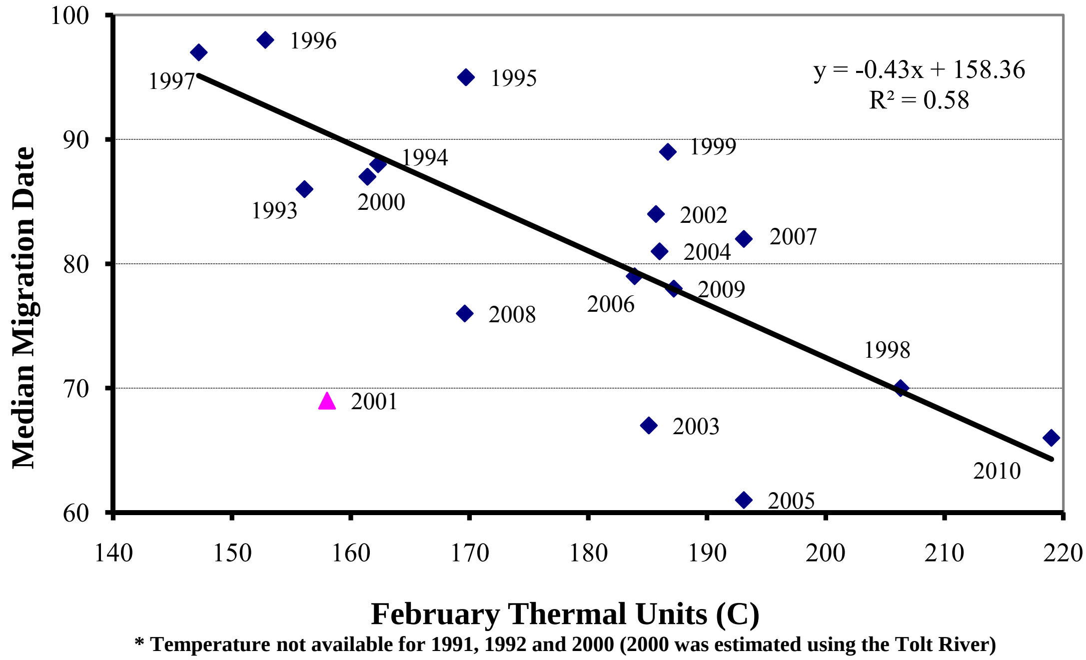

Figure 6. Median migration date (Julian Calendar day) for natural-origin sockeye fry in the Cedar River as a function of cumulative February thermal units (Celcius), migration years 1993-2010. Stream temperature data was measured at the USGS Renton gage Station #12119000. Migration year 2001 was treated as an outlier and not included in analysis.

Egg-to-Migrant Survival of Natural-Origin Fry

Egg-to-migrant survival of the 2009 brood Cedar River sockeye was estimated to be 56.6 % (Table 4). Survival was based on 12.5 million natural-origin fry surviving from a potential 22.1 million eggs deposited by 6,251 females (A. Bosworth, Washington Department of Fish and Wildlife, personal communication). Average fecundity for the 2009 brood was 3,540 eggs per female sockeye (Cuthbertson 2010). This is the highest egg-to-migrant survival observed since juvenile monitoring began in the Cedar River.

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 =0.35, 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 17.38% and a range between 5.03% and 56.6%. Above peak flows of 5,000 cfs, survival has been less variable with an average of 4.7% and a ranged between 1.91% and 5.90%.

Table 4. Egg-to-migrant survival of natural-origin sockeye fry in the Cedar River and peak mean daily flows during egg incubation period for brood years 1991 - 2009. Flow was measured at the USGS Renton gage Station #12119000.

Brood Year	Spawners	Females (@50%)	Fecundity	Potential Egg Deposition	Fry Production	Survival Rate	Peak Incubation Flow (cfs)	Date
1991	77,000	38,500	3,282	126,357,000	9,800,000	7.76%	2,060	01/28/1992
1992	100,000	50,000	3,470	173,500,000	27,100,000	15.62%	1,570	01/26/1993
1993	76,000	38,000	3,094	117,572,000	18,100,000	15.39%	927	01/14/1994
1994	109,000	54,500	3,176	173,092,000	8,700,000	5.03%	2,730	12/27/1994
1995	22,000	11,000	3,466	38,126,000	730,000	1.91%	7,310	11/30/1995
1996	230,000	115,000	3,298	379,270,000	24,390,000	6.43%	2,830	01/02/1997
1997	104,000	52,000	3,292	171,184,000	25,350,000	14.81%	1,790	01/23/1998
1998	49,588	24,794	3,176	78,745,744	9,500,000	12.06%	2,720	01/01/1999
1999	22,138	11,069	3,591	39,748,779	8,058,909	20.27%	2,680	12/18/1999
2000	148,225	74,113	3,451	255,762,238	38,447,878	15.03%	627	01/05/2001
2001	119,000	59,500	3,568	212,296,000	31,673,029	14.92%	1,930	11/23/2001
2002	194,640	97,320	3,395	330,401,400	27,859,466	8.43%	1,410	02/04/2003
2003	110,404	55,202	3,412	188,349,224	38,686,899	20.54%	2,039	01/30/2004
2004	116,978	58,489	3,276	191,609,964	37,027,961	19.32%	1,900	01/18/2005
2005	50,887	25,444	3,065	77,984,328	10,861,369	13.90%	3,860	01/11/2006
2006	106,961	53,481	2,910	155,628,255	9,246,243	5.90%	5,411	11/09/2006
2007	45,489	22,745	3,450	78,468,525	25,072,141	31.95%	1,820	12/03/2007
2008	15,995	7,998	3,135	25,072,163	1,630,081	6.50%	9,390	01/08/2009
2009	12,501	6,251	3,540	22,126,770	12,519,260	56.58%	2,000	11/19/2009

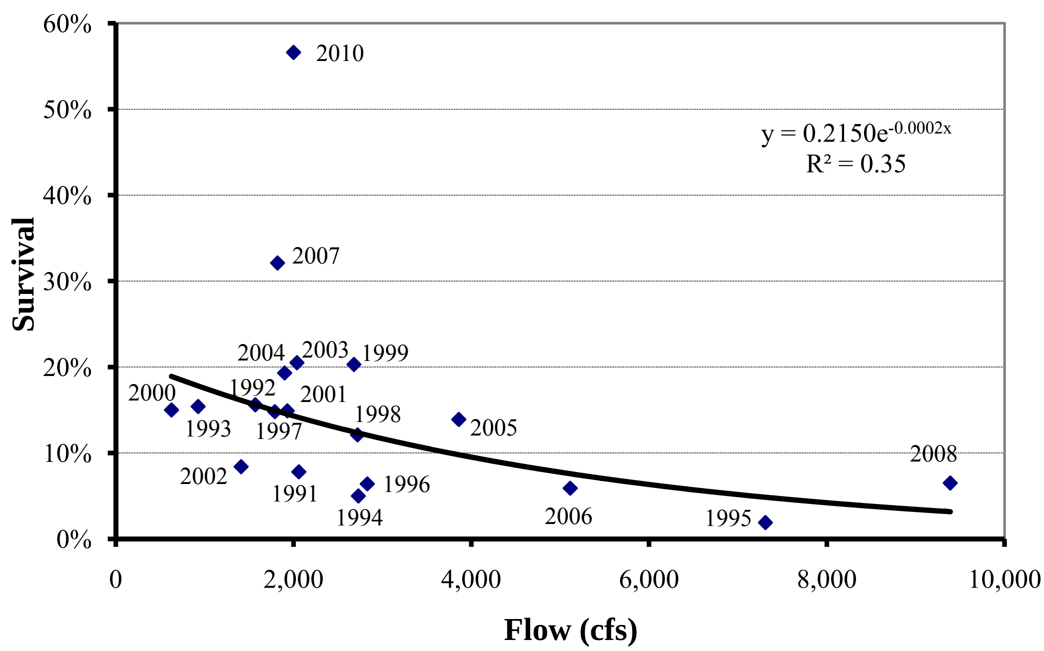

Figure 7. Egg-to-migrant survival of natural-origin sockeye in the Cedar River as a function of peak flow during the winter egg incubation period (November 1 through January 31). Survival for brood years 1991 to 2009 is fit with a decreasing exponential curve.

Chinook

Catch and Estimated Missed Catch

Inclined-Plane Trap

Total catch (actual and missed) of natural-origin Chinook in the inclined-plane trap was estimated to be 7,522 sub yearlings. A total of 4,948 Chinook were captured and an estimated 2,574 additional fry should have been caught if the inclined-plane trap fished continuously (day and night) between January 17 and April 15. Catch was partially missed on four nights due to large amounts of debris. Day-to-night catch ratios used to calculate missed day catch ranged from 0% to 33.9%.

Screw Trap

Total catch (actual and missed) of natural-origin Chinook in the screw trap was estimated to be 3,567 sub yearlings between April 15 and July 4, 2010. A total of 3,287 natural-origin (unmarked) and 19 hatchery (adipose fin clipped or ad-marked) Chinook were caught in the screw trap. Estimated catch for outage periods was 280 natural-origin Chinook and accounted for 7.8% of the total estimated catch. Catch was estimated for 8 periods when the trap was stopped by debris (3 night periods and 5 day periods). Catch was also estimated for 17 day periods that the trap was intentionally not operated due to either high flows or public safety precautions. Production estimate was based on catches of natural-origin Chinook only.

Production Estimate

Inclined-Plane Trap

A total of 57 efficiency trials, ranging in size from 100 to 1,668 sockeye (surrogates for Chinook), were released. Trials were aggregated into twenty-two strata. Recapture rates for the efficiency strata ranged from 3.3% to 14.7%.

Chinook migration was estimated to be 111,684 fry between January 17 and April 15, 2010 (Appendix B 2). A total of 3,790 Chinook fry were estimated to have migrated between January 1 and 16 (i.e., prior to inclined-plane trap operation). This extrapolation combined with the migration estimate during trap operation yields a total migration of 115,474 ± 13,058 (95% C.I.) Chinook fry through April 15 (Table 5).

During weeks 16 (beginning April 15) through 18 (ending May 2), both the inclined-plane and screw traps operated simultaneously. Migration estimates and average size of Chinook were not significantly different during the overlapping period, and the average fork lengths of Chinook caught in both traps were greater than 55 mm. In general, the inclined-plane trap does not capture larger migrants as efficiently as the screw trap. Since the average size Chinook caught in the inclined-plane trap was greater than 55 mm, it did not seem appropriate to assume sockeye recapture rates were similar to larger Chinook recapture rates for estimating migration. Therefore, the Chinook migration from April 16 forward was estimated based on screw trap data.

Table 5. Abundance of natural-origin juvenile migrant Chinook in the Cedar River in 2010. 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 - 16		3,790	3,008	4,572	10.5%
Inclined-Plane Trap	January 17-April 15	7,522	111,684	102,416	128,532	5.8%
Total Fry		**7,522**	**115,474**			
Screw Trap	April 16-July 4	3,567	36,754	31,380	42,128	7.5%
Post-Trapping	July 5-July 30		162	145	179	5.2%
Total Parr		**3,567**	**36,916**			
	Season Total	**11,089**	**152,390**	**138,269**	**166,510**	**4.7%**

Screw Trap

A total of 43 efficiency trials, ranging in size from 1 to 155 Chinook, were conducted. Trials were aggregated into 2 final strata resulting in recapture rates of 8.9% and 11.2% (Appendix B3). Migration of natural-origin Chinook between April 16 and July 4 was estimated to be 36,754 ± 5,326 (95% C.I.) parr (Table 5).

Combined Estimate

In total, 152,390 sub yearling Chinook are estimated to have migrated from the Cedar River into Lake Washington in 2010. This estimate is the combination of the Chinook production estimated from the interpolated pre-trapping period, the inclined-plane trap from January 17 through April 15, the estimate from the screw trap for April 16 to July 4 (Table 5), and the post-trapping period.

Migration Timing

Timing of the Chinook migration was bi-modal, similar to previous years (Figure 8). Migration was 25%, 50%, and 75% complete by roughly February 18, March 9, and April 9, respectively (Figure 9). Chinook fry migration quickly climbed above 1,000 fish per night at the beginning of the season. Fry migration peaked on March 12 with 6,450 fry passing the trap in a single day. Two additional peaks occurred on March 8 and 29, both over 6,000 fish. Migration then declined, with daily migrations being similar to estimated screw trap migrations. Parr peak migration occurred May 3 when 3,693 Chinook were estimated to have passed the trap in a single day. Juvenile Chinook emigrated mostly as fry, which represented 76% of the total migration (Table 6).

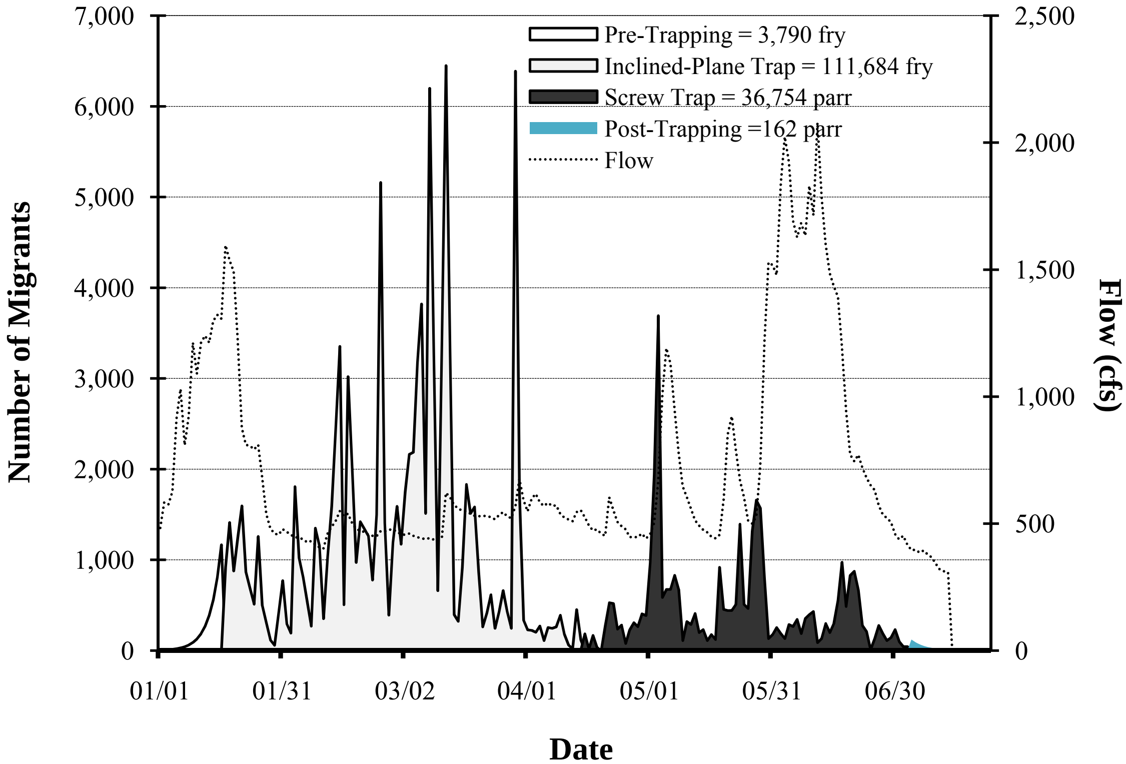

Figure 8. Estimated daily migration of sub yearling Chinook from the Cedar River in 2010 based on inclined-plane (January 17 to April 15) and screw trap estimates (April 16 to July 4). Graph includes mean daily flows during this time period (USGS Renton gage, Station #12119000) in 2010.

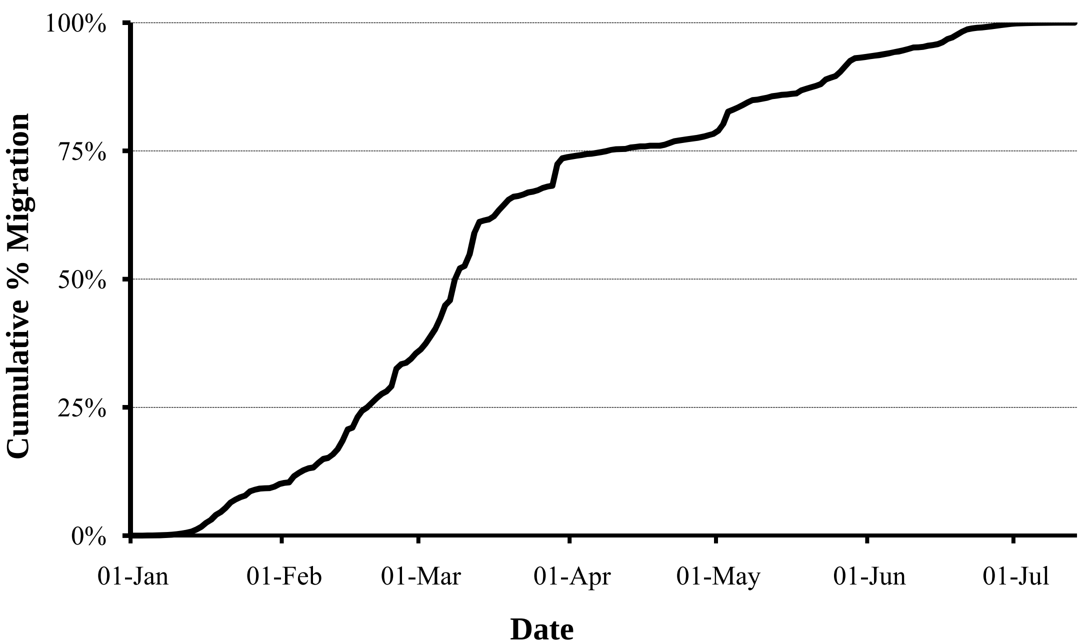

Figure 9. Cumulative percent migration of sub yearling Chinook from the Cedar River in 2010.

Table 6. 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 2009.

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%	180	810,000	255	105	360	5.7%	2.3%	8.0%
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%

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2009 brood of Cedar River Chinook was estimated to be 11.9% (Table 6). Survival was based on 152,390 natural-origin sub yearlings surviving from a potential 1.28 million eggs deposited by 285 female spawners (Burton et al. 2010). Average fecundity for the 2009 brood was assumed to be 4,500 eggs per female.

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 7, Figure 10). During screw trap operation, sizes ranged from 45 mm to 127 mm FL and averaged 82.9 mm FL. Chinook caught in the screw trap increased in size from a weekly average fork length of 68.7 mm in mid-April to 95.6 mm in July (Table 7). Chinook averaged more than 70 mm FL by late-April. The average fork length of fry in 2010 was the largest in the 10-year dataset while parr lengths were near the median of the 10-year data set (Table 8).

Table 7. Fork lengths (mm) of natural-origin juvenile Chinook caught in the Cedar River inclined-plane and screw traps in 2010. Data are mean, standard deviation (s.d.), range, sample size (n), and catch for each statistical week.

Statistical Week			Inclined-Plane Trap						Screw Trap					
					Range						Range			
Begin	End	No.	Avg.	s.d.	Min	Max	n	Catch	Avg.	s.d.	Min	Max	n	Catch
01/11	01/17	3	38.2	1.4769	36	41	14	63						
01/18	01/24	4	38.8	1.4694	34	42	92	352						
01/25	01/31	5	39.7	1.5837	36	42	46	156						
02/01	02/07	6	39.8	1.29	38	43	52	199						
02/08	02/14	7	38.5	2.62	35	44	81	622						
02/15	02/21	8	40.6	2.70	35	47	82	661						
02/22	02/28	9	40.3	2.52	37	47	36	499						
03/01	03/07	10	41.0	3.95	37	62	63	564						
03/08	03/14	11	44.0	6.25	37	58	48	933						
03/15	03/21	12	43.7	5.78	37	67	69	343						
03/22	03/28	13	47.7	10.09	36	72	49	142						
03/29	04/04	14	49.0	8.99	35	76	170	328						
04/05	04/11	15	57.6	10.77	40	81	49	57						
04/12	04/18	16	58.6	10.53	42	83	37	38	68.7	10.59	52	88	42	42
04/19	04/25	17	65.5	10.38	47	80	26	62	73.2	7.91	56	92	171	213
04/26	05/02	18	65.7	10.77	47	89	30	65	74.8	9.64	50	96	180	300
05/03	05/09	19							76.1	7.94	53	98	690	883
05/10	05/16	20							77.3	10.77	45	103	85	144
05/17	05/23	21							83.1	8.02	66	104	202	277
05/24	05/30	22							84.9	7.25	67	109	486	618
05/31	06/06	23							85.8	5.58	78	96	13	51
06/07	06/13	24							92.2	8.05	65	112	147	158
06/14	06/20	25							94.3	8.12	74	125	308	323
06/21	06/27	26							93.9	7.62	75	127	208	217
06/28	07/04	27							95.6	7.41	81	113	59	61
Season Totals			45.5	10.10	34	89	944	5,084	82.9	11.28	45	127	2,591	3,287

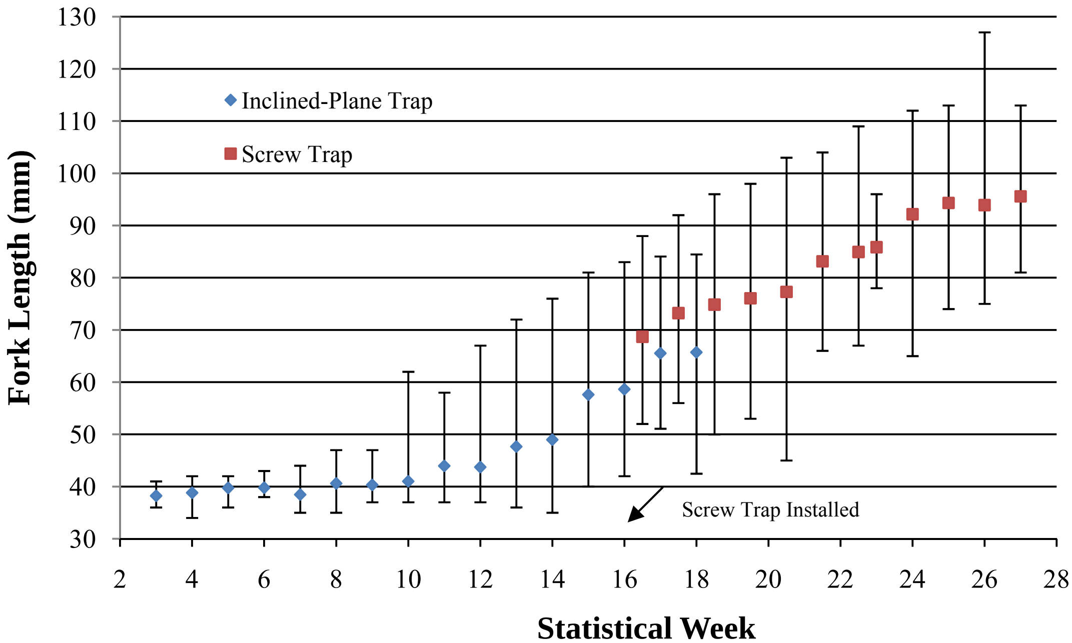

Figure 10. Fork lengths of natural-origin juvenile Chinook sampled from the Cedar River, 2010. Graph shows average, minimum, and maximum lengths by statistical week.

Table 8. Fork lengths (mm) of natural-origin juvenile Chinook measured over ten years (brood years 2000-2009) at the Cedar River inclined-plane and screw traps.

Brood	Inclined-Plane Trap						Screw Trap					
Year	Avg	s.d.	Min	Max	n	Catch	Avg	s.d.	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

Coho

Catch and Estimated Missed Catch

A total catch (actual and missed) in the screw trap was estimated to be 6,528 coho smolts. This included 6,321 natural-origin coho caught in the screw trap between April 16 and July 4 and 207 coho smolts that should have been caught had the trap fished continuously.

Production Estimate

A total of 63 efficiency trials, ranging in size from 6 to 153 coho, were conducted. Original efficiency trials were aggregated into four strata. Recapture rates for these strata ranged between 4.1% and 15.6% (Appendix B 4).

Total coho production was estimated to be 83,060 smolts. Coho production during trap operation was estimated to be 81,720 ± 13,008 (95% C.I.) smolts (Appendix B 4). Pre-trapping migration was estimated to be 1,091 and post-trapping migration was estimated to be 249 coho.

Migration Timing

Migration of coho smolts was already under way when the screw trap began operating. Migration came to an abrupt peak of an estimated 6,031 coho passing by the trap on May 4 (Figure 11). Migration declined thereafter with three prominent peaks over 3,500 coho each on May 7, 19 and 29. Nearly 77% of the season's migration occurred during the month of May. Daily migrations dropped sharply at the beginning of June and averaged less than 250 coho per day through the remainder of the season.

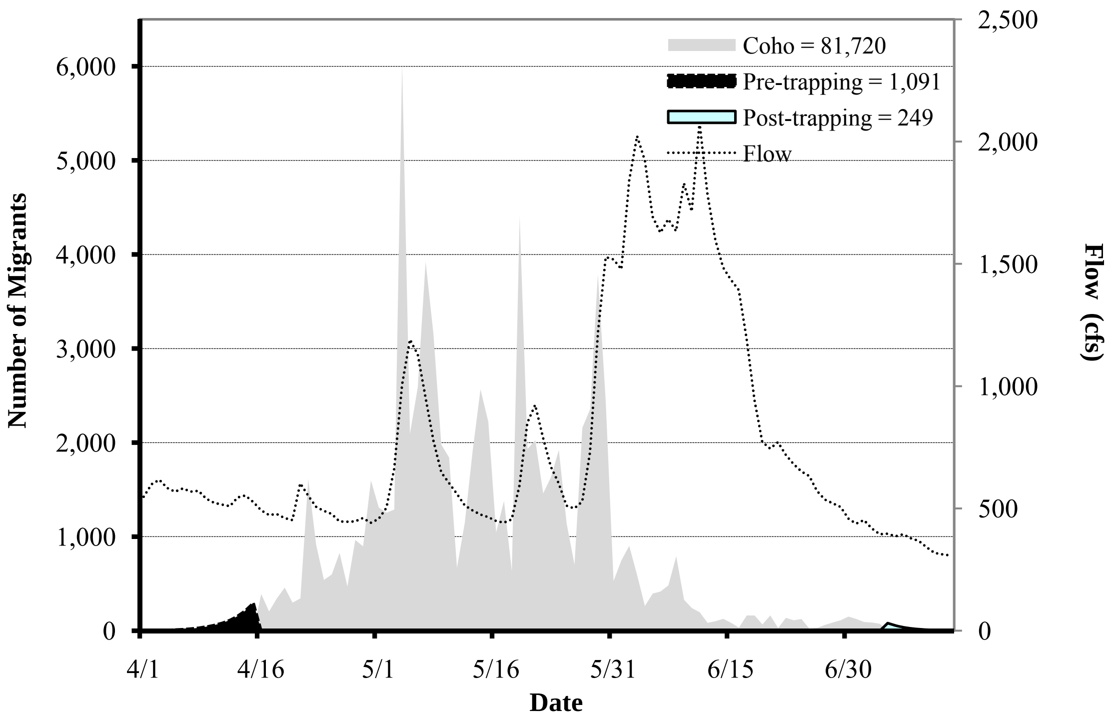

Figure 11. Daily coho migration and daily average flow (USGS Renton gage Station #12119000) at the Cedar River screw trap, 2010.

Size

Average fork length of all measured coho migrants was 104.3 mm; weekly averages ranged from 92.4 mm to 116.8 mm FL. Individuals ranged from 49 mm to 141 mm FL (Table 9, Figure 12). Coho lengths were the smallest observed since trapping began (Table 24).

Table 9. Fork length (mm) of coho migrants from the Cedar River screw trap in 2010. Data are mean, standard deviation (s.d.), range, sample size (n), and catch for each statistical week.

Statistical Week			Avg.	s.d.	Range		n	Catch
Begin	End	No.			Min	Max		
04/12	04/18	16	116.8	9.28	97	138	58	82
04/19	04/25	17	114.7	11.00	52	141	144	414
04/26	05/02	18	109.5	9.69	89	137	140	637
05/03	05/09	19	104.9	13.98	50	131	156	1,827
05/10	05/16	20	108.4	9.76	87	132	141	988
05/17	05/23	21	105.1	11.19	49	130	148	1,171
05/24	05/30	22	101.2	12.30	63	131	143	702
05/31	06/06	23	100.7	8.87	86	115	21	110
06/07	06/13	24	99.4	14.36	68	136	111	112
06/14	06/20	25	94.3	8.12	77	111	87	94
06/21	06/27	26	96.1	12.01	58	132	77	81
06/28	07/04	27	92.4	11.79	56	111	100	103
		Season Totals	104.3	13.37	49	141	1,326	6,321

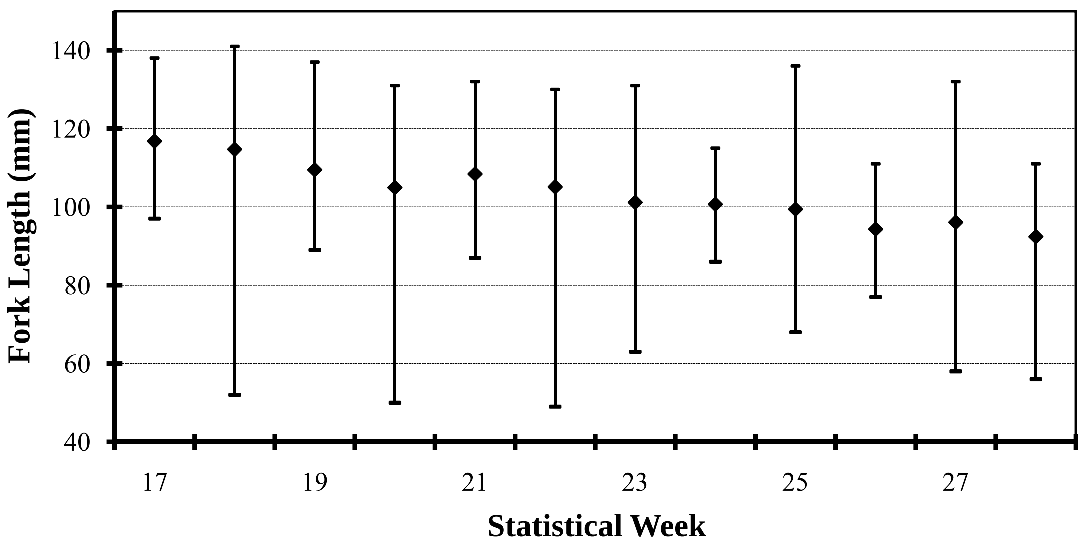

Figure 12. Fork lengths for coho migrants captured in the Cedar River screw trap in 2010. Data are mean, minimum, and maximum lengths.

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). We acknowledge that 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 8 steelhead migrants and 73 cutthroat trout were captured in the screw trap. No rainbow trout were caught. Catches were too small to develop migration estimates. *O. mykiss* fork lengths ranged from 111 mm to 370 mm and averaged 212.6 mm. Cutthroat fork lengths ranged from 109 mm to 198 mm, and averaged 148.9 mm.

PIT Tagging

To support the ongoing, multi-agency evaluation of salmonid survival within the Lake Washington basin, natural-origin Chinook were tagged with passive integrated transponder (PIT) tags. Tagging occurred two to three times a week from April 20 through June 30, 2010; therefore, only the 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 2,250 natural-origin Chinook parr were tagged (Table 10). This tag group comprised 6.1% of the estimated Chinook parr production from the Cedar River in 2010, the largest percentage of the parr migration that has been PIT tagged to date.

A total of 504 Chinook PIT tags (22.4%) were detected as fish moved through the smolt flumes at the Chittenden Locks while exiting Lake Washington. The first fish was detected on May 24 and the last on August 25, 2010. Median migration date of fish detected at the Locks was June 24, 2010. Individual travel times averaged 29.9 days (St. Dev. = 10.3).

Table 10. Natural-origin Chinook parr PIT tagged and released from the Cedar River screw trap in 2010.

Stat Week			#	Length (mm)			Portion of Parr Migration Tagged	# Detected @ Locks	% of Tags Detected @ Locks
#	Start	End	Tagged	Avg	Min	Max			
17	04/19	04/25	137	76.1	66	92	7.3%	16	11.7%
18	04/26	05/02	123	78.6	66	96	4.7%	21	17.1%
19	05/03	05/09	636	77.3	65	98	7.0%	118	18.6%
20	05/10	05/16	21	77.7	66	103	1.3%	7	33.3%
21	05/17	05/23	182	82.9	66	104	5.9%	42	23.1%
22	05/24	05/30	487	84.9	67	109	6.3%	148	30.4%
23	05/31	06/06	13	85.8	78	96	0.9%	7	53.8%
24	06/07	06/13	146	92.0	65	112	7.5%	59	40.4%
25	06/14	06/20	209	93.7	74	113	5.7%	54	25.8%
26	06/21	06/27	251	94.0	75	127	10.3%	30	12.0%
27	06/28	07/04	45	95.8	81	113	5.2%	2	4.4%
Season Total			**2,250**	**84.2**	**65**	**127**	**6.1%**	**504**	**22.4%**

Mortality

One Chinook mortality occurred while operating the inclined-plane trap.

During screw trap operations, 42 Chinook mortalities resulted from high water and heavy debris and 2 from PIT tagging.

Incidental Catch

Incidental catches in the inclined-plane trap included 142 coho fry, 52 coho smolts, 813 pink fry, 38 chum fry, 3 sockeye smolts, 1 rainbow trout and 1 cutthroat smolt. Other species caught included three-spine stickleback (*Gasterosteus aculeatus*), unspecified sculpin species (*Cottus spp*.), lamprey (*Lampetra spp.*), largescale sucker fry (*Catostomus macrocheilus*), long-fin smelt (*Spirinchus thaleichthys*), and speckled dace (*Rhinichthys osculus*).

Other salmonids caught in the screw trap include 19 ad-marked hatchery Chinook parr, 1 sockeye smolt, 18 chum fry, 404 sockeye fry, and 15 trout fry. Other species caught included three-spine stickleback, unspecified sculpin species, large-scale suckers, peamouth (*Mylocheilus caurinus*), speckled dace, lamprey, northern pikeminnow (*Ptychocheilus oregonensis)*, and brown bullhead catfish (*Ameiurus nebulosus*).

Bear Creek Results

Sockeye

Catch and Estimated Missed Catch

An estimated 8,881 sockeye fry should have been caught had the inclined-plane trap fished the entire period. During inclined-plane trap operations from January 31 to April 16, 4,880 sockeye fry were caught and an additional 4,001 fry estimated for the 28 nights not fished.

Production Estimate

Twenty-eight efficiency trials were conducted during the season and aggregated into two final strata, with recapture rates of 6.7% and 8.1% (Appendix C 1). At the beginning of the season, catches were too low to form an efficiency trial until February 15. Thereafter, marked fish were released nearly every night the trap fished.

A total of 129,903 ± 19,443 (95% C.I.) sockeye fry were estimated to have migrated from Bear Creek in 2010, with an associated 7.6% coefficient of variation (Table 11). The estimate includes migration prior to, during, and following inclined-plane trap operation. During inclined-plane trap operation (January 31 and April 16), 129,092 sockeye fry are estimated to have migrated passed the trap (Table 11). An additional 86 fry were estimated to have passed the trap between January 1 and January 30 (Table 11). The sockeye fry migration was still underway when the screw trap replaced the inclined-plane trap on April 16. Rather than attempting to calibrate the screw trap for sockeye fry, the end of the sockeye migration was estimated using linear extrapolation. Migration between April 17 and April 30 was estimated to be 725 fry.

Migration Timing

The sockeye migration was low at the beginning of the season with daily migrations under 1,000 sockeye per day through the month of February. Daily migrations then increased to over 2,000 per day during the month of March with two prominent peaks, March 11 of 6,384 and March 25 of 8,448 (Figure 13). Nearly 82% of the sockeye migration occurred during the month of March.

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2009 brood of Bear Creek sockeye was estimated to be 4.7% (Table 12). Survival was based on 129,903 fry migrants and a PED of 2.77 million eggs. PED was estimated based on 784 female spawners in 2009 (A. Bosworth, Washington Department of Fish and Wildlife, personal communication) and an average fecundity of 3,540 eggs per female (Cuthbertson 2010).

Table 11. Abundance of sockeye fry migrants from Bear Creek in 2010. Table includes abundance of fry migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*).

Period	**Dates**	**Fry Abundance**	***CV***	**95% C.I.**	
				Low	**High**
Pre-Trapping	Jan 1-Jan 30	86	24.3%	45	127
Inclined-Plane Trap	January 31-April 16	129,092	7.7%	109,650	148,533
Post-Trapping	April 17-April 30	725	15.7%	503	947
	Season Totals	129,903	7.6%	110,460	149,345

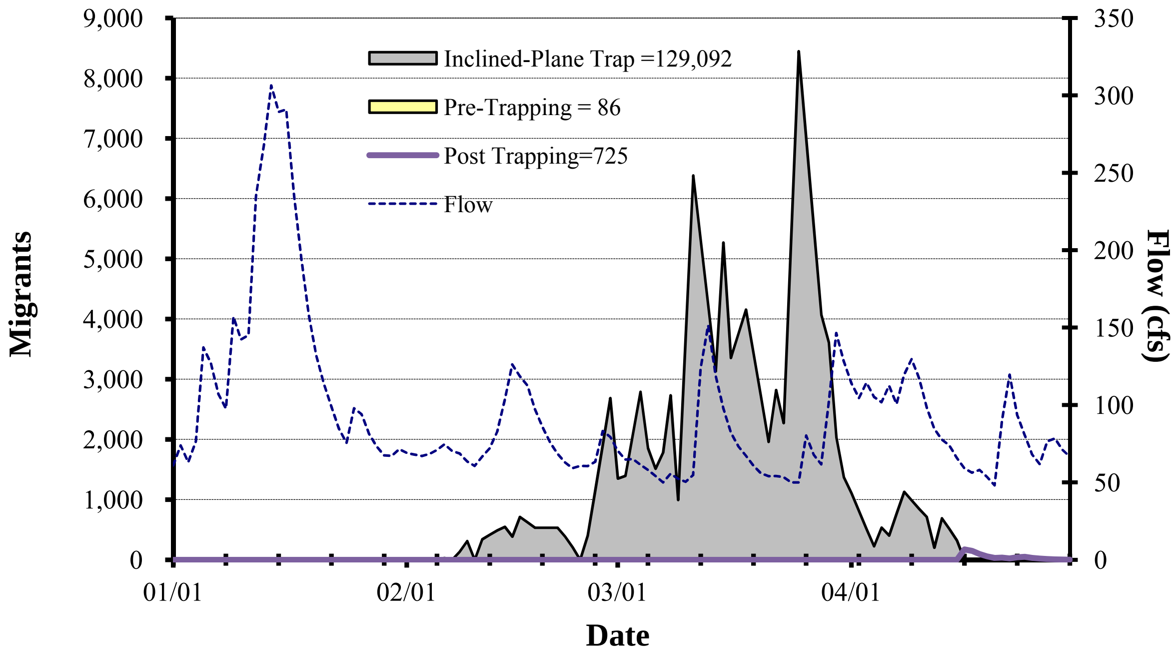

Figure 13. Estimated daily migration of sockeye fry from Bear Creek and daily average flow measured by the King County gage 02a at Union Hill Road in 2010 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Table 12. 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	01/23/2003
2003	1,765	883	3,412	3,011,090	177,801	5.9%	660	01/30/2004
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	01/31/2005
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	12/04/2007
2008	577	289	3,135	904,448	327,225	36.2%	546	01/08/2009
2009	1,568	784	3,540	2,775,360	129,903	4.7%	309	11/27/2009

Chinook

Catch and Estimated Missed Catch

Inclined-Plane Trap

An estimated 104 Chinook fry should have been caught had the inclined-plane trap fished the entire period. In total, 54 Chinook fry were captured in the inclined-plane trap and an estimated 50 Chinook fry were missed during the 28 nights not fished.

Screw Trap

A total of 1,316 Chinook should have been caught had the screw trap operated continuously. A total of 1,266 Chinook were caught over the 79 days the screw trap operated and an estimated 50 Chinook were missed during the three occasions (May 11, May 23, and July 1) when debris stopped the trap.

Production Estimate

Inclined-Plane Trap

A total of 28 efficiency trials were conducted with sockeye fry, ranging in size from 24 to 274 fish. Trials were pooled into 2 strata with trap efficiencies of 6.7% and 8.1%. Chinook migration was estimated to be 1,554 ± 415 (95% C.I.) between January 31 and April 16 (Table 13, Appendix C 2). Since Chinook were not captured until the second week of trapping and catches thereafter were scarce, migration prior to trapping is assumed to be zero.

Screw Trap

Thirty-nine Chinook efficiency trials were aggregated into nine strata; capture rates of these strata ranged between 5.8% and 52.9%. Chinook migration during screw trap operation was estimated to be 7,631 ± 2,372 (95% C.I.) (Table 13, Appendix C3).

Combined Estimate

Total production includes fry estimates from the inclined-plane trap and parr estimates from the screw trap. The abundance of natural-origin Chinook migrants was estimated to be 9,185 ± 2,408 (95% C.I.) sub yearlings with a coefficient of variation of 13.4%.

Fry migration was estimated using inclined-plane trap data and parr migration was estimated using the screw trap data. The Chinook fry migration was small and had two prominent peaks on March 11 of 195 Chinook fry and April 15 of 205 Chinook fry. Chinook parr daily migrations were larger than fry migrations with 63% of the Chinook migration occurring in the month of May. Migration peaked with an estimated 1,326 Chinook passing the trap on May 20. Migration was bi-modal with 16.7% of the migration emigrating as fry and 83.3% emigrating as parr (Figure 14, Table 14).

Table 13. Abundance of natural-origin juvenile Chinook emigrating from Bear Creek in 2010. 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	
Inclined-Plane Trap	January 31-April 16	104	1,554	1,139	1,969	13.60%
Screw Trap	April 17-July 4	1,316	7,631	5,259	10,003	15.90%
	Season Totals	1,420	9,185	6,777	11,593	13.38%

Table 14. 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 2009 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%	276	1,242,000	4	46	50	0.1%	0.9%	1.0%
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%

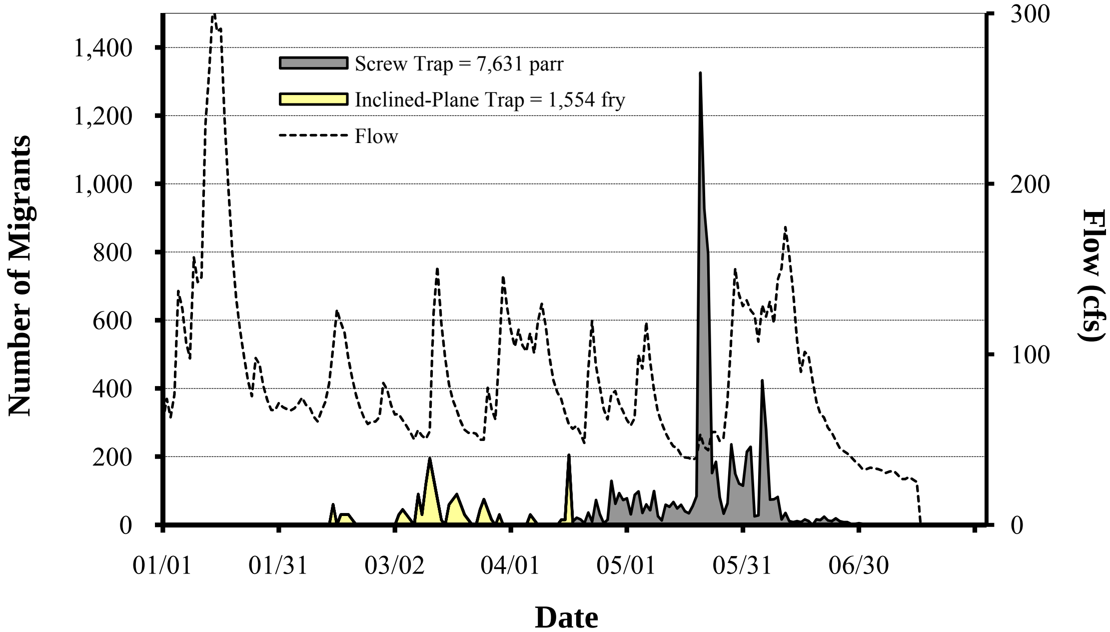

Figure 14. Daily migration of sub yearling Chinook and daily average flow from Bear Creek, 2010. Daily mean flows were measured at King County gage 02a at Union Hill Road in 2010 (http://green.kingcounty.gov/wlr/waterres/hydrology)..

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2009 brood of Bear Creek Chinook was estimated to be 4.3% (Table 14). Survival was based on 9,185 sub yearling migrants and a PED of 216,000 eggs. The PED was estimated based on 48 female spawners (A. Bosworth, Washington Department of Fish and Wildlife, personal communication) and an assumed fecundity of 4,500 eggs per female (M. Wilson, Washington Department of Fish and Wildlife, personal communication).

Size

From early February through mid- April, Chinook fry captured in the inclined-plane trap averaged 41.2 mm FL and ranged from 34 mm to 52 mm FL (Table 15).

Fork lengths of Chinook caught in the screw trap ranged from 48 mm to 99 mm, averaged 75.3 mm, and increased over the season. In mid-April, the Chinook weekly average lengths was 51.8 mm FL, with the weekly average quickly growing to be larger than 70 mm FL mid-May. By early June, weekly average lengths reached 80 mm FL (Table 15, Figure 15). The average fry and parr length in 2010 was near the median of those observed in the previous nine years (Table 16).

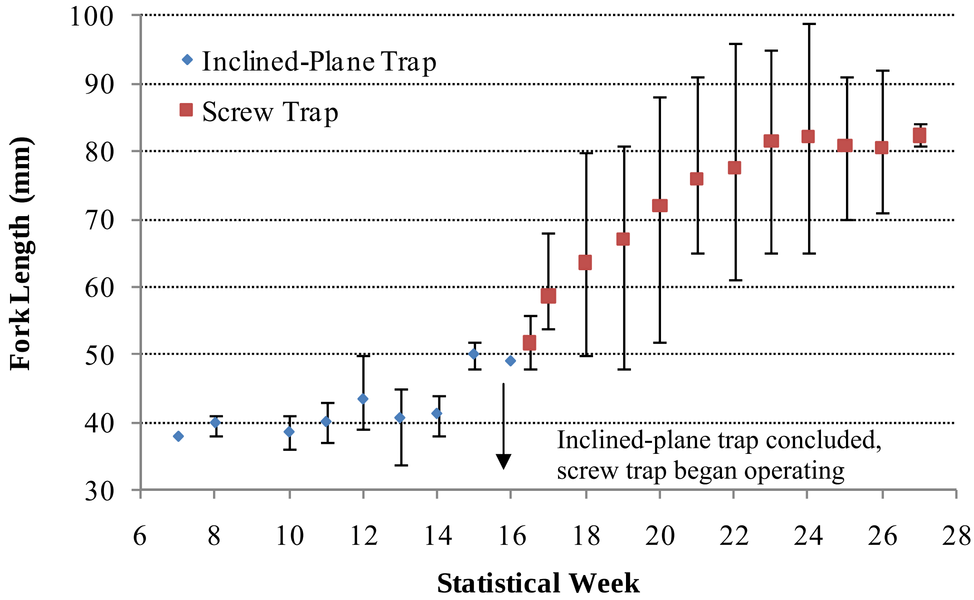

Figure 15. Fork lengths of sub yearling Chinook sampled from Bear Creek in 2010. Data are mean, minimum, and maximum lengths for each statistical week.

Table 15. Fork lengths of juvenile Chinook and coho captured in the Bear Creek inclined-plane and screw traps in 2010. Data are mean fork lengths (mm), standard deviation (s.d.), ranges, sample sizes (n), and catch.

Gear	Statistical Week			Chinook						Coho					
	Begin	End	No.	Avg.	s.d.	Range Min	Range Max	n	Catch	Avg.	s.d.	Range Min	Range Max	n	Catch
Inclined-Plane Trap	02/08	02/14	7	38.0	0.00	38	38	4	4						
	02/15	02/21	8	40.0	1.41	38	41	4	4						
	02/22	02/28	9	---	---	---	---	0	0						
	03/01	03/07	10	38.7	2.52	36	41	3	3						
	03/08	03/14	11	40.2	1.71	37	43	19	22						
	03/15	03/21	12	43.5	3.27	39	50	11	11						
	03/22	03/28	13	40.7	4.46	34	45	5	5						
	03/29	04/04	14	41.3	3.06	38	44	2	2						
	04/05	04/11	15	50.0	2.83	48	52	2	2						
	04/12	04/18	16	49.0	N/A	49	49	1	1						
			Totals	41.2	3.59	34	52	51	54						
Screw Trap	04/12	04/18	16	51.8	4.02	48	56	5	6	119.3	15.98	101	148	10	10
	04/19	04/25	17	58.7	4.25	54	68	27	34	119.7	13.75	92	163	98	141
	04/26	05/02	18	63.6	6.73	50	80	70	93	111.9	11.65	92	148	140	351
	05/03	05/09	19	67.0	6.14	48	81	65	97	111.5	12.75	86	149	120	494
	05/10	05/16	20	72.0	6.90	52	88	109	148	117.7	11.86	89	149	130	242
	05/17	05/23	21	76.0	5.94	65	91	248	301	115.0	9.62	97	146	132	349
	05/24	05/30	22	77.5	6.99	61	96	163	238	110.9	11.72	87	142	111	167
	05/31	06/06	23	81.6	6.60	65	95	121	169	112.3	12.85	92	149	57	77
	06/07	06/13	24	82.1	6.72	65	99	101	113	100.1	15.29	85	160	27	30
	06/14	06/20	25	80.9	5.27	70	91	13	28	98.7	9.98	83	118	11	16
	06/21	06/27	26	80.5	5.81	71	92	27	35	98.6	8.01	88	122	17	18
	06/28	07/04	27	82.3	1.53	81	84	3	5						
			Totals	75.3	8.94	48	99	952	1,267	113.3	12.86	83	163	853	1,895

Table 16. Fork lengths of natural-origin Chinook measured over ten years (brood years 2000-2009) at the Bear Creek inclined-plane and screw traps.

Brood Year	Inclined-Plane Trap Avg	s.d.	Min	Max	n	Catch	Screw Trap Avg	s.d.	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	774	54	75.3	8.94	48	99	952	1,267

Coho

Catch

A total of 1,895 coho smolts were caught in the screw trap over the 79-day trapping season. If the trap had fished without interruptions, a total of 1,954 coho are estimated to have been caught between April 17 and July 4.

Production Estimate

Abundance of coho smolts was based on catch and 51 efficiency trials, which were aggregated into three strata. Recapture rates of efficiency strata ranged from 12.3% to 16.2%. Coho production was estimated to be 13,100 ± 1,673 (95% C.I.) smolts with a coefficient of variation of 6.5% (Figure 16, Appendix C 4). Total abundance included a pre-trapping period between April 1 and April 16 and the period the trap was operating. No post-trapping migration was estimated as catches declined to zero near the end of the season.

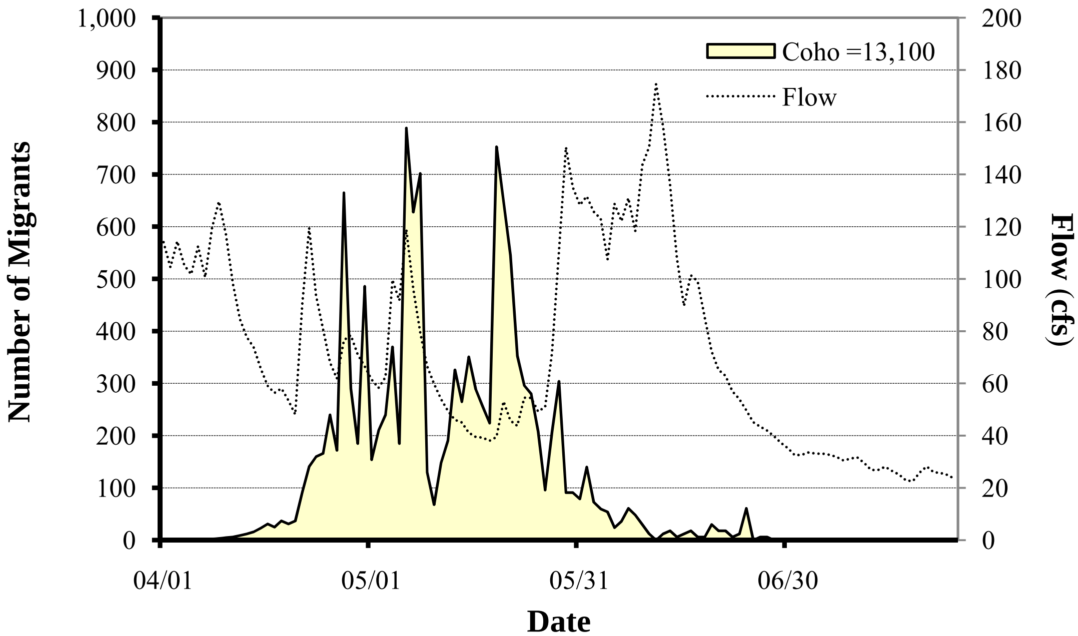

Figure 16. Daily migration of coho smolts in Bear Creek from April 1 to July 4, 2010. Graph also shows mean daily flows during this period. Flow data were measured at King County gage 02a at Union Hill Road in 2010 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Size

Over the trapping period, fork lengths ranged from 83 mm to 163 mm and averaged 113.3 mm (Figure 17). Weekly mean lengths ranged from 98.6 mm to 119.7 mm FL during screw trap operation (Table 15). Coho were near the median observed in previous years of study (Table 17).

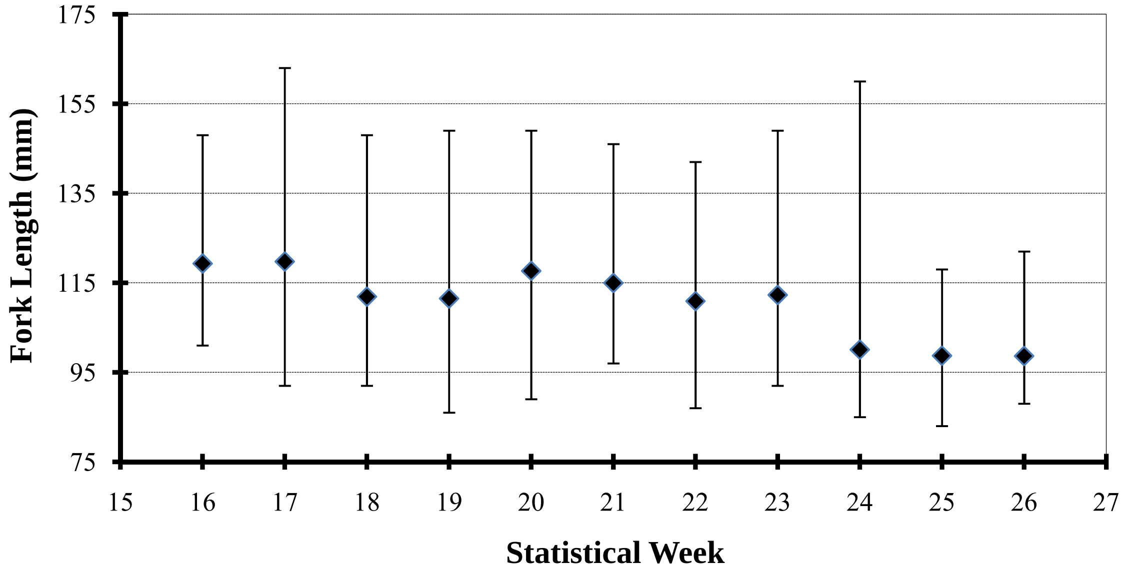

Figure 17. Fork lengths of migrating coho smolts caught at the Bear Creek screw trap in 2010. Data are statistical week mean, minimum, and maximum lengths.

Table 17. Fork lengths of natural-origin coho smolts in Bear Creek over migration years (2002-2010).

Migration	Screw Trap					
Year	Avg	s.d.	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

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 2010 trapping season in Bear Creek.

A total of 759 cutthroat trout were captured in the screw trap in 2010. Results from Marshall et al. (2006), suggest that that some Bear Creek fish identified by phenotype to be cutthroat trout may have been rainbow cutthroat hybrids. of the fish identified as cutthroat trout may have been hybrids of rainbow and cutthroat trout. From April 17 to May 17, catches totaled three-quarters of the entire season's catch. Thereafter, catches were intermittent with 34 cutthroat being the largest daily catch.

Forty-one different efficiency trials of cutthroat were conducted over the season, ranging from 1 to 55 cutthroat per release. Trials were aggregated into three strata with capture rates ranging from 3.9 % to 20.1%. Migration was estimated to be 5,209 ± 769 cutthroat, with a coefficient of variation of 14.8% (Figure 18, Appendix C 5) for the trapping period (April 17 through July 4). During the 2000 season, when the screw trap operated from January through June on Bear Creek, 35% of the cutthroat migration occurred prior to April 5. If this time allocation for the migration is applied to cutthroat estimates from the 2010 trapping season, a total 8,013 are estimated to have migrated from Bear Creek.

Cutthroat trout fork lengths averaged 154.9 mm and ranged between 105 mm and 268 mm throughout the trapping season (Table 18). Average fork lengths showed no consistent trend across weeks.

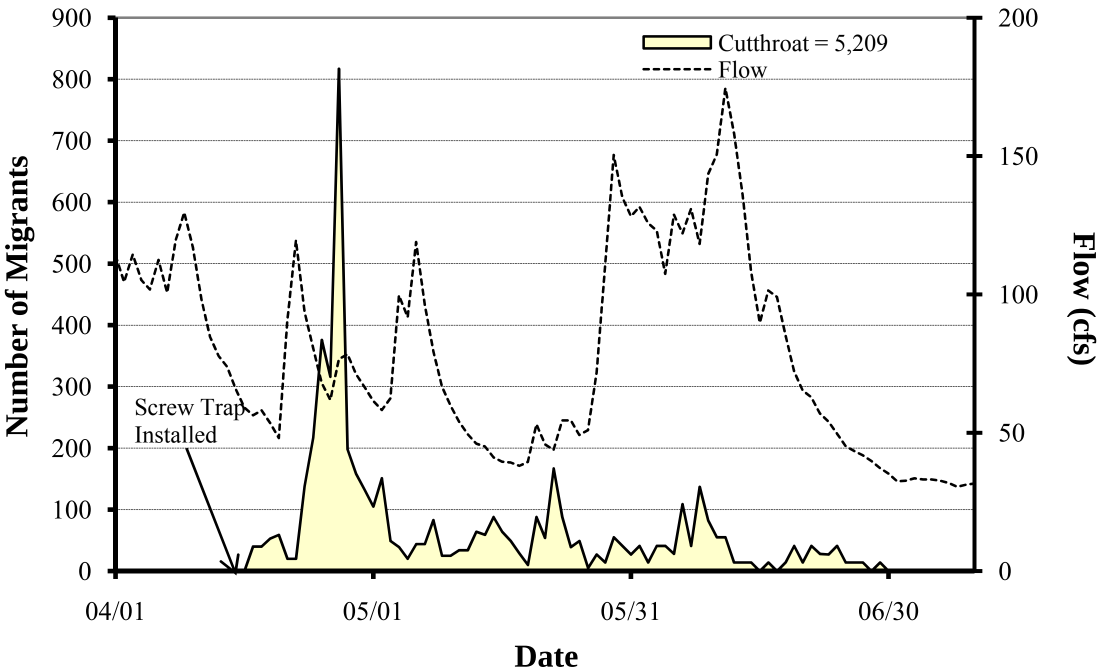

Figure 18. Daily migration of cutthroat trout passing the Bear Creek screw trap in 2010. Flow data were measured at the King County gauging station at Union Hill Road.

Table 18. Cutthroat fork length (mm), standard deviation (s.d.), range, sample size (n), and catch by statistical week in the Bear Creek screw trap, 2010.

Statistical Week			Avg.	s.d.	Range		n	Catch
No.	Begin	End			Min	Max		
16	04/12	04/18	149.3	20.58	118	178	11	12
17	04/19	04/25	171.8	29.36	121	261	82	134
18	04/26	05/02	153.9	21.99	109	251	136	285
19	05/03	05/09	159.6	27.74	121	241	53	62
20	05/10	05/16	153.9	25.14	117	268	71	72
21	05/17	05/23	146.4	21.07	105	250	76	93
22	05/24	05/30	149.0	21.35	111	192	26	29
23	05/31	06/06	150.3	16.25	121	181	16	22
24	06/07	06/13	139.9	12.13	115	164	26	29
25	06/14	06/20	157.4	19.33	132	183	5	7
26	06/21	06/27	145.5	11.97	123	162	10	13
27	06/28	07/04						1
Season Totals			**154.9**	**24.92**	**105**	**268**	**512**	**759**

PIT Tagging

As part of an ongoing multi-agency monitoring of Chinook migrating from the Lake Washington system, Chinook parr in Bear Creek were PIT tagged and released in 2010. Tagging began on May 5 and occurred three times a week through June 11. Fish were often held overnight to increase the number tagged per day. A total of 589 natural-origin Chinook were PIT tagged in Bear Creek throughout the season (Table 19).

A total of 103 Bear Creek PIT tagged Chinook (17.5%) were detected moving through the smolt flumes at the Chittenden Locks. The first fish was detected on June 6 and the last on July 7, 2010. Median migration date of fish detected at the Locks was June 23, 2010. Individual travel times averaged 26.1 days (St. Dev. = 9.1).

Table 19. Natural-origin Chinook parr PIT tagged and released from the Bear Creek screw trap in 2010.

Stat Week			#	Length			Portion of Parr	# Detected @ Locks	% of Tags Detected @ Locks
#	Start	End	Tagged	Avg	Min	Max	Migration Tagged		
19	05/03	05/09	9	71.0	67	76	1.8%		0.0%
20	05/10	05/16	28	72.3	66	82	8.0%	4	14.3%
21	05/17	05/23	228	75.9	65	91	6.8%	40	17.5%
22	05/24	05/30	115	76.3	65	96	13.2%	20	17.4%
23	05/31	06/06	111	81.9	65	94	8.4%	21	18.9%
24	06/07	06/13	98	81.9	65	99	32.6%	18	18.4%
Season Totals			**589**	**77.9**	**65**	**99**	**7.8%**	**103**	**17.5%**

Mortality

Four Chinook mortalities occurred in the screw trap; three of these were PIT tagged Chinook that were recaptured and the other was a result of heavy debris in the live box.

Incidental Species

In addition to sockeye and Chinook fry, 7 coho fry and 42 pink fry were also caught in the inclined-plane trap. Other species included lamprey (*Lampetra spp.*), sculpin (*Cottus spp.*), yellow perch (*Perca flavescens),* pumpkinseed (*Lepomis gibbosus),* three-spine stickleback (*Gasterosterus aculeatus*), and large-scale suckers (*Catostomus macrocheilus*). One adult nutria (*Myocastor coypus)* was also caught in the inclined plane trap on Bear Creek in 2010.

In addition to target species, the screw trap captured 10 coho fry, 4 sockeye fry, 33 trout fry, 6 hatchery trout plants from Cottage Lake and 3 cutthroat adults. Other species caught included lamprey, three-spine stickleback, sculpin, pumpkinseed, largescale sucker, whitefish (*Prosopium spp.*), peamouth (*Mylocheilus caurinus*), speckled dace (*Rhinichthys osculus*), Oriental Weatherfish (*Misgurnus anguillicaudatus*), bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*), and crappie (*Pomoxis spp).*

Discussion

The number of Cedar River sockeye spawners in 2009 was the lowest observed since the juvenile monitoring study began in 1991, however the egg-to-migrant survival was the highest. This resulted in a Cedar River sockeye production estimate of 12.5 million fry, well above the lowest levels of production observed since 1991. In comparison, the production of natural-origin sockeye fry from Bear Creek was the lowest observed since juvenile monitoring began. Sockeye returns to Bear Creek in 2009 were low, and egg-to-migrant survival was 4.7%. Incubation flows were low in both watersheds suggesting that the different survival rates cannot be explained by flow-related mortality alone. Potential explanations for high Cedar River sockeye survival are provided below.

Chinook returns to the Cedar River in 2009 were moderate compared to the range observed since juvenile monitoring began. Chinook survival rate of 11.9% resulted in a slightly below average production of 152,405 sub yearling migrants. In comparison, Chinook spawner returns to Bear Creek were the lowest observed since juvenile monitoring began. A survival rate of 4.3% for the 2009 brood Chinook resulted in the lowest production of juvenile migrants since the 2000 brood year. Egg-to-migrant survival of Chinook in Bear Creek has been consistently lower than that in the Cedar River.

The 2010 juvenile migrant study in the Lake Washington basin was designed to meet the assumptions of mark-recapture estimation (Seber 1973, Volkhardt et al. 2007). As a result, the estimates are considered to be unbiased. Precision of juvenile sockeye and Chinook estimates had a coefficient of variation less than 15%, which is consistent with monitoring recommendations by the National Oceanic Atmospheric Administration (Crawford and Rumsey 2011). During this trapping season we tested three assumptions related to the quality of the abundance estimates. These assumptions were that (1) all fish within a species have equal probability of capture, (2) sockeye fry could be used as surrogates for Chinook trap efficiency, and (3) juvenile sockeye and Chinook only migrate at night in Bear Creek. In addition, recapture rates were high enough to derive abundance estimates for both coho and cutthroat trout migrants. In 2010 we evaluated age structure and migration timing of coho from the Cedar River.

Cedar River Sockeye Egg-to-Migrant Survival

Over the past 18 years of evaluating sockeye fry migrations in the Cedar River, egg-to-migrant survival has ranged from 1.91% to 31.95%. The 2009 brood sockeye egg-to-migrant survival was estimated to be 56.58%, nearly twice the highest survival estimated since trapping began. A possible number of factors, such as bias of adult and juvenile migrant estimates as well as environmental conditions may have contributed to such an unexpectedly high egg-to-migrant survival.

One possible explanation for the unexpectedly high survival is that spawner abundances were underestimated. If AUC methodology is contributing to a biased low estimate of spwaner abundance, the egg-to-migration survival of the 2009 sockeye brood will be biased high.

Estimates based on the AUC methodology have been used prior to and since sockeye fry monitoring began in 1992. However multiple assumptions associated with the adult abundance estimation have not been tested in recent years. The AUC method currently used was developed for large returns of sockeye. However, in recent years, returns have been one-quarter to one-half the levels of historical returns, exposing potential flaws in the escapement methodologies (Figure 19). Errors in the calculation of AUC stemming from assumptions of stream life and even sex ratios of spawners in the river could contribute to systematic bias in estimates of potential egg deposition used in survival estimates. Spawning ground count adjustment for tower counts may compound into biased estimates in years with low adult returns of sockeye to the Cedar River. Further refinement of an unbiased estimate with known precision may be achieved by implementing a re-sampling study design (e.g., mark-recapture, probabilistic sampling) and meeting the assumptions required for the abundance estimator (Seber 1973, Schwarz and Taylor 1988).

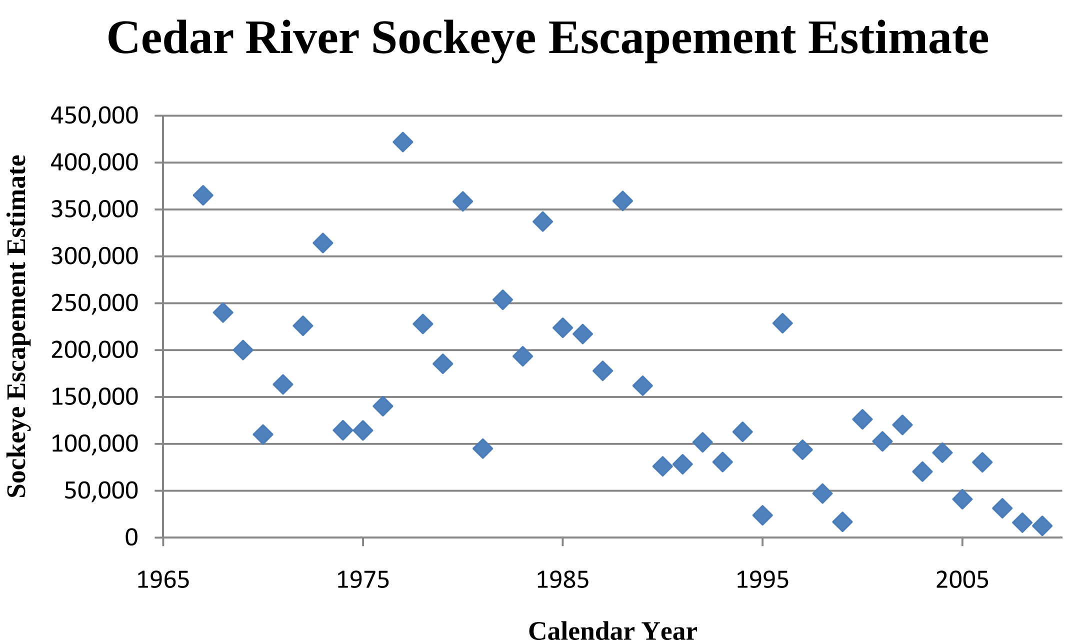

Figure 19. Cedar River sockeye escapement estimates from 1967 to 2009.

Despite the uncertainties, the 2009 adult sockeye escapement in the Cedar River could have been predicted from an existing correlation between Ballard Locks counts and Cedar escapement estimates (Figure 20). When freshwater harvest is removed from the Locks counts, the average of annual ratios between Cedar River escapement and Locks counts is 56.9% (±15.3%), 1 St.Dev.). Based on the slope of the relationship between Locks and Cedar Escapement (setting the intercept to zeros), this ratio was 49.2% (Figure 20). For the 2009 return, the Cedar:Locks (minus freshwater harvest) ratio was 57.0%. From these comparisons, the 2009 estimate of Cedar River escapement was on average or slightly above the average that would be predicted based on sockeye counts at Ballard Locks.

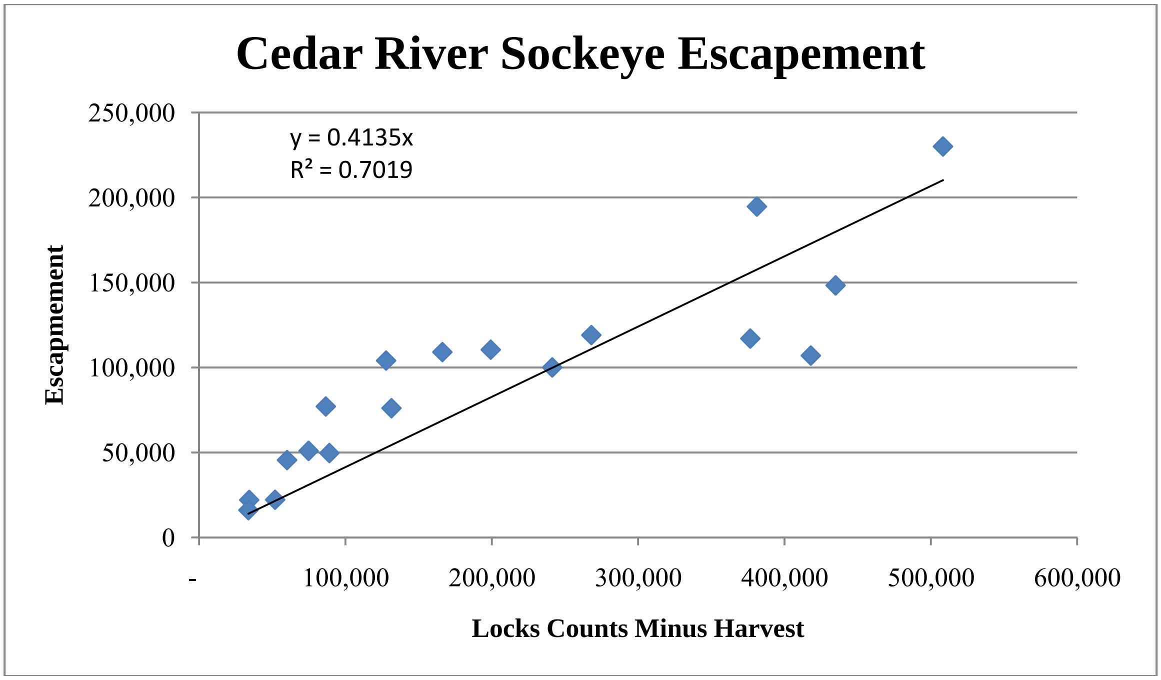

Figure 20. Cedar River sockeye escapement versus Hiram Chittenden Locks counts. Locks counts exclude freshwater harvest estimates.

A second possible explanation for the unexpectedly high survival is related to an overestimate of juvenile migrant abundances. However, the mark-recapture study design for sockeye fry migrants was developed in order to ensure an unbiased estimate. If the assumptions of the mark-recapture methodology are met, the resulting estimate is unbiased and of known precision (Seber 1973, Volkahrdt et al 2007). The assumption of the mark-recapture abundance estimation and their application to the Cedar River sockeye fry estimate are:

(1) *Population is closed geographically and demographically.* This assumption is likely met. Demographic closure assumption is met or minimized. Mortalities due to in-river predation are minimized by releasing marked fry at Logan Street bridge approximately 0.3 miles upstream of the trap. Geographic closure assumption is technically violated since all fish are emigrating. In juvenile migrant studies, this issue is accommodated by assuming that the entire juvenile population emigrates past the trap within the defined period of time (i.e., the trapping period, Volkhardt et al. 2007).

(2) *All fish have an equal probability of being caught.* The study design has been modified to address violations of this assumption. This assumption would be violated if the probability of capture changes over the trapping season. Probability of capture is assessed by trap efficiency trials (releases, recaptures). Data are stratified based on time periods with similar probabilities of capture. The methodology used to make these stratifications has varied between 1991 and 2009 and is a potential source of estimate bias among years. Between 1992 and 2008, sockeye fry abundances were estimated by applying nightly trap efficiencies directly to catch or by applying the average seasonal trap efficiency to catch. In 2009 and 2010, a *G*-test approach was used to stratify trap efficiencies before applying them to catch. However, differences in the abundance estimates resulting from these analysis methods appear to be minimal. Recalculation of the 2010 data using nightly efficiencies and seasonal average efficiency resulted in an estimated sockeye fry

abundance of 12.3 million and 11.7 million fry respectively. These values lower the estimated egg-to-migrant survival by a maximum of 3%.

(3) *Marking does not affect catchability*. This assumption is likely met. This assumption would be violated if marked and released fish exhibited a trap "happy" or "shy" behavior. The small size of fry migrants should minimize their ability to manipulate their swimming position relative to the trap. This assumption would also be violated if marking affected the swimming ability of the fish. The use of highly trained and long-term staff on the Cedar trap ensures that the marking process has a minimal impact on the fish. However, no specific assessment is done to quantify catchability for marked fry migrants.

(4) *Marked and unmarked fish are randomly mixed in the second sample*. This assumption is likely met. The assumption is violated if the release site is too close to the trap to allow for adequate mixing of marked and unmarked fish. The current release site was selected because it was deemed far enough above the trap that adequate mixing would occur. In 2011, we initiated a series of releases further upstream to test the validity of this assumption.

(5) *No marks are lost*. This assumption is likely met. This assumption would be violated if fish lost the dye coloration between release and recapture. Bismark Brown dye is known to stain the fish for at least a three day interval (WDFW, unpublished data). Most of the released sockeye are recaptured within a 6-hour interval. The use of highly trained and long-term staff on the Cedar trap ensures that the dye marking process is conducted to a quality standard. In 2011, we initiated a procedure for holding a portion of the marked fish through the release period in order to test for any decrease in dye saturation over this period.

(6) *All marks are detected*. This assumption is likely met. This assumption would be violated if marked fish recaptured in the live box of the trap were not detected by field staff. The staff who sort marked and unmarked fish and record the data are highly trained and experienced.

Based on the consideration of these assumptions and an evaluation of the estimation methods, both the 2009 adult escapement and 2010 outmigration fry abundance estimates are found to be credible. However, an egg-to-migrant survival of 56.8% is high and requires some further consideration. For brood year 1991 to 2009, sockeye fry production has had a positive correlation with potential egg deposition in the Cedar River (Figure 21). Average egg-to-migrant survival (brood year 1991-2008) was 13.1%, shown as the red line in Figure 21. Using this average survival rate as a model accounts for only 27% of the variance in fry production (R^2 = 0.27). A least-squares linear regression model improves this fit to explain 44% of the variance in fry production. Whereas the ratio model (i.e., average survival) predicts that natural production for brood year 2009 will be 1,639,950 fry, the linear regression predicts that natural production for brood year 2009 will be 8,845,030 fry. Based on the regression model that includes PED, brood year 2009 fry production was greater than expected (i.e., positive residual of 3,674,230); however, considering all other years where the residual in fry abundance was positive, brood year 2009 does not appear extreme (Figure 21).

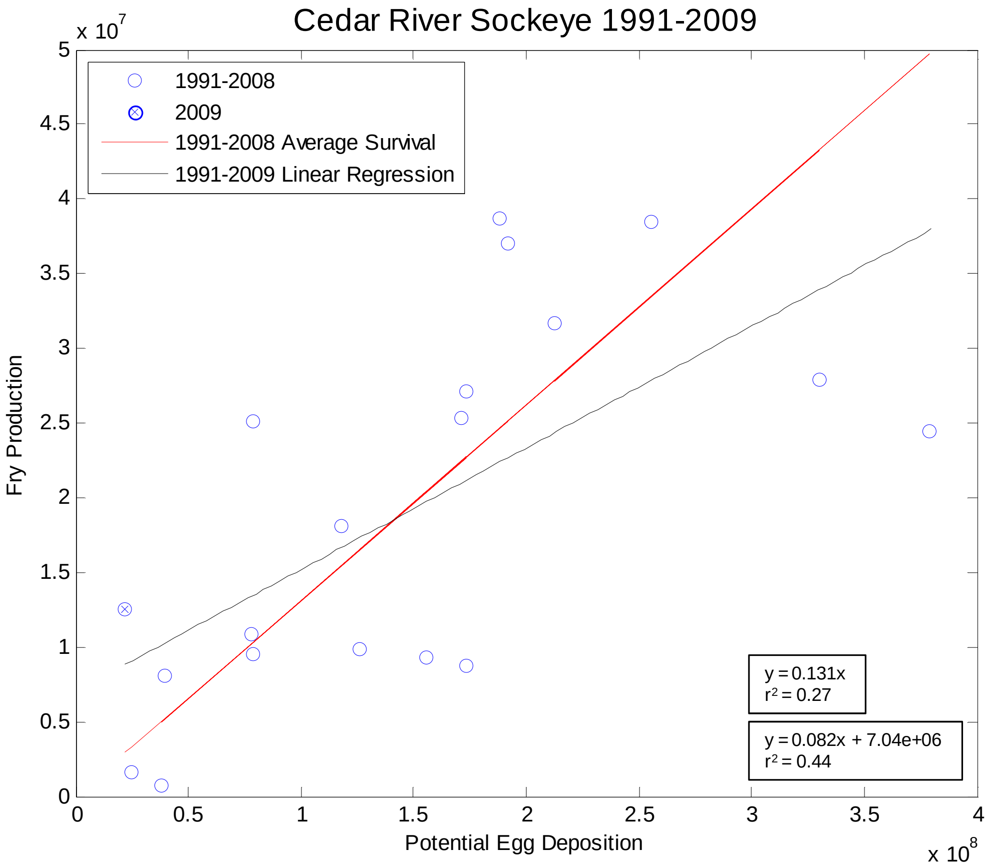

Figure 21. Cedar River sockeye fry production from 1991 to 2009 as a function of potential egg deposition.

The variance in sockeye fry production can be further explained by peak incubation flows (Figure 22). All years with higher than expected fry abundance (i.e., positive residuals from regression model) had low peak incubation flows (flow), within a narrow range of 627 – 2,039 cfs (mean: 1,623 cfs), compared with years with lower than expected fry abundance with flow range of 1,410 – 9,390 cfs (mean: 4,040 cfs). When the linear regression model includes PED and flow as predictors and fry abundance as the dependent, model fit improved from 44% to 62% (Figure 23) and the predicted natural production from brood year 2009 was approximately 14,594,000 fry, approximately 2,074,500 more fry than our estimate. Considering only PED and flow, the brood year 2009 fry abundance is as expected or perhaps less than expected.

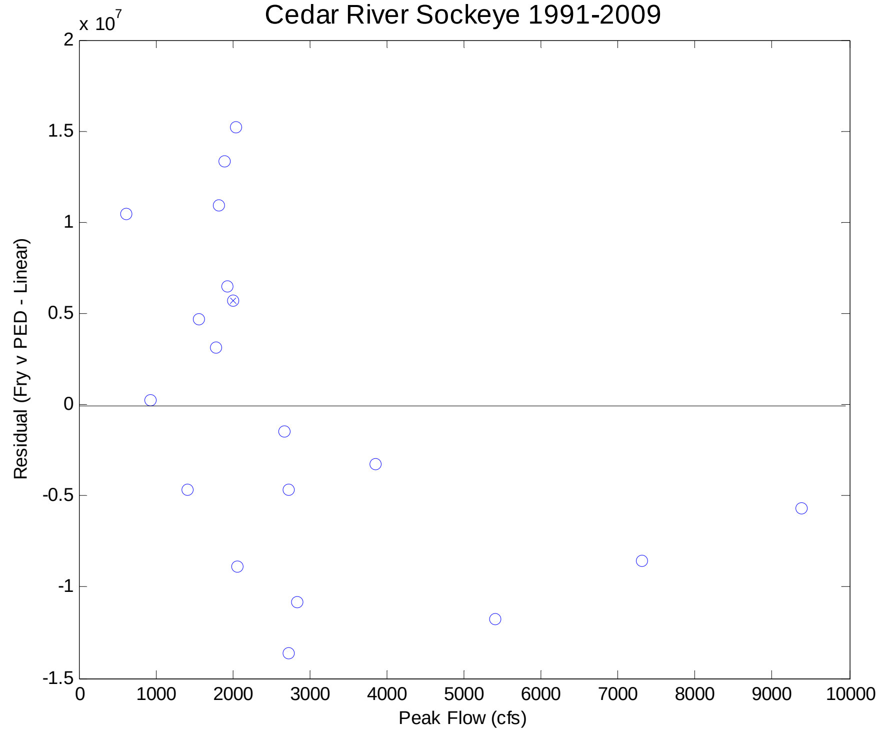

Figure 22. Residuals from fry production versus PED as a function of peak incubation flow in the Cedar River as measured by USGS Renton gage Station #12119000.

This analysis indicates that a combination of incubation flows and PED are necessary to understand the long-term sockeye data set from the Cedar River. For example, potential egg depositions in 2008 and 2009 were the two lowest since 1991 (25,072,163 and 22,126,770, respectively). Based on PED alone, we would expect that these two years would have similar fry abundance and therefore egg-to-migrant survival. However, fry abundance for brood year 2008 was 1,630,081, the second lowest since 1991, producing an egg-to-migrant survival of just 6.5%. This compares with the estimated 56.8% egg-to-migrant survival for brood year 2009. Incubation flows experienced by brood year 2008 reached a peak of 9,390 cfs, the highest since 1991, whereas peak incubation flow for brood year 2009 was just 2,000 cfs.

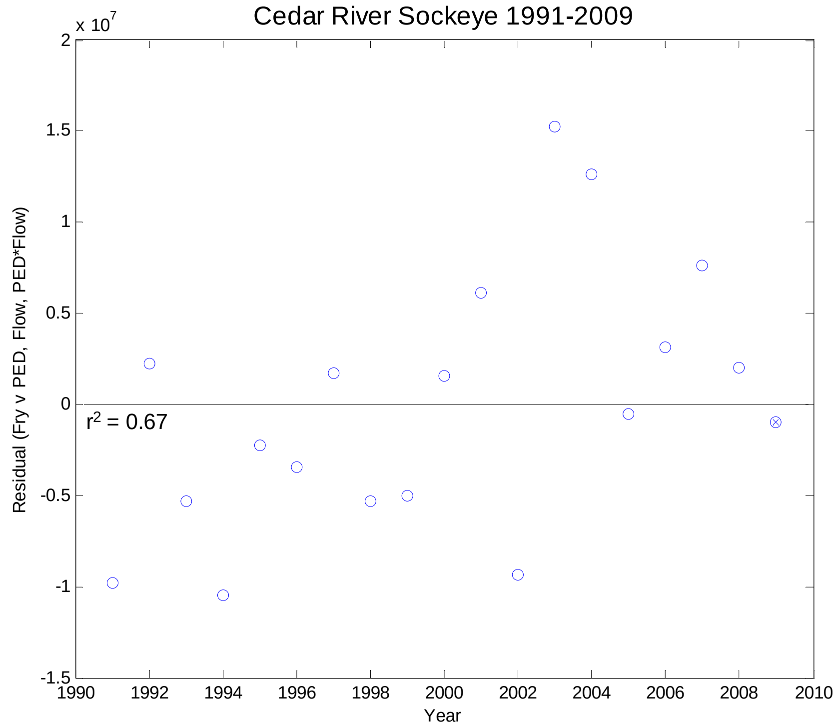

Figure 23. Residuals from fry versus PED and flow regression plotted by brood year for Cedar River sockeye.

An additional biological explanation for the high egg-to-migrant survival of Cedar River sockeye was that the interaction between spawner abundance and incubation flows may have contributed to this occurrence. The highest egg-to-migrant survival before the 2009 brood (2007 brood = 31.95%) corresponded to the combination of low adult returns and low spawning and incubation flows. All of these variables are thought to positively influence per capita survival. Although the egg-to-migrant survival of the 2009 brood seems high, Thomas (1975) reports Chinook egg-to-migrant survival in spawning channels between 78.5% and 85%. Royal (1964) reports pink salmon fry surviving at 52.4% and decreasing by half when spawning density doubled, pointing to possible spawning density dependence. The 2009 adult return was the lowest return since juvenile monitoring began in the Cedar River (an estimated 12,501 naturally spawning sockeye). Incubation flows were relatively low (October - January flows averaged 725 cfs). Maximum flows of 2,000 cfs at the Renton USGS flow gage were not expected to have major impacts on egg mortality. Warner (1963) documents Atlantic salmon survival from egg deposition to eyed egg stage at rates ranging from 88.8% to 96.9% and attributes such high survival rates to stable stream flow and mild temperatures. High survival may also have been assisted by newly available spawning habitat. This is the first adult return of sockeye to the Cedar River since the record flood in January 2009, which redistributed gravels and may have improved spawning areas (Hans Berge, King County, personal communication). The combination of factors may have contributed to higher egg-to-migrant survival observed in 2010.

Estimator Assumptions

The 2010 trap season provided an opportunity to test a number of assumptions associated with estimating the abundance of juvenile migrants. In both the Bear Creek and Cedar River screw traps, the assumption that all fish have an equal probability of being captured was tested by comparing fork lengths of marked and recaptured fish. On the Cedar River fry trap, the assumption that capture rates of marked sockeye are adequate surrogates for expanding catch of Chinook fry was tested by comparing sockeye and Chinook capture rates in paired efficiency trials. On Bear Creek, the assumption that there is little or no day-time movement of sockeye and Chinook fry was re-evaluated.

Equal Probability of Capture

One assumption of a mark-recapture approach to estimating abundance is that all individuals have an equal probability of being captured (Seber 1973; Hayes et al. 2007). When using a screw trap to capture juvenile salmonids, one possible violation of this assumption are the changing river conditions throughout the trapping season. The ability of the screw trap to capture and retain fish may vary with the rotation speed of the cone, as well as water velocity. In order to accommodate for changes in capture rates due to changing river conditions, the data were stratified by time periods. Additionaly, larger fish are more powerful swimmers and can avoid capture in screw traps unless the velocity of the water column is greater than the ability of a fish to avoid it.

In 2010, at both the Cedar River and Bear Creek screw traps, the assumption that large and small fish of the same species have an equal probability of being captured was assessed. This assumption was tested for Chinook and coho in both watersheds, and for cutthroat in Bear Creek. Cutthroat catches and recaptures were too low in the Cedar River this assessment. This assumption was particularly important to test in Bear Creek as overall trap efficiencies for Chinook parr and coho smolts have consistently decreased over time. Upon initial capture, the fork length of a portion of each species was measured, and the fish were marked and released upstream as part of an efficiency trial. Upon recapture, the fork length of all marked fish was measured. Fork lengths of maiden capture fish were compared to fork lengths of recaptured fish using the Kolmogorov-Smirnov test ($\alpha = 0.05$).

In the Cedar River screw trap, lengths of recaptured Chinook were shorter than those initially captured ($P = 0.00031$), although the difference between mean length of maiden and recaptured Chinook was minimal (2.4 mm). Lengths of maiden captured coho and recaptured coho did not differ ($P = 0.1065$, Table 20). These results were puzzling given that coho are larger in size than Chinook parr. However, the “statistical” difference observed in maiden and recaptured Chinook lengths was so small in magnitude that it was unlikely to have biological meaning in terms of overall abundance estimates and may have been an artifact of large sample sizes used for comparison. The interpretation of these results and their application to the abundance estimate is a current area of research that will be investigated in the future.

Table 20. Sample size, average length, minimum and maximum lengths, and *P* values for Cedar River and Bear Creek size selectivity analysis for Chinook, coho, and cutthroat in 2010.

Cedar River					
	Sample Size	**Average Length**	**Min**	**Max**	***P* Value**
Chinook					
Maiden	2,025	83.6	45	127	0.0003
Recapture	262	81.2	60	106	
Coho					
Maiden	1,275	105.5	63	141	0.1065
Recapture	315	104.0	78	132	
Bear Creek					
	Sample Size	**Average Length**	**Min**	**Max**	***P* Value**
Chinook					
Maiden	921	75.9	48	99	0.9991
Recapture	235	75.8	55	94	
Coho					
Maiden	853	113.3	83	163	0.0012
Recapture	227	109.3	85	142	
Cutthroat					
Maiden	512	155	105	268	7.43E-06
Recapture	87	141.9	103	215	

In the Bear Creek screw trap, capture rates appear to be size biased for the yearling migrants (coho and cutthroat) but not for sub yearling Chinook migrants. Lengths of maiden and recaptured Chinook parr did not differ (P = 0.9991). However, maiden coho and cutthroat lengths were found to be significantly longer than lengths of recaptured fish (P = 0.0012, P = 7.43E-6, respectively (Table 20)). These results indicate that the Bear Creek screw trap captures smaller yearling migrants at a higher rate than larger yearling migrants. Size selectivity of the Bear Creek occurs near 110 mm for coho and 125 mm for cutthroat. This bias may under estimate the overall abundance by under-representing larger migrants.

Since 2008, the Bear Creek screw trap has suffered from periodic decreases in water velocity due to a beaver dam downstream. As the rotation of the trap slowed, larger and stronger fish may be better able to avoid the trap. During the 2010 trap season, a motor and belt was attached to the cone to compensate for lack of velocity by increasing the rotation per minute. This was the first attempt by WDFW to motorize a screw trap. A number of complications were encountered and the motor was found to be unsuccessful. Future years provide an opportunity to continue to experiment.

Capture Rates of Cedar River Chinook Fry

In past years, catches of Cedar River Chinook fry have been too low to form efficiency trials during inclined-plane trap operations. Consequently, sockeye fry efficiencies had been applied to estimate Chinook fry productions. Sockeye fry capture rates were assumed to be a good surrogate for Chinook fry due to the similar 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, twelve paired releases were conducted to test the assumption that the rate in which sockeye fry are captured is similar enough to Chinook capture rates to be used as surrogates to estimate Chinook fry production. Efficiency trials were conducted in the same manner described in the Methods section for sockeye. Efficiency trials ranged in size from 100 to 265 of each species with an equal number of each species released, except for one night when there was one sockeye mortality during the marking process (January 25).

Chinook had a lower efficiency than sockeye in eight out of twelve trials (Figure 24). The *G*-test was used to compare each paired release in order to determine if the ratio of seen and unseen differed between species. Of the twelve trials, recapture rates were different for only one paired trial ($P < 0.02$, February 17 release, Table 21). A paired t-test indicated that recapture rates did not differ between species ($t_{1\ 1}$= -1.41, $P = 0.18$). Based on these comparisons (n = 12, pooled St. Dev. = 0.024, $\alpha = 0.05$), the power of a paired t-test to detect a 2% difference in trap efficiency between sockeye and Chinook fry was $\beta = 0.76$. Therefore, we tentatively conclude that sockeye are an adequate surrogate to estimate trap efficiencies for Cedar River Chinook. 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.

Difference in Chinook and sockeye capture rates in the Cedar River are not transferable to Bear Creek because Chinook appear to have longer freshwater residency in Bear Creek. Therefore a lower capture rate of Chinook than 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 high enough to make this comparison.

Table 21. Paired Cedar River sockeye and Chinook efficiency trial data and P values of G-test results.

Date	Number	Recaptured		Efficiency		P Value
	Released	Chinook	Sockeye	Chinook	Sockeye	
22-Jan	100	5	9	5.0%	9.0%	0.40
25-Jan	100	7	11	7.0%	11.1%	0.44
08-Feb	100	9	7	9.0%	7.0%	0.79
10-Feb	117	4	8	3.4%	6.8%	0.37
15-Feb	265	17	20	6.4%	7.6%	0.61
17-Feb	253	11	25	4.4%	9.9%	0.01
22-Feb	124	15	9	12.1%	7.3%	0.20
24-Feb	169	6	8	3.6%	4.7%	0.78
01-Mar	100	4	5	4.0%	5.0%	1.00
03-Mar	114	8	7	7.0%	6.1%	1.00
08-Mar	127	11	13	8.7%	10.2%	0.67
12-Mar	114	8	8	7.0%	7.0%	0.80

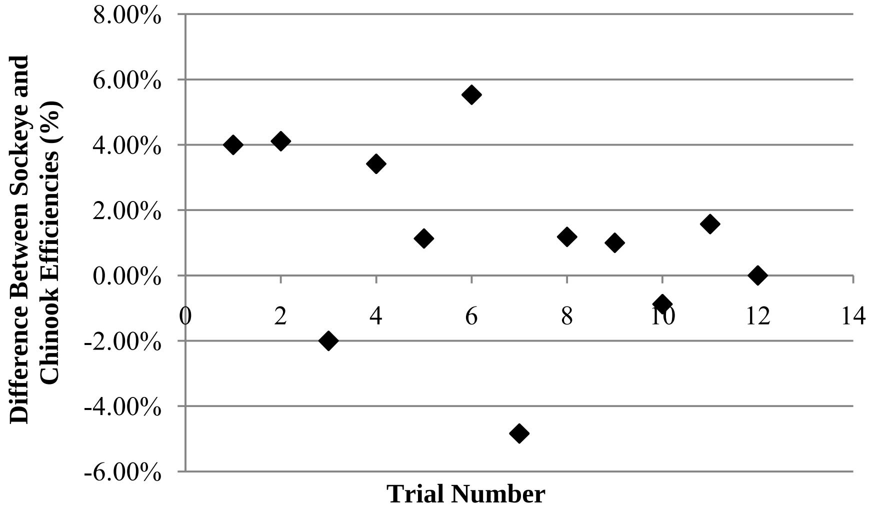

Figure 24. Plot of the difference between paired Cedar River sockeye and Chinook efficiency trials in 2010.

Day-time Migration in Bear Creek

During the 2000-2002 trap seasons, daylight movement of sockeye and Chinook fry in Bear Creek were evaluated and found to be minimal (Seiler et al 2003, 2004a, and 2004b). Since this time, day migration has not been accounted for in the production estimate. Re-evaluating such an assumption was necessary to continue to justify this approach to the analysis because this uncertainty could lead to underestimating the juvenile migrant abundance for both species.

In 2010, the Bear Creek inclined-plane trap operated during five day-time intervals (February 9 and 23, and March 8, 23, and 6) to assess day-time fry movement. A total of four Chinook and six sockeye were caught during the day periods. A day-to-night ratio was calculated using the same methods described for Cedar River. Chinook day-to-night ratios were calculated for two periods at 200% and 280% (Table 23) and added an estimated 27 Chinook to the total catch and increased the abundance estimate by 371 Chinook (a 23.9% increase). No Chinook were caught in the remaining three periods. Sockeye day-to-night ratios ranged from 0% to 9.7% (Table 22) and increased total catch by 114 and abundance estimate by 1,520 sockeye (a 1.2% increase). While the day-time migration of sockeye does not seem to be significant, the day migration of Chinook may be higher than assumed. These results are consistent with the wide range of day-to-night capture ratios observed for Chinook in the Skagit River juvenile trap (Kinsel et al. 2008). These conclusions are preliminary because the catches and migrations of both sockeye and Chinook in 2010 were the lowest observed since trapping began and may not accurately represent either species' movements in larger return years. Further evaluation of day-time movements in subsequent years will be necessary to validate the conclusions from the 2010 trapping season.

Table 22. Day-to-night capture ratios for sockeye fry in the Bear Creek inclined-plane trap, 2010.

Night				Day				D:N
Date	Catch	Time Fished (hr)	catch/hr	Date	Catch	Time Fished (hr)	catch/hr	
08-Feb	9	14	0.64	09-Feb	1	10	0.1	**9.66%**
09-Feb	20	14	1.43					
	29	28	1.04					
22-Feb	26	14	1.86	23-Feb	0	10	0	**0.00%**
23-Feb	14	14	1.00					
	40	28	1.43					
07-Mar	120	14	8.57	08-Mar	1	10	0.1	**0.92%**
08-Mar	183	14	13.07					
	303	28	10.82					
22-Mar	190	14	13.57	23-Mar	1	10	0.1	**0.82%**
23-Mar	152	14	10.86					
	342	28	12.21					
05-Apr	45	12	3.75	06-Apr	3	12	0.25	**7.89%**
06-Apr	31	12	2.58					
	76	24	3.17					

Table 23. Day-to-night capture ratios for Chinook fry in the Bear Creek inclined-plane trap, 2010.

Night				Day				D:N
Date	Catch	Time fished (hr)	catch/hr	Date	Catch	Time fished (hr)	catch/hr	
08-Feb	0	14	0.00	09-Feb	0	10	0.00	**0.00%**
09-Feb	0	14						
	0	28						
22-Feb	0	14	0.00	23-Feb	0	10	0.00	**0.00%**
23-Feb	0	14						
	0	28						
07-Mar	0	14	0.00	08-Mar	3	10	0.30	**280.00%**
08-Mar	3	14	0.21					
	3	28	0.11					
22-Mar	0	14	0.00	23-Mar	0	10	0.00	**0.00%**
23-Mar	0	14						
	0	28						
05-Apr	0	12	0.00	06-Apr	1	12	0.08	**200.00%**
06-Apr	1	12	0.08					
	1	24	0.04					

Cedar River Coho Migration

The diversity of Cedar River coho migrants captured in the screw trap was notable in 2010 and led to a closer investigation of coho age structure and migration timing. At least two age classes of coho smolts were observed in the trap catches. The two age classes were of comparable body lengths and initially recognized by the different eye to head proportions – smaller in sub yearling smolts and larger in yearling smolts. The early portion of the outmigration consisted of migrants that displayed typical physical attributes of a coho smolt – large body size both in length and girth, large eye, and silvery coloration typically associated with the smoltification process. The latter portion of the outmigration that moved in June was composed of much smaller coho, some similar in length to the early portion but typically much slimmer with a small eye, but silver in coloration like a smolting coho. Silver coloration is often an indicator of the physiological changes occurring while coho are actively migrating to salt water. However, in the Lake Washington system, coloration can be a problematic characteristic for distinguishing smolts from large parr that are migrating to the lake to rear. A substantial amount of freshwater rearing habitat occurs downstream of the trap and an unknown portion of coho that are not yet silver at the Cedar River screw trap may take on the silver coloration in this lake habitat. Relative eye size (to total head size) has also been a physical characteristic useful in field classification of sub yearling and yearling coho of comparable lengths (P. Topping, WDFW Fish Science, personal communication). However, no systematic study has been completed to test the use of relative eye size as a characteristic to classify Cedar River coho as sub yearling or yearling fish. This may be an important area of research in the future.

Table 24. Fork lengths of natural-origin coho migrants over twelve migration years (1999-2010) in the Cedar River. Trap location was not optimal during years marked with * and may have been size biased. 2010 migration brood data includes all coho migrants caught in the screw trap. Previous years' summary may only reflect data of those thought to be coho smolts.

Migration	Screw Trap					
Year	Avg	s.d.	Min	Max	n	Catch
1999	105.9	11.46	82	242	839	5,105
2000	107.0	13.15	76	175	212	2,446
2001	112.0	11.20	60	172	621	5,927
2002	107.7	10.11	84	142	459	3,406
2003	111.6	10.94	62	175	1,406	3,763
2004	109.8	10.01	86	145	466	2,668
2005	110.0	9.90	84	158	1,430	2,899
2006*	107.7	9.19	84	141	388	796
2007*	109.0	10.00	86	148	403	482
2008*	105.3	12.35	81	168	232	315
2009	105.9	10.50	75	148	833	5,549
2010	104.3	13.37	49	141	1,326	6,321

Between migration years 1999 and 2009, coho were defined as either parr (0+) or smolts (1+) based on some of the characteristics mentioned above. It is possible that in previous years, coho were misclassified. In 2010, we chose to define the Cedar River coho production based on the total number of coho migrants that passed the trap, rather than assigning some arbitrary definition of a smolt to the later-time portion of the run. We acknowledge that a portion of the 2010 migrants included coho that might be considered too small to leave the system. However, the proportion of coho lengths less than 80 mm constituted just 3.6% of the total fish measured and represent approximately 2,900 coho smolts of the total production estimated. We do not believe that this change significantly influences the calculations of the average size of coho or annual production relative to previous years (Table 24). In addition, in order to better understand coho age diversity and migration timing, coho smolts were visually classified to age based on phenotype, aged (via scale samples), and PIT tagged in 2010. Between May 18 and June 30, a total of 100 coho were PIT tagged and 81 were sampled for scales.

Coho were first identified to age class based on phenotype (small eye – sub yearling, large eye – yearling) and then identified to age class based on scale analysis. Using the size of the eye of the coho led to properly identifying the age class of a coho 91.4% of the time (Table 25). One coho, or 1.2%, was identified as age 1 based on phenotype but was an age 2 fish according to scale analysis. One coho was identified as an age-1 fish based on phenotype but was an age-0 fish according to scale analysis. The remaining misclassifications were identified as age-0 based on phenotype but assigned to age-1 based on scale analysis.

Table 25. Classification of coho migrants caught in the Cedar River screw trap. Coho were classified based on phenotype (big eye, small eye) in the field. Ages of these same coho were identified from scale samples. Data are mean fork lengths (mm), sample sizes (n), and phenotype-age assignments.

Statistical Week			Large Eye						Small Eye			
			Age 0		Age 1		Age 2		Age 0		Age 1	
Begin	End	No.	n	Avg. FL	n	Avg. FL	n	Avg. FL	n	Avg. FL	n	Avg. FL
05/17	05/23	21			6	90.2	1	92.0				
05/24	05/30	22			18	86.1						
05/31	06/06	23			1	86.0						
06/07	06/13	24							15	91.2	4	85.3
06/14	06/20	25							8	84.5		
06/21	06/27	26	1	81.0					4	84.5	1	86.0
06/28	07/04	27							22	94.9		
		Total	**1**	**81.0**	**25**	**87.0**	**1**	**92.0**	**49**	**91.2**	**5**	**85.4**

Coho identified to age class based on eye size were also PIT tagged in order to assess migration timing and age at migration through the Hiram Chittenden Locks. PIT tag detections at the Locks included 20.3% of the age-0 coho and 37.0% of the age-1 coho. The first PIT tag was detected on June 8 and the last tag was detected on July 9, 2010. Travel time through Lake Washington averaged 34.7 days (St. Dev. = 6.0) for age-0 coho and 22.3 days (St. Dev. = 6.2) for age-1 coho smolts.

Although movement of sub yearling coho is expected in systems where freshwater habitat occurs downstream of a trapping location, smolting of sub yearling coho is not typically observed in western Washington. However, sub yearling smolts are also observed in the Deschutes River in southern Puget Sound (P. Topping, WDFW Fish Science, personal communication). Severely depressed run sizes in the Deschutes River may result in resources for coho to rear to smolt size (~90 mm) in a few months and exit the system as sub yearlings. Adult coho returns to the Deschutes indicate that sub yearling migrants contribute to the returning spawners. A comparable situation of underseeded habitat may explain the presence of sub yearling coho smolts on the Cedar River. Beginning in 2003, coho spawners were passed above Landsburg Diversion dam and allowed to recolonize 17 miles of main stem and tributary habitat in the upper Cedar River watershed. Access to habitat above Landsburg has nearly doubled the total number of river miles that are available for coho spawning and rearing in the Cedar watershed.

Recommendations

The 2010 trapping season in Cedar River and Bear Creek experienced a number of successes. For example, all traps operated successfully through the entire outmigration season to produce precise abundance estimates for all target species. In the Cedar River, large numbers of Chinook fry migrants allowed for estimation of Chinook fry capture rates in the inclined-plane trap. In Bear Creek, movement of sockeye and Chinook fry were re-evaluated. In both watersheds, catches and recaptures were large enough to assess a key assumption in mark-recapture studies: equal probability within species of being captured.

Furthermore, when evaluating 2010 data for both systems, a number of assumptions associated with the uncertainty of our estimates became apparent and will be addressed in the 2011 trap season. Tests of these assumptions 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 basin.

Recommendation 1: Test assumption that there is very little, or no, sockeye and Chinook fry movement occurring during daylight hours in Bear Creek. This was a recommendation that was tested during the 2010 trap season but needs further assessment. Although daylight movement in Bear Creek was tested in the 1990s, it seems appropriate to periodically retest assumptions to confirm that salmonids are still behaving as expected. The consequence of missing day-time catch of juvenile salmonids is an underestimate of the juvenile migration. The 2009 sockeye and Chinook brood were products of the lowest adult return for both species and resulted in the lowest migration since trapping began. Due to such low catches, we believe that these results may not accurately reflect day migrations in larger return years. In 2011, the Bear Creek inclined-plane trap will operate periodically throughout the season during daylight hours to continue assessment of daylight fry migrations, develop day-to-night ratios, and to reassess day-time migration.

Recommendation 2: 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 ESA listed. During the 2010 trapping season, this assumption was tested when Chinook fry abundance was large enough to form adequate size release groups. However flows were steady through most of the migration. Ideally multiple releases throughout a wide range of flows would occur to better understand differences in movement over time. 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. Therefore, paired releases of sockeye and Chinook fry will be conducted in 2011 over as wide a range of flows as possible given available catch and river conditions.

Recommendation 3. Test assumption that eye size on coho migrants is a useful field tool in visually identifying coho age at migration passed the Cedar River screw trap, and further

investigate later-timed coho migration time through the Hiram Chittenden Locks through PIT tagging. The coho migration on the Cedar River consists of two distinct movements: an earlier pulse of larger coho, silver in color, with distinct large eyes associated with age 1 coho, and a second pulse which occurs later in the season with smaller coho, still silver but with a much smaller eye. The uncertainty of the age of these later timed coho contributes to some uncertainty in the coho production estimate relating to a specific brood year. In 2010, a portion of coho were scale sampled, PIT tagged, and visually identified as either age 0 or age 1 coho based on the size of their eye. This visual identification method proved 91.4% accurate. In 2011, scale sampling, PIT tagging, and eye size classification will continue to improve understanding of coho movement through Lake Washington and coho use of Lake Washington for freshwater rearing.

Appendix A

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

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Statistician
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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,

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

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

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

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

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, 2010.

Appendix B 1. Catch and migration by strata for Cedar River natural-origin sockeye fry, 2010.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	01/17/10	01/28/10	5,736	6.76%	83,826	1.07E+08
2	01/29/10	02/01/10	5,955	3.34%	173,701	1.16E+09
3	02/02/10	02/02/10	2,180	9.12%	23,467	1.00E+07
4	02/03/10	02/03/10	2,530	5.01%	49,221	5.98E+07
5	02/04/10	02/08/10	18,730	7.38%	251,998	5.26E+08
6	02/09/10	02/10/10	6,302	10.12%	61,817	3.04E+07
7	02/11/10	02/17/10	44,003	7.65%	572,547	2.38E+09
8	02/18/10	02/19/10	15,040	14.71%	101,832	4.82E+07
9	02/20/10	02/22/10	22,993	9.02%	252,937	5.30E+08
10	02/23/10	02/24/10	16,771	4.70%	350,407	2.06E+09
11	02/25/10	02/26/10	23,387	10.13%	229,041	4.76E+08
12	02/27/10	03/03/10	139,021	5.10%	2,697,305	9.94E+10
13	03/04/10	03/05/10	41,811	8.11%	509,783	4.69E+09
14	03/06/10	03/07/10	33,839	3.98%	830,689	1.68E+10
15	03/08/10	03/15/10	135,313	7.05%	1,910,802	1.73E+10
16	03/16/10	03/16/10	13,414	4.55%	288,561	1.66E+09
17	03/17/10	03/17/10	21,636	8.74%	244,793	6.30E+08
18	03/18/10	03/28/10	162,666	7.01%	2,316,654	1.40E+10
19	03/29/10	03/29/10	4,187	3.25%	124,298	5.18E+08
20	03/30/10	03/30/10	5,015	6.01%	81,822	1.29E+08
21	03/31/10	04/06/10	29,007	7.88%	365,963	1.69E+09
22	04/07/10	05/02/10	55,112	6.14%	894,921	2.29E+09
		Total	**804,648**		**12,416,385**	**1.67E+11**

Appendix B 2. Catch and migration by strata for Cedar River natural-origin Chinook fry, 2010.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	01/17/10	01/28/10	704	6.76%	10,293	1.69E+06
2	01/29/10	02/01/10	52	3.34%	1,545	2.27E+05
3	02/02/10	02/02/10	17	9.12%	193	2.35E+03
4	02/03/10	02/03/10	92	5.01%	1,808	1.10E+05
5	02/04/10	02/08/10	296	7.38%	3,995	2.91E+05
6	02/09/10	02/10/10	153	10.12%	1,507	3.06E+04
7	02/11/10	02/17/10	1,075	7.65%	14,004	2.24E+06
8	02/18/10	02/19/10	143	14.71%	974	1.75E+04
9	02/20/10	02/22/10	435	9.02%	4,799	2.41E+05
10	02/23/10	02/24/10	318	4.70%	6,660	8.66E+05
11	02/25/10	02/26/10	183	10.13%	1,800	1.03E+06
12	02/27/10	03/03/10	405	5.10%	7,869	8.99E+05
13	03/04/10	03/05/10	439	8.11%	5,363	1.16E+06
14	03/06/10	03/07/10	216	3.98%	5,334	6.37E+06
15	03/08/10	03/15/10	1,702	7.05%	24,047	2.60E+07
16	03/16/10	03/16/10	42	4.55%	916	3.39E+04
17	03/17/10	03/17/10	294	8.74%	3,337	1.50E+05
18	03/18/10	03/28/10	404	7.01%	5,761	7.68E+05
19	03/29/10	03/29/10	214	3.25%	6,389	1.52E+06
20	03/30/10	03/30/10	105	6.01%	1,728	8.19E+04
21	03/31/10	04/06/10	128	7.88%	1,626	3.55E+04
22	04/07/10	04/14/10	106	6.14%	1,736	1.34E+06
		Total	**7,522**		**111,683**	**4.51E+07**

Appendix B 3. Catch and migration by strata for Cedar River natural-origin Chinook parr, 2010.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/17/10	05/04/10	1196	11.20%	10,516	1.80E+06
2	05/05/10	07/04/10	2371	8.98%	26,238	5.72E+06
		Total	**3,567**		**36,754**	**7.52E+06**

Appendix B 4. Catch and migration by strata for Cedar River natural-origin coho migrants, 2010.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/16/10	05/26/10	5453	8.66%	62,764	1.52E+07
2	05/27/10	06/11/10	758	4.11%	16,697	2.87E+07
3	06/12/10	06/20/10	116	11.11%	994	5.75E+04
4	06/21/10	07/04/10	201	15.63%	1,265	3.90E+04
	Total		**6,528**		**81,720**	**4.40E+07**

Appendix C

Catch and Migration Estimates by Strata for Bear Creek
Sockeye, Chinook, Coho Salmon, and Cutthroat Trout, 2010.

Appendix C 1. Catch and migration by strata for Bear Creek sockeye, 2010.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	01/31/10	03/30/10	7,945	6.71%	117,961	9.32E+07
2	03/31/10	04/16/10	936	8.11%	11,131	5.22E+06
		Total	**8,881**		**129,092**	**9.84E+07**

Appendix C 2. Catch and migration by strata for Bear Creek natural-origin Chinook fry, 2010.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	01/31/10	03/30/10	99	6.71%	1,484	4.40E+04
2	03/31/10	04/16/10	5	8.11%	70	9.28E+02
		Total	**104**		**1,554**	**4.49E+04**

Appendix C 3. Catch and migration by strata for Bear Creek natural-origin Chinook parr, 2010.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/17/10	05/04/10	169	18.18%	875	4.70E+04
2	05/05/10	05/12/10	117	22.22%	506	9.37E+03
3	05/13/10	05/19/10	184	47.26%	388	1.52E+03
4	05/20/10	05/22/10	207	5.75%	3,050	1.26E+06
5	05/23/10	05/28/10	251	33.04%	749	1.10E+04
6	05/29/10	06/02/10	116	13.48%	830	3.25E+04
7	06/03/10	06/04/10	28	52.94%	52	1.02E+02
8	06/05/10	06/06/10	63	6.98%	703	9.29E+04
9	06/07/10	07/04/10	181	37.25%	480	4.32E+03
		Total	**1,316**		**7,631**	**1.46E+06**

Appendix C 4. Catch and migration by strata for Bear Creek natural-origin coho smolts, 2010.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/17/10	05/16/10	1262	16.15%	7,775	3.74E+05
2	05/17/10	05/28/10	521	12.29%	4,175	3.16E+05
3	05/29/10	07/04/10	171	16.00%	1,038	3.92E+04
		Total	**1,954**		**12,988**	**7.28E+05**

Appendix C 5. Catch and migration by strata for Bear Creek cutthroat migrants, 2010.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/17/10	05/02/10	431	14.91%	2,838	1.74E+05
2	05/03/10	05/26/10	255	20.09%	1,252	3.32E+04
3	05/27/10	07/04/10	82	3.85%	1,120	3.87E+05
		Total	**768**		**5,209**	**5.94E+05**

Citations

Cases

Burton, K., Larry Lowe, and Hans Berge. 2010. Cedar River Chinook Salmon (*Oncorhynchus tshawytscha*) Redd and Carcass Surveys; Annual Report 2009. Seattle, Washington. 18, 30

Carlson, S. R., L. G. Coggins, and C. O. Swanton. 1998. A simple stratified design for mark-recapture estimation of salmon smolt abundance. Alaska Fishery Research Bulletin 5:88-102. 16

Columbia Basin Fish and Wildlife Authority and the PIT Tag Steering Committee. 1999. PIT Tag Marking Procedures Manual. 11

Cramer, S.P., J. Norris, P.R. Mundy, G. Grette, K.P. O'Neal, J.S. Hogle, C. Steward and P. Bahls. 1999. Status of Chinook salmon and their habitat in Puget Sound. Vol 2. 6

Crawford, B. A. and Rumsey, S. M. 2011. Guidance for monitoring recovery of Pacific Northwest salmon and steelhead listed under the Federal Endangered Species Act. National Marine Fisheries Service, Northwest Region, http://www.nwr.noaa.gov/Salmon-Recovery-Planning/recovery-monitor.cfm. 51

Cuthbertson, C. 2010. 2009-2010 Cedar River Sockeye Hatchery Annual Report. WDFW, Olympia WA. 7. .... 18, 22, 24, 38

Hayes, D. B., J. R. Bence, T. J. Kwak, and B. E. Thompson. 2007. Abundance, biomass, and production. Pages 327-374 in C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland. 53

Kinsel, C., M. S. Zimmerman, L. Kishimoto, and P. Topping. 2008. 2007 Skagit River salmon production evaluation, FPA 08-08. Washington Department of Fish and Wildlife, Olympia, Washington. 56

Kiyohara, K. and Zimmerman, M. 2011. Evaluation of juvenile salmon production in 2009 from the Cedar River and Bear Creek, FPA 11-03. Washington Department of Fish and Wildlife, Olympia, Washington. 24

NMFS. 1999. Endangered and threatened species; threatened status for three Chinook salmon Evolutionary Significant Units (ESUs) in Washington and Oregon, and endangered status for one Chinook salmon ESU in Washington. Federal Register, Vol. 64, No.56, 14308-14328..... 6

Royal, L. A. 1965. Annual report for the year of 1964. International Pacific Salmon Fisheries Commission. New Westminster, B.C. 36. 52

Schwarz, C. J., and G. G. Taylor. 1998. The use of stratified-Petersen estimator in fisheries management: estimating pink salmon (Oncorhynchus gorbuscha) on the Frazier River. Canadian Journal of Fisheries and Aquatic Sciences 55:281-297. 52

Seber, G. A. F. 1973. The estimation of animal abundance. Charles Griffin and Company Limited, London. 51, 52, 53

Seiler, D., G. Volkhardt and L. Kishimoto. 2003. Evaluation of downstream migrant salmon production in 1999 and 2000 from three Lake Washington tributaries: Cedar River, Bear Creek and Issaquah Creek. WDFW Olympia WA. 199. .... 6, 9, 56

Seiler, D., G. Volkhardt, and L Fleischer. 2004b. Evaluation of downstream migrant salmon production in 2002 from the Cedar River and Bear Creek, FPA 04-09. Washington Department of Fish and Wildlife, Olympia, Washington. 56

Seiler, D., G. Volkhardt, and L. Fleischer. 2004a. Evaluation of downstream migrant salmon production in 2001 from the Cedar River and Bear Creek, FPA 04-07. Washington Department of Fish and Wildlife, Olympia, Washington. 56

Seiler, D., S. Neuhauser and M. Ackley. 1981. Upstream/downstream salmonid project 1977-1980. WDFW Olympia WA 195 .... 6, 9

Sokal, R. R. and Rohlf, F. J. 1981. Biometry, 2nd edition. W. H. Freeman and Company, New York. 16

Thomas, A. E. 1975. Effects of egg concentration in an incubation channel on survival of Chinook salmon fry. USFWS. Stuttgart, Arkansas. 336. 52

U.S. Army Corps of Engineers, Seattle District. 1997. Cedar River Section 205 flood damage reduction study. Final Environmental Impact Statement... 9

Volk, E.C., S.L. Schroder and K.L. Fresh. 1990. Inducement of unique otolith banding patterns as a practical means to mass-mark juvenile Pacific Salmon. Am Fish Soc. Symp 7:203-215... 6

Volkhardt, G. C., S. L. Johnson, B. A. Miller, T. E. Nickelson, and D. E. Seiler. 2007. Rotary screw traps and inclined plane screen traps. Pages 235-266 in D. H. Johnson, B. M. Shrier, J. S. O'Neal, J. A. Knutzen, X. Augerot, T. A. O-Neil, and T. N. Pearsons, editors. Salmonid field protocols handbook: techniques for assessing status and trends in salmon and trout populations. American Fisheries Society, Bethesda, Maryland. 13, 16, 51

Warner, K. 1963. Natural spawning success of landlocked salmon Salmo salar. Maine Department of Inland Fish and Game. Ashland, Maine. 162 52

WRIA 8 (Lake Washington/Cedar/Sammamish Lake Washington/Cedar/Sammamish Watershed Steering Committee). 2005. Lake Washington/Cedar/Sammamish Watershed (WRIA 8) Chinook Salmon Conservation Plan. (http://www.govlink.org/watersheds/8/planning/chinook-conservation-plan.aspx) 6