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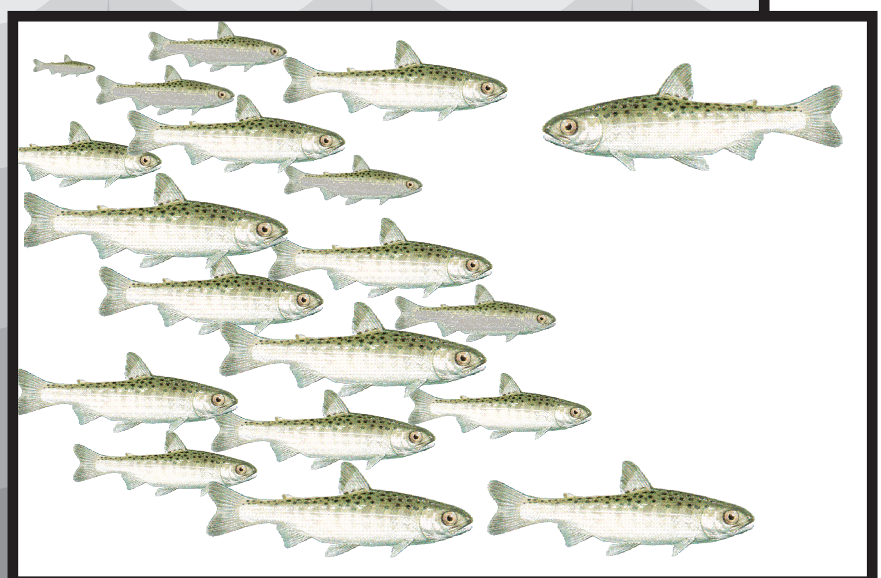
Evaluation of Juvenile Salmon Production in 2011 from the Cedar River and Bear Creek



by Kelly Kiyohara, and Mara Zimmerman

Washington Department of FISH AND WILDLIFE
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Evaluation of Juvenile Salmon Production in 2011 from the Cedar River and Bear Creek

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Cedar River

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

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

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

The United States Geological Survey provided continuous flow monitoring.

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Bear Creek

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

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

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Executive Summary

This report describes the emigration of five salmonid species from two heavily spawned tributaries in the Lake Washington watershed: Cedar River and Bear Creek. Cedar River flows into the southern end of Lake Washington; Bear Creek flows into the Sammamish River, which flows into the north end of Lake Washington. In each 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 coho production estimates to be derived, and steelhead and cutthroat trout movement to be assessed.

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

The primary study goal of this program in 2011 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 2010 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 30 and May 25, 2011. A rotary screw trap was operated at R.M 1.6, just under the I-405 Bridge between April 27 and July 16, 2011. 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 2011 due to insufficient catch.

Production of natural-origin sockeye fry in the Cedar River was estimated to be 4.5 million ± 1.0 million (±95% C.I.). This estimate was based on a total catch of 122,133 between January 30 and May 25 and trap efficiencies ranging from 0.72% to 7.88%. Survival of sockeye fry from egg deposition to lake entry was 4.39%, based on an estimated deposition of 102.9 million eggs. Over the season, 8.78 million hatchery-origin sockeye fry were released into the Cedar River at two different locations. A portion of these (6 million) were released below the inclined-plane trap at the Cedar River Trail Park where in-river survival is assumed to be 100%. The remaining 2.7 million fry were released at R.M. 13.5. Estimates of hatchery fry survival above the trap ranged from 0% to 49.9%. An estimated 12.4 million combined natural and hatchery-origin sockeye fry entered Lake Washington from the Cedar River in 2011.

Median migration date for natural-origin sockeye fry was March 25, 2011, four days later than the long-term average and thirty-five days later than that of the hatchery fry releases. The timing of sockeye outmigration was correlated with February stream temperatures (R^2=0.58) and the 2011 daily average February temperatures (5.8°C) was cooler than the 19-year average of 6.4°C.

Production of natural-origin Chinook was estimated to be 187,806 ± 63,560 (±95% C.I.) sub yearlings, based on operation of both the inclined-plane and screw traps. Between January 1 and May 9, 2011, 177,803 ± 63,481(±95% C.I.) natural-origin Chinook were estimated to have passed the inclined-plane trap. This estimate was based on a total catch of 5,239 and trap efficiencies ranging from 0.72% to 7.88%. Between May 10 and July 31, 2011, 10,003 ± 3,099 (±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 a trap efficiency of 7.84%. Egg-to-migrant survival of the 2010 brood year Chinook was estimated to be 15.7%, the third highest estimated since trapping began.

Weekly average lengths of sub yearling Chinook increased from 37.7-mm fork length (FL) in January to 95.4-mm FL by the end of the season. Migration timing was bi-modal. The small fry emigrated between January and early-May and comprised 82% of all sub yearlings. The large parr emigrated between early-May and July and comprised 18% of the total migration.

A total of 52,458 ± 7,813 (±95% CI) natural-origin coho were estimated to have migrated passed the screw trap in 2011 during the period the trap was operating. Steelhead/rainbow and cutthroat trout production were not estimated in 2011 due to low catches (12 steelhead/rainbow and 47 cutthroat).

Bear Creek

An inclined-plane trap was operated 100 yards downstream of the Redmond Way Bridge between January 23 and April 22, 2011. On April 26, a rotary screw trap replaced the inclined-plane trap and was fished until July 16, 2011. The abundance of natural-origin juvenile migrants was estimated for sockeye fry, sub yearling Chinook, coho, and cutthroat trout. No steelhead/rainbow trout were caught in the Bear Creek traps during the 2011 trapping season.

Sockeye fry migration in 2011 was estimated to be 8,160,976 ± 1,063,587 (±95% C.I.). This estimate was based on a total catch of 492,773 sockeye fry and trap efficiencies ranging from 3.5% to 10.4%. An egg-to-migrant survival rate of 42.4% was based on an egg deposition of 19.2 million and was the highest estimate of survival since trapping began in 1998.

Production of natural-origin Chinook was estimated to be 18,175 ± 1,687 (±95% C.I.) sub yearlings. This estimate was based on catch in the inclined-plane and screw traps. A total of 1,651 ± 390 (±95% C.I.) Chinook were estimated to have migrated passed the inclined-plane trap between January 23 and April 26. This estimate was based on a total catch of 49 Chinook and efficiencies ranging from 3.5% and 10.4%. A total of 16,524 ± 1,641 (±95% C.I.) Chinook were estimated to have migrated passed the screw trap between April 27 and July 16. This estimate is based on a total catch of 4,434 Chinook and screw trap efficiencies ranging from 13.0% to

56.3%. Egg-to-migrant survival of the 2010 brood year natural-origin Chinook was estimated to be 6.7%, the second highest survival measured.

Weekly average lengths of sub yearling Chinook migrants averaged 39.5-mm FL in February and increased to an average of 86.3-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 5.1% of the total migration. Large parr migrants emigrated between May and July and represented 94.9% of total production in Bear Creek during 2011.

A total of 34,513 ± 8,813 (±95% C.I.) natural-origin coho and 4,569 ± 1,403 (±95% C.I.) cutthroat trout were estimated to have migrated from Bear Creek in 2011.

Introduction

This report describes the emigration of five salmonid species 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 2011 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.

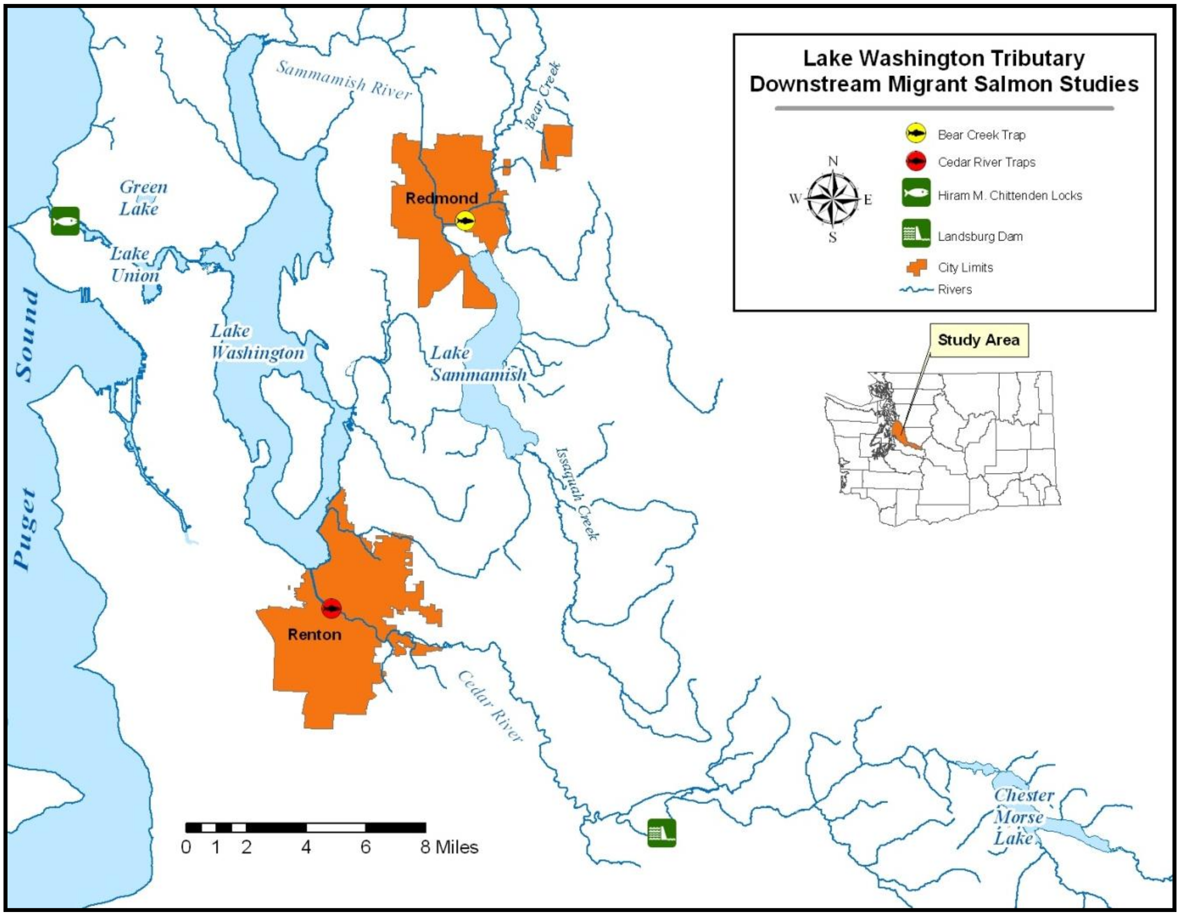

Figure 1. Map of Lake Washington trap sites used to monitor abundance of juvenile migrant salmonids in the Cedar River and Bear Creek, near Renton and Redmond, respectively.

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 88,886 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 brood year). Over the duration of the juvenile monitoring study, escapement has ranged from 577 to 43,298 spawners, with an average return of 10,750 sockeye. Survival from egg deposition to migration in Bear Creek has ranged between 3.0% and 42.2%.

Puget Sound Chinook salmon are listed as “threatened” under the authority of the Endangered Species Act (NMFS 1999) and consequently are an important management concern. Baseline information available at the time of listing included escapement estimates in the Cedar River and Bear Creek 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 six months and includes an early migration of newly emerged fry and a late migration of large Chinook (parr). Two different gear types have been used to sample the entire Chinook migration. An inclined-plane trap gently captures early-timed fry but is ineffective at capturing larger migrants late in the season. A rotary screw trap more effectively catches the 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 1.7% 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 20 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 2011, the inclined-plane trap was anchored at RM 0.8, just downstream of the South Boeing Bridge (Figure 2). This trap positioned 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 27 nights when only one trap was operated due to high flows, debris loads or hatchery releases.

The inclined-plane trap began operating on the night of January 30 was operated 63 nights between January 30 and May 25. 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 beginning of April. Captured fish were removed from the trap, identified by species, and counted each hour. Fork lengths were randomly sampled on a weekly basis from all salmonid species, except for sockeye.

The Landsburg Hatchery released hatchery reared sockeye fry into the Cedar River above the trap at R.M. 13.5 on seven nights throughout the season. Of the seven releases located above the inclined-plan trap, only five occurred during nights the trap was operating; January 31, February 8, March 1 and 8, and April 1. Flows increased dramatically and lodged a large log in the trap on April 1. Trap operations were halted by 2 AM. With the exception of April 1, survival of hatchery fry was estimated for the nights listed above.

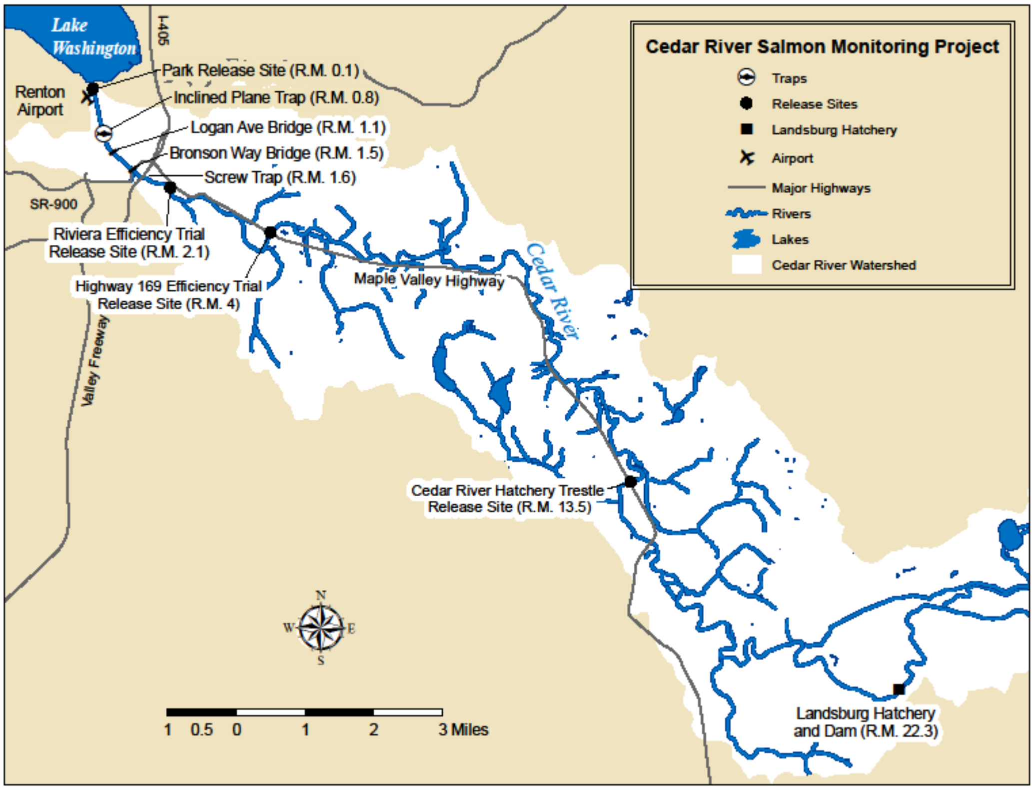

Figure 2. Site map of the lower Cedar River watershed depicting the inclined-plane and screw trap locations and hatchery sockeye release site for the 2011 trapping season.

In 2011, the screw trap was operated at R.M 1.6, just under the I-405 Bridge (Figure 2), between the evening of April 27 and July 16, except during 11 night outage periods (April 28, May 15, 18, June 3, 9, 10, and July 4, 9, 10, and 11) caused by high debris loads and 3 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 late April to capture Chinook, coho, steelhead/rainbow, and cutthroat.

The inclined-plane trap was operated between January 23 and April 22. 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. The trap did not fish between April 23 and April 25 due to staffing and gear changes. On April 26, 2011, the screw trap replaced the inclined-plane trap and fished for the remainder of the season.

The screw trap was operated between April 27 and the morning of July 16, except during four outage periods (May 19, 26, and June 19, 25) 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.

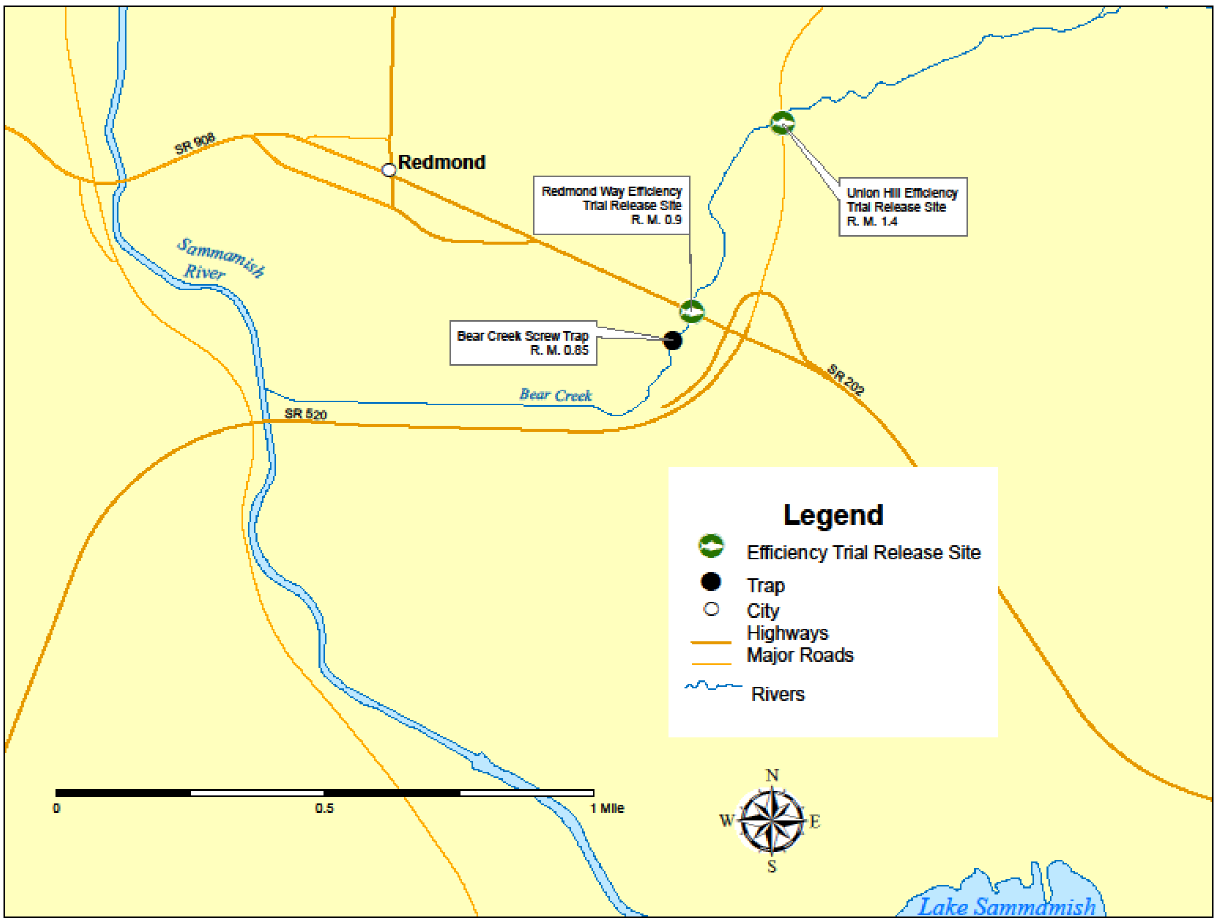

Figure 3. Site map of the Bear Creek watershed in the North Lake Washington Basin showing trap location for the 2011 trapping season.

PIT Tagging

During screw trap operation at both sites, a portion of natural-origin Chinook and coho migrants were tagged with Passively Integrated Transponder (PIT) tags. Captured steelhead were tagged as well. Tagging occurred two to three times a week, depending on catches, between April 28 and July 15, 2011. 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 and coho longer than 65-mm that displayed good physical health were considered for tagging. Fork lengths were measured for all PIT tagged fish. Protocols for tagging follow those outlined for the Columbia River basin by the Columbia Basin Fish and Wildlife Authority and the PIT Tag Steering Committee (1999).

Upon exiting the Lake Washington basin through the Hiram Chittenden Locks facility, tagged fish could be detected by a PIT tag antenna if they used one of two routes; one of four smolt flumes that operated between April 20 and September 14, 2011 or the adult fish ladder whose antenna operated from April 20, 2011 through the end of December 2011. 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 hatchery origin or natural-origin sockeye fry released above the trap. Hatchery-origin sockeye, obtained from the Cedar River Hatchery, were used when natural-origin sockeye were not abundant enough to form an efficiency trial. This occurred mostly near the beginning of the migration with a few later in the season. There were a total of ten efficiency trials that consisted of only hatchery fry. When natural-origin fry were used, fish captured in the early hours of the night were used for efficiency trials. All fry used for efficiency trials were marked in a solution of Bismarck brown dye (14 ppm for 1.5 hours). The health of marked fish was assessed prior to release. Deceased or compromised fish were not included in releases. Release groups, ranging from 95 to 2,189 marked sockeye fry, were released at the Logan Street Bridge (R.M. 1.1) on 29 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. Beginning April 28, Chinook parr longer than 65-mm FL and coho 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 both species.

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 2 to 100 juveniles of each species. Catches were examined for marks or tags and recaptures were noted during each trap check.

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 93 to 404 sockeye and were released approximately 100 yards upstream of the trap at the Redmond Way Bridge. Fry releases occurred on 40 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 8 to 100 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 capture rates throughout the season. The general approach was to estimate (1) missed catch, (2) efficiency strata, (3) abundance for each strata, (4) extrapolated migration prior to and post trapping, and (5) total production.

Missed Catch

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

Missed catch 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 (Kiyohara and Zimmerman 2011).

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

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

Equation 2

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

where:

k = number of sample nights used in the interpolation,

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

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

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

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

Equation 3

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

Missed Catch for Partial Day and Night Periods

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:

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

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

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 in both watersheds was January 1 to July 13. Pre- and post-season migration was not estimated for coho or cutthroat.

Total Production

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

Equation 13

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

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

Hatchery Catch and Survival

Hatchery catch and survival was estimated for nights when releases occurred above the trap and the trap was operating. If the trap was not operating on a release night, catch and survival were not estimated and survival was noted as 100% for lack of data to prove otherwise. The trap was operating on four nights when hatchery releases occurred above the trap; January 31, February 8, March 1 and March 8. Due to the inability to visually distinguish hatchery and natural-origin sockeye, the portion of each in the catch is unknown on hatchery release nights. Therefore, on nights of releases, natural-origin migration was assumed to be intermediate between natural-origin migration the night before and after the release, and the interpolation method was applied to estimate natural-origin migration on hatchery release nights. Hatchery catch was the total catch minus estimated natural-origin catch. Total hatchery migration was estimated by expanding estimated hatchery catch by the measured nighttime efficiency. If an efficiency trial was not conducted on a hatchery release night, then the appropriate strata efficiency was applied.

Survival of releases above the trap was calculated by dividing estimated hatchery migration passed the trap by total number of sockeye released above the trap.

Egg-to-Migrant Survival

Egg-to-migrant survival for sockeye and Chinook was the survival between egg deposition and migration of juveniles into Lake Washington. Survival was estimated by dividing the 2011 abundance of natural-origin juvenile migrants by the 2010 potential egg deposition (PED) for each species and watershed. PED was the product of the number of female spawners and their fecundity. Sockeye spawner abundances in the Cedar River and Bear Creek were Area-Under-the-Curve estimates that were calculated and agreed upon in a multi-agency effort. This estimate assumed an even sex ratio for sockeye. Cedar River sockeye fecundity was the average number of eggs per female during 2010 sockeye brood stock collection for the Landsburg Hatchery on the Cedar River (Cuthbertson 2011). Fecundity of Bear Creek sockeye was assumed to be the same as the fecundity of Cedar River sockeye. The number of female Chinook was based on annual redd counts conducted by state and local agencies and assumed to represent one female per redd (Burton et al. 2011). Chinook fecundity was based on a long-term average fecundity at the Soos Creek Hatchery (M. Wilson, Washington Department of Fish and Wildlife, personal communication).

Cedar River Results

Sockeye

Catch and Estimated Missed Catch

Total catch (actual and estimated missed) in the inclined-plane trap was 122,133 sockeye fry. A total of 60,628 natural-origin sockeye fry were caught in the inclined-plane trap during trap operations. An additional 48,666 sockeye fry should have been caught had the inclined-plane trap fished continuously at night between January 30 and May 25, 2011. Five day intervals were trapped to evaluate day-time migration: February 8, 14, March 7, 22, and April 5. Flows on these days ranged from 672 cfs to 2,270 cfs at the Cedar River USGS gage (#12119000) and were representative of flows throughout the season. Day-to-night catch ratios ranged from 2.03% to 48.15%. An estimated 12,839 fry should have been caught had the trap fished during all day-time periods. Missed day-time catch represented 10.5% of the season's total catch.

Production Estimate

A total of 29 efficiency trials, ranging in size from 95 to 2,189 sockeye, were conducted in 2011. Efficiency data were aggregated into eleven strata. Capture rates for these strata ranged from 0.72% to 7.88%.

An estimated 12.4 million sockeye fry entered Lake Washington from the Cedar River in 2011 (Table 1, Figure 4, Appendix B1). This migration included 4.52 million ± 1.0 million (±95% C.I.) natural-origin fry and 7.87 million hatchery fry. Pre-season migration (January 1 through January 29) was estimated to be 25,999 fry, and the post-season migration (May 26 through June 30) was estimated to be 60,745 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 11.33%.

Table 1. Abundance of natural-origin and hatchery sockeye fry entering Lake Washington from the Cedar River in 2011. Table includes abundance of fry migrants, 95% confidence intervals (C.I.), and coefficients of variation (*CV*). Hatchery totals are adjusted to reflect estimated survival of releases above the trap.

Component	Period	Dates	Fry Abundance	95% C.I. Low	95% C.I. High	*CV*	Proportion of Total
Natural Origin	Pre Trapping	January 1 - 29	25,999	21,661	30,337	8.51%	0.58%
	During Trapping	January 30-May 25	4,430,961	3,428,023	5,433,899	11.55%	98.08%
	Post Trapping	May 26- June 30	60,745	54,141	67,349	5.55%	1.37%
		Subtotal	**4,517,705**	**3,514,735**	**5,520,675**	**11.33%**	
Hatchery	Below Trap	January 26-March 21	6,026,000				
	Above Trap (Unfished)	January 27-April 1	1,274,000				
	Above Trap (Fished)	January 31-March 8	571,376	571,331	571,422	0.0040%	
		Subtotal	**7,871,376**				
		Total	**12,389,081**				

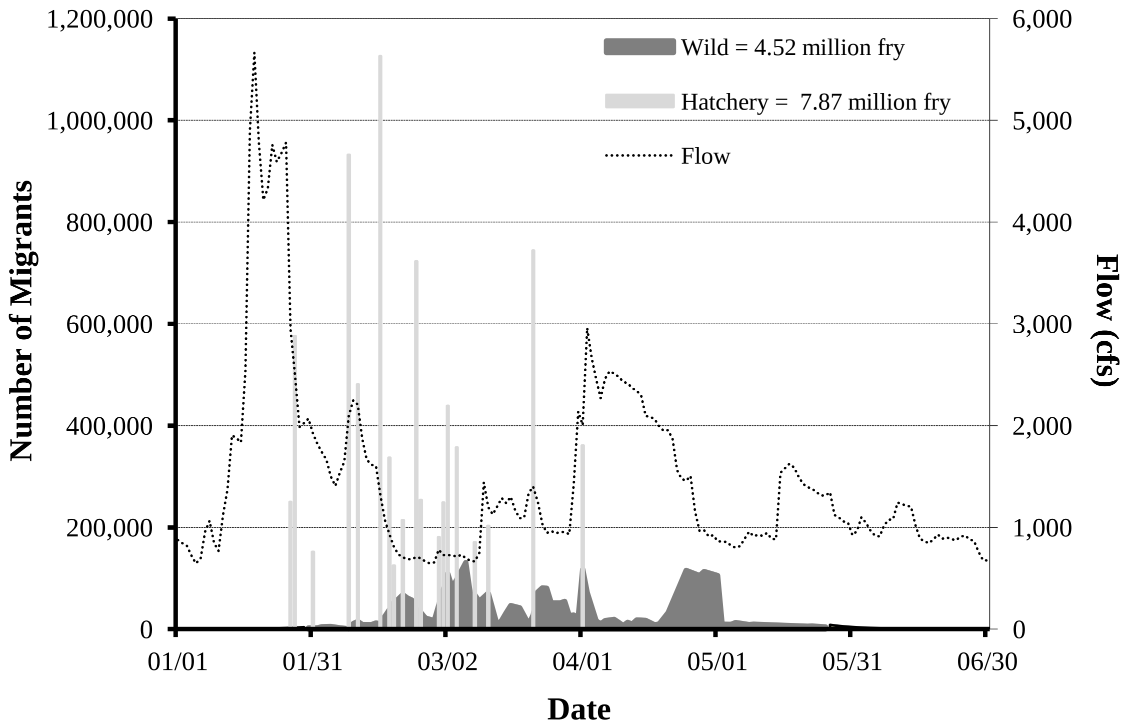

Figure 4. Estimated daily migration of natural-origin and hatchery sockeye fry migrating from the Cedar River into Lake Washington between January 26 and May 25, 2011. Graph includes daily average flows during this period (USGS Renton gage Station #12119000).

Survival of Hatchery Release Groups

Over the season a total of 8,770,000 hatchery-produced sockeye were released into the Cedar River. Slightly more than 6 million sockeye were released at R.M. 0.1 on 13 different nights (Table 2). Releases at this location are assumed to have 100% survival from point of release to the lake entry. An additional 2.7 million were released at R.M. 13.5 on 7 separate nights. Survival was estimated for the nights of January 31, February 8, and March 1 and 8 with respective rates of 32.2%, 0%, 49.9%, and 39.5% (Table 3). Accounting for the estimated loss of hatchery fish mentioned above, total hatchery production in the Cedar River is reduced to 7.87 million sockeye fry.

Table 2. Hatchery sockeye fry released into the Cedar River in 2011 (Cuthbertson 2011).

Release Date	Number Released Below Trap (RM 0.1)	Number Released Above Trap (RM 13.5)
01/26/2011	250,000	
01/27/2011		576,000
01/31/2011 *		472,000
02/08/2011 *	929,000	74,000
02/10/2011	481,000	
02/15/2011	1,126,000	
02/17/2011		337,000
02/18/2011	125,000	
02/20/2011	214,000	
02/23/2011	723,000	
02/24/2011	254,000	
02/28/2011	181,000	
03/01/2011 *		499,000
03/02/2011	439,000	
03/04/2011	357,000	
03/08/2011 *		432,000
03/11/2011	203,000	
03/21/2011	744,000	
04/01/2011		361,000
Total	**6,026,000**	**2,751,000**

* indicates nights when trap was operating. Totals are number of fish released and to not reflect estimated loss.

Table 3. Estimated hatchery sockeye migration, variance, and survival for releases conducted above the Cedar River inclined-plane trap on nights of trap operation, 2011. Flow data was measured at the USGS Renton gage Station #12119000.

Date Released	Sockeye Released	Daily Average Flow (cfs)	Estimated Hatchery Sockeye		
			Migration	Variance	Survival
01/31/2011	472,000	1,927	151,941	2.28E-09	32.91%
02/08/2011	74,000	2,096	0	0	0.00%
03/01/2011	499,000	729	248,740	1.23E-01	49.90%
03/08/2011	432,000	664	170,696	5.31E+02	39.51%

Natural and Hatchery-Origin Timing

In 2011, 31.3% of hatchery sockeye were released upstream of the Cedar River inclined-plane trap while the remaining 68.7% were released below the trap. Releases of hatchery fry began on January 26 and continued through April 4 (Table 2, Figure 4). Median migration date for hatchery fry released downstream of the inclined-plane trap was February 18 (Table 4).

Migration of natural-origin sockeye fry was under way when trapping began on January 30. The number of natural-origin juvenile migrants increased moderately at the beginning of the season, averaging only 38,000 fry per night. Peak daily migration occurred on March 6 when 130,780 sockeye were estimated to have passed the trap in a single night (Figure 4). The median migration date for natural-origin fry occurred on March 25, thirty-five days later than the hatchery median migration date (Table 4). Natural-origin migration was 25%, 50% and 75% completed by March 5, March 25, and April 24, respectively (Figure 5).

Stream temperatures were correlated with median migration date of sockeye fry. After evaluating temperature data throughout the period of fry incubation and migration, total thermal units in the Cedar River for the month of February best explained observed variation in migration timing (R^2 = 0.58, Figure 6). Temperature data was acquired from the USGS Renton gage Station # 12119000. February stream temperatures averaged 5.8° C in 2011, cooler than the average of 6.4°C in the 19-year data set, however median migration date was earlier than the 19-year average median migration date (Table 4). 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, possibly inducing a false median migration date earlier than what temperatures would estimate.

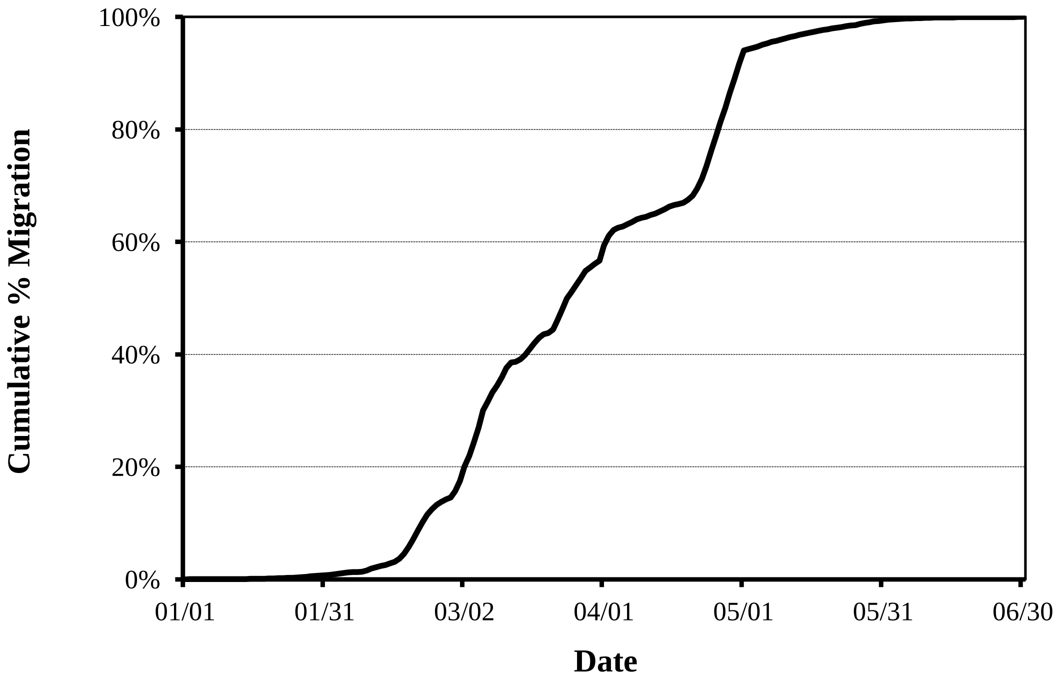

Figure 5. Cumulative migration of natural-origin sockeye fry from the Cedar River into Lake Washington in 2011.

Table 4. Median migration dates of natural-origin, hatchery, and total (combined) sockeye fry from the Cedar River for brood years 1991 to 2010. Total thermal units for February were measured in degrees Celsius at the USGS Renton gage Station #12119000. Temperature was not available for the 1991 brood year. Brood year 2000 was treated as an outlier and not included in this analysis.

Brood Year i	Trap Year i+1	February Thermal Units	Median Migration Date Wild	Hatchery	Combined	Difference (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
2010	2011	163	03/25	02/18	03/01	35
	Average		03/21	02/27	03/12	23

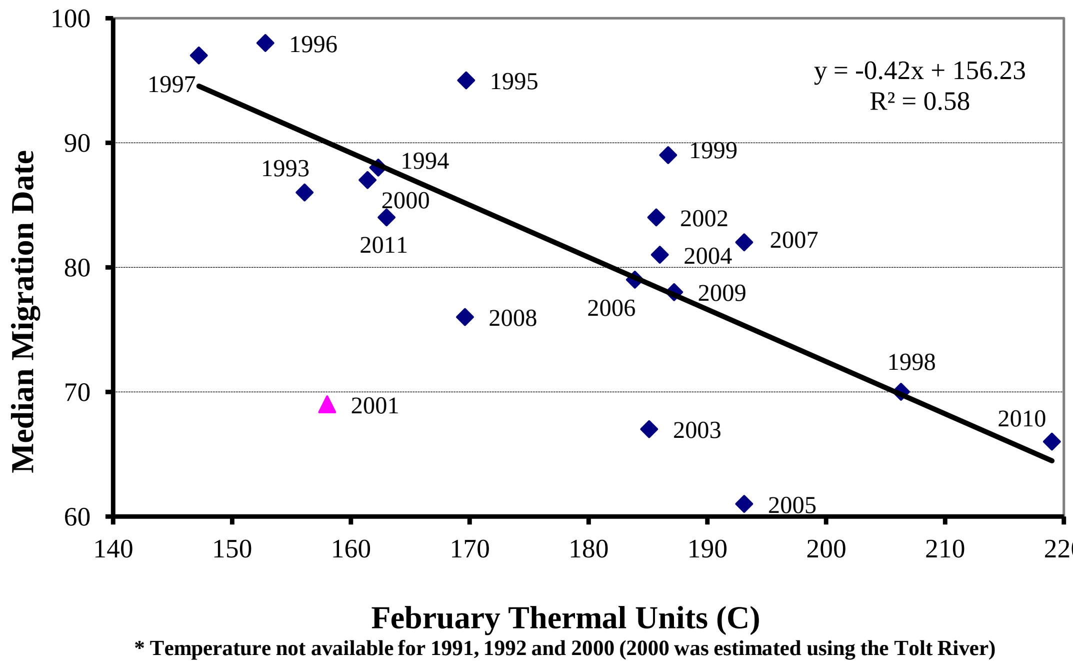

Figure 6. Median migration date (Julian Calendar day) for natural-origin sockeye fry in the Cedar River as a function of cumulative February thermal units (Celsius), migration years 1993-2011. Stream temperature data was measured at the USGS Renton gage Station #12119000. Migration year 2001 was treated as an outlier and not included in analysis.

Egg-to-Migrant Survival of Natural-Origin Fry

Egg-to-migrant survival of the 2010 brood Cedar River sockeye was estimated to be 4.39% (Table 5). Survival was based on 4.5 million natural-origin fry surviving from a potential 102.9 million eggs deposited by 66,910 females (A. Bosworth, Washington Department of Fish and Wildlife, personal communication). Average fecundity for the 2010 brood was 3,075 eggs per female sockeye (Cuthbertson 2011). This is the second lowest 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 lower and less variable with an average of 4.7% and a ranged between 1.91% and 5.90%.

Table 5. Egg-to-migrant survival of natural-origin sockeye fry in the Cedar River and peak mean daily flows during egg incubation period for brood years 1991 - 2010. Flow was measured at the USGS Renton gage Station #12119000.

Brood Year	Spawners	Females (@50%)	Fecundity	Potential Egg Deposition	Fry Production	Survival Rate	Peak Incubation Flow (cfs)	Peak Incubation Flow Date
1991	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
2010	66,910	33,455	3,075	102,874,125	4,517,705	4.39%	5,960	01/18/2011

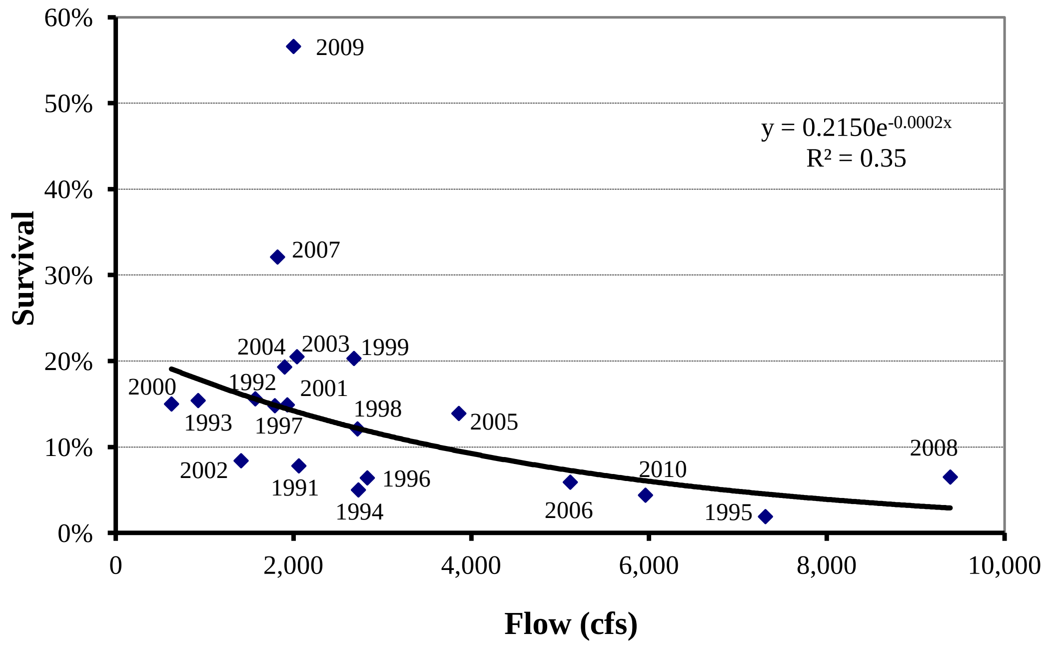

Figure 7. Egg-to-migrant survival of natural-origin sockeye in the Cedar River as a function of peak flow during the winter egg incubation period (November 1 through January 31). Survival for brood years 1991 to 2010 is fit with a decreasing exponential curve. Flow was measured at the USGS Renton gage, Station #12119000.

Chinook

Catch and Estimated Missed Catch

Inclined-Plane Trap

Total catch (actual and missed) of natural-origin Chinook in the inclined-plane trap was estimated to be 5,239 sub yearlings. A total of 2,952 Chinook were captured and an estimated 2,287 additional fry should have been caught if the inclined-plane trap fished continuously (day and night) between January 30 and May 9. Day-to-night catch ratios used to calculate missed day catch ranged from 0% to 45.98%.

Screw Trap

Total catch (actual and missed) of natural-origin Chinook in the screw trap was estimated to be 797 sub yearlings between May 10 and July 16, 2011. A total of 766 natural-origin (unmarked) and 10 hatchery (adipose fin clipped) Chinook were caught in the screw trap. Estimated catch for outage periods was 31 natural-origin Chinook and accounted for 3.9% of the total estimated catch. Catch was estimated for 10 periods when the trap was stopped by debris (1 night period and 9 day periods). Catch was also estimated for 3 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 29 efficiency trials, ranging in size from 95 to 2,189 sockeye (surrogates for Chinook), were conducted. Trials were aggregated into eleven strata. Capture rates for the efficiency strata ranged from 0.72% to 7.88%.

Chinook migration was estimated to be 176,005 fry between January 30 and May 9, 2011 (Appendix B 2). A total of 1,798 Chinook fry were estimated to have migrated between January 1 and 29 (i.e., prior to inclined-plane trap operation). This extrapolation combined with the migration estimate during trap operation yields a total migration of 177,803 ± 61,683 (95% C.I.) Chinook fry through May 9 (Table 6).

During weeks 16 (beginning April 12) through 18 (ending May 2), both the inclined-plane and screw traps operated simultaneously. Flows during inclined-plane trapping ebbed and flowed in an oscillating pattern throughout the season which caused daily migrations to follow the same pattern, higher flows equated to greater daily migrations. The screw trap was installed during a higher flow period and daily migration estimates did not reflect the same migration pattern displayed in the inclined plane trap. Inclined-plane trap migration estimates were greater than screw trap estimates for the entire overlap period. Inclined-plane trap catches allowed for larger efficiency trial groups and subsequently more confident capture rates and migration estimates. Due to low catches in the screw trap, efficiency trial groups were small and capture rates were low. Chinook production was estimated using inclined-plane trap estimates from the beginning of the season through May 9 and screw trap estimates from May 10 through the remainder of the season.

Screw Trap

A total of 24 efficiency trials, ranging in size from 3 to 50 Chinook, were conducted. Trials were aggregated into 1 final stratum resulting in a recapture rate of 7.84% (Appendix B3). Migration of natural-origin Chinook between May 10 and July 16 was estimated to be 9,909 ± 3,099 (±95% C.I.) parr (Table 6).

Table 6. Abundance of natural-origin juvenile migrant Chinook in the Cedar River in 2011. 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 - 29		1,798	1,148	2,448	18.45%
Inclined-Plane Trap	January 30-May 9	5,239	176,005	112,524	239,486	18.40%
Total Fry		**5,239**	**177,803**	**114,322**	**241,284**	**18.22%**
Screw Trap	May 10- July 16	797	9,909	6,810	13,008	15.96%
Post-Trapping	July 17 - July 30		94	86	102	4.41%
Total Parr		**3,567**	**10,003**	**6,904**	**13,102**	**15.81%**
	Season Total	**6,036**	**187,806**	**124,246**	**251,366**	**17.3%**

Combined Estimate

In total, 187,806 ± 63,560 (±95% C.I.) sub yearling Chinook are estimated to have migrated from the Cedar River into Lake Washington in 2011. This estimate is the combination of the Chinook production estimated from the interpolated pre-trapping period, the inclined-plane trap from January 30 through May 9, the estimate from the screw trap for May 10 to July 16 (Table 6), and the post-trapping period.

Migration Timing

Timing of the Chinook migration was bi-modal (Figure 8). Early migrants (fry) were estimated with inclined-plane trap estimates while late migrants (parr) were estimated with screw trap estimates. Juvenile Chinook emigrated mostly as fry, which represented 82% of the total migration (Table 6). Migration was 25%, 50%, and 75% complete by roughly March 3, March 18, and April 2 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 9 with 8,878 fry passing the trap in a single day. Two additional peaks occurred on March 25 and April 27, both over 5,000 fish. Migration then declined through the remainder of the season. Daily parr migrations were low in abundance compared to inclined-plane trap migrations. Two more prominent peaks occurred June 9 and 26 when 522 and 547 Chinook were estimated to have passed the trap in a single day.

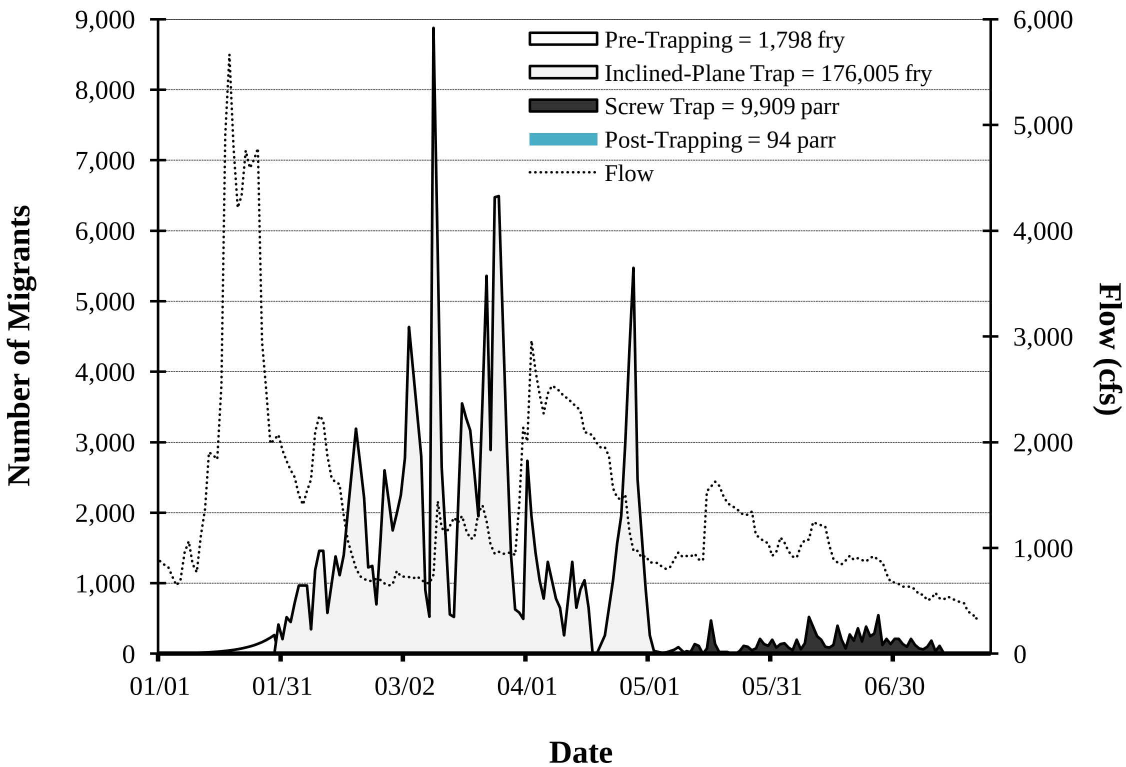

Figure 8. Estimated daily migration of sub yearling Chinook from the Cedar River in 2011 based on inclined-plane (January 30 to May 9) and screw trap estimates (May 10 to July 16). Graph includes mean daily flows during this time period (USGS Renton gage, Station #12119000) in 2011.

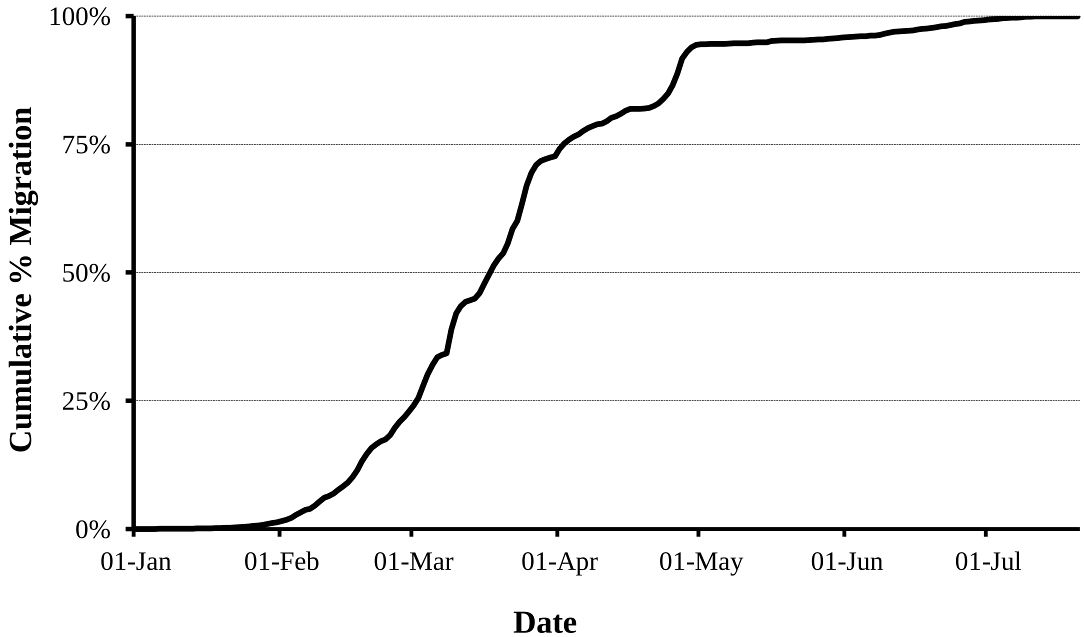

Figure 9. Cumulative percent migration of sub yearling Chinook from the Cedar River in 2011.

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2010 brood of Cedar River Chinook was estimated to be 15.7% (Table 6). Survival was based on 187,806 natural-origin sub yearlings surviving from a potential 1.2 million eggs deposited by 266 female spawners (Burton et al. 2011). Average fecundity for the 2010 brood was assumed to be 4,500 eggs per female.

Table 7. Abundance, productivity (juveniles per female), and survival of Chinook fry and parr among brood years. Fry migration was assumed to be January 1 to April 15. Parr migration was assumed to be April 16 through July 13. Egg-to-migrant survival was calculated from potential egg deposition (PED) for returning spawners. Data are Cedar River broods 1998 to 2010.

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

Size

Chinook fry caught in the inclined-plane trap had an average fork length (FL) of less than 50-mm between January and early April (Table 8, Figure 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 8). Chinook averaged more than 70-mm FL by late-April. The average fork length of 2011 fry migrants were smaller than the average of the 11-year dataset while parr lengths were near the median of the 11-year data set (Table 9).

Table 8. Fork lengths (mm) of natural-origin juvenile Chinook caught in the Cedar River inclined-plane and screw traps in 2011. Data are mean, standard deviation (s.d.), range, sample size (n), and catch for each statistical week.

Statistical Week			Inclined-Plane Trap						Screw Trap					
Begin	End	No.	Avg.	s.d.	Range Min	Range Max	n	Catch	Avg.	s.d.	Range Min	Range Max	n	Catch
01/24	01/30	5	37.7	0.95	36	39	10	10						
01/31	02/06	6	38.5	1.23	36	41	61	74						
02/07	02/13	7	39.7	1.37	37	43	48	78						
02/14	02/20	8	39.6	2.22	37	50	50	336						
02/21	02/27	9	40.2	1.60	37	46	78	334						
02/28	03/06	10	40.4	2.22	30	48	71	540						
03/07	03/13	11	40.6	1.79	38	48	66	426						
03/14	03/20	12	39.8	1.10	38	42	40	241						
03/21	03/27	13	42.0	2.56	38	52	75	699						
03/28	04/03	14	43.0	1.70	41	46	10	81						
04/04	04/10	15	41.3	1.27	39	44	18	29						
04/11	04/17	16	43.5	8.21	39	68	11	25						
04/18	04/24	17	42.8	1.93	40	47	15	15						
04/25	05/01	18	44.8	5.10	39	60	52	54	61.0	8.23	40	78	30	35
05/02	05/08	19	53.0	9.76	41	67	7	8	59.6	7.88	44	73	16	17
05/09	05/15	20	61.5	6.36	57	66	2	2	67.8	8.75	52	84	21	32
05/16	05/22	21	77.4	6.02	72	87	5	5	74.7	8.48	56	87	12	55
05/23	05/29	22	84.3	5.38	78	91	4	4	76.4	8.26	57	95	45	58
05/30	06/05	23							77.7	7.37	59	92	49	66
06/06	06/12	24							80.2	9.09	62	106	110	115
06/13	06/19	25							86.8	9.71	66	112	104	104
06/20	06/26	26							91.3	8.47	71	118	170	180
06/27	07/03	27							90.1	8.63	71	114	80	93
07/04	07/10	28							91.4	9.86	66	118	56	62
07/11	07/17	29							95.4	9.43	84	109	15	15
Season Totals			41.5	5.98	30	91	623	2,961	84.3	12.48	40	118	708	832

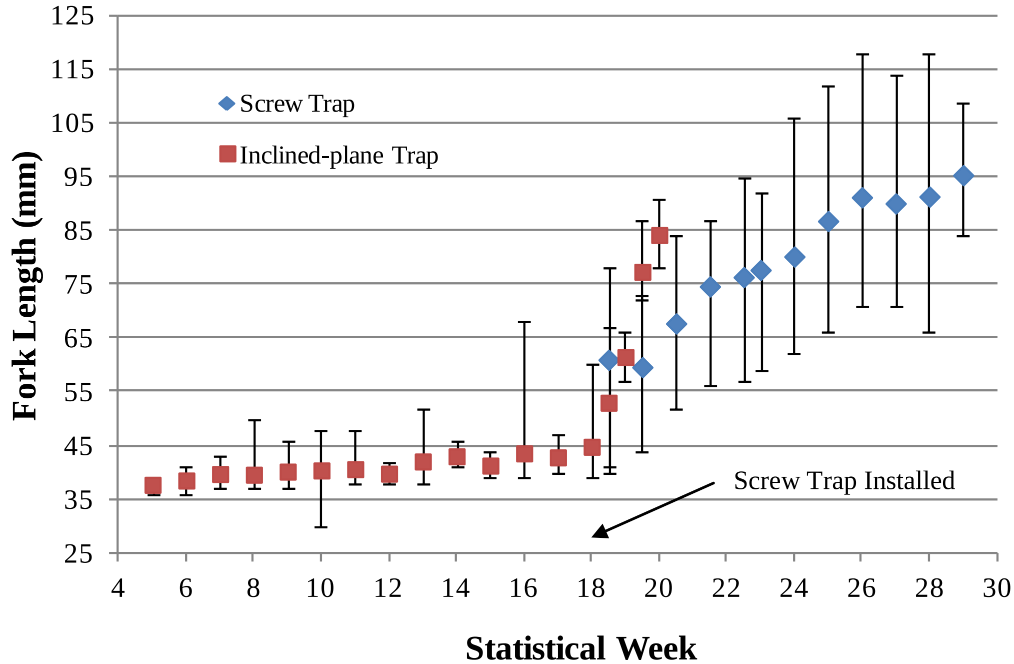

Figure 10. Fork lengths of natural-origin juvenile Chinook sampled from the Cedar River, 2011. Graph shows average, minimum, and maximum lengths by statistical week.

Table 9. Fork lengths (mm) of natural-origin juvenile Chinook measured over eleven years (brood years 2000-2010) 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
2010	41.5	5.98	30	91	623	2,961	84.3	12.48	40	118	708	832

Coho

Catch and Estimated Missed Catch

A total catch (actual and missed) in the screw trap was estimated to be 4,930 coho smolts. This included 4,910 natural-origin coho caught in the screw trap between April 27 and July 16 and 20 coho smolts that should have been caught had the trap fished continuously.

Production Estimate

A total of 34 efficiency trials, ranging in size from 8 to 100 coho, were conducted. Efficiency trials were aggregated into seven strata. Capture rates for these strata ranged between 5.56% and 31.25% (Appendix B 4). Total coho production was estimated to be 52,458 ± 7,813 (±95% C.I.) smolts for the period the trap was operating with a coefficient of variation of 7.6% (Table 10, Appendix B 4).

Table 10. Catch and abundance of Cedar River juvenile coho migrants for brood years 1997-2009. Gaps in data for brood years 1998 and 2006 prevented calculation of CV.

Year		Catch		Trapping Dates		Est'd	95% CI		CV
Brood	Trap	Actual	Est'd	Start	End	Production	Low	High	
1997	1999	5,018		03/18	07/27	39,088	35,241	42,935	5.00%
1998	2000	2,446		04/27	07/13	32,169	30,506	33,833	n/a
1999	2001	5,927	335	04/08	07/22	82,462	60,293	104,661	13.70%
2000	2002	3,406	310	04/01	07/22	60,513	50,286	70,740	8.60%
2001	2003	3,763	201	04/10	07/12	74,507	58,947	90,067	10.70%
2002	2004	2,668	140	04/14	07/20	70,044	46,735	93,353	17.00%
2003	2005	2,889	29	04/01	07/28	72,643	42,725	102,561	21.40%
2004	2006	795	0	04/01	07/16	38,023	16,416	59,629	28.90%
2005	2007	482	0	04/01	07/20	33,994	8,291	59,697	40.80%
2006	2008	315	0	04/14	07/19	13,322	3,392	23,372	n/a
2007	2009	5,549	256	04/21	07/18	52,691	45,600	49,781	6.87%
2008	2010	6,321	207	04/22	07/04	83,060	70,049	96,071	7.99%
2009	2011	4,910	20	04/27	07/16	52,458	44,645	60,271	7.60%

Migration Timing

Migration of coho smolts was already under way when the screw trap began operating. Migration continued to climb and came to a moderate peak of 2,526 coho passing by the trap on May 16 (Figure 11). Migration declined thereafter with one additional notable peak on June 4 of 1,711 smolts. Migration during the trapping period was 25%, 50%, and 75% complete by May 9, May 16, and May 24, 2011, respectively. Nearly 80% of the season's migration occurred during the month of May. Daily migrations dropped sharply at following the June 4 peak and averaged less than 98 coho per day through the remainder of the season.

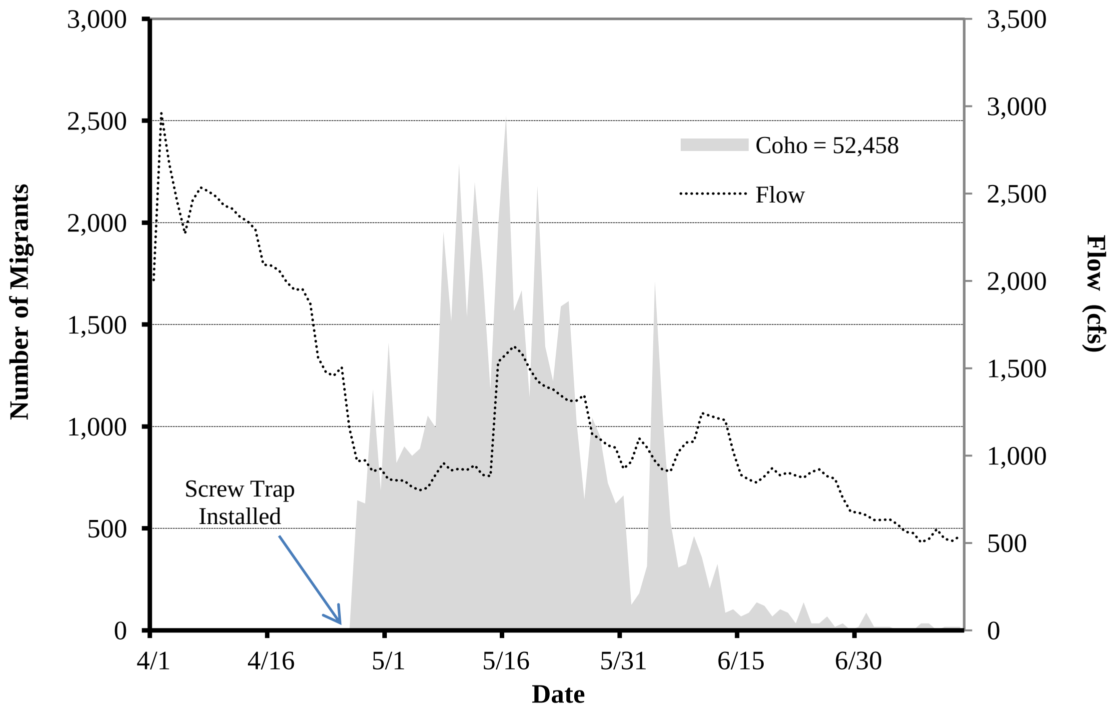

Figure 11. Daily coho migration and daily average flow (USGS Renton gage Station #12119000) at the Cedar River screw trap, 2011.

Size

Average fork length of all measured coho migrants was 106.3-mm FL; weekly averages ranged from 105.0-mm to 111.3-mm FL. Individual migrants ranged from 66-mm to 154-mm FL (Table 11, Figure 12).

Table 11. Fork length (mm) of coho migrants from the Cedar River screw trap in 2011. 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		
04/25	05/01	18	105.8	10.11	83	141	138	323
05/02	05/08	19	105.2	10.51	84	148	448	646
05/09	05/15	20	106.7	11.48	84	154	454	1237
05/16	05/22	21	105.6	9.87	85	139	379	1261
05/23	05/29	22	105.0	8.79	66	141	347	719
05/30	06/05	23	107.4	7.96	72	128	325	509
06/06	06/12	24	109.5	8.80	84	127	122	127
06/13	06/19	25	111.3	9.99	84	132	36	39
06/20	06/26	26	106.7	13.37	84	134	28	29
06/27	07/03	27	100.1	10.82	85	118	11	11
07/04	07/10	28	107.2	8.64	95	118	5	5
07/11	07/17	29	110.5	9.00	100	118	4	4
Season Totals			106.3	10.08	66	154	2,297	4,910

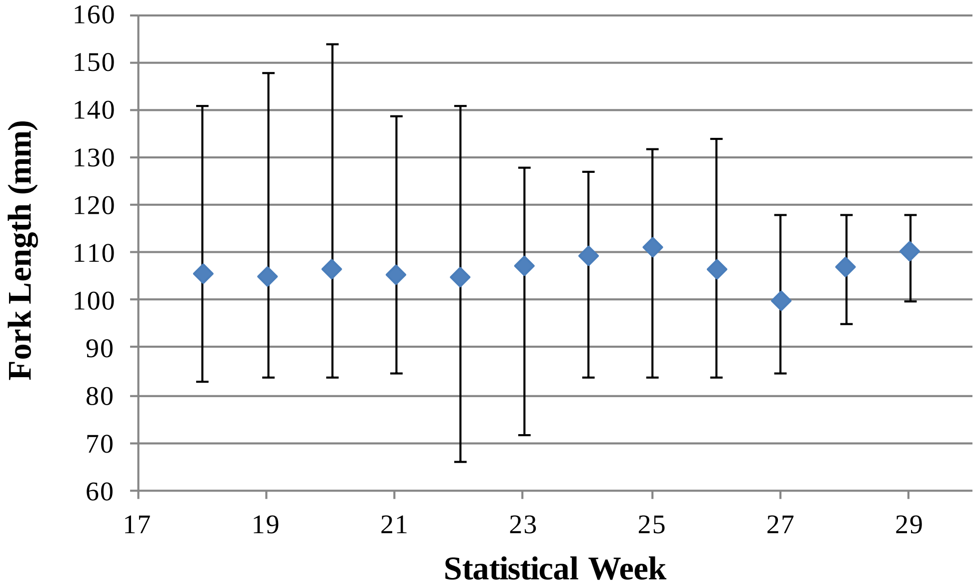

Figure 12. Fork lengths for coho migrants captured in the Cedar River screw trap in 2011. Data are mean, minimum, and maximum lengths.

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 12 steelhead migrants and 47 cutthroat trout were captured in the screw trap. No rainbow trout were caught. Catches were too few to develop migration estimates. *O. mykiss* fork lengths ranged from 158-mm to 242-mm FL and averaged 184.5-mm FL. Cutthroat fork lengths ranged from 97-mm to 283-mm FL, and averaged 153.0-mm FL.

PIT Tagging

To support the ongoing, multi-agency evaluation of salmonid survival within the Lake Washington basin, natural-origin Chinook and coho were tagged with passive integrated transponder (PIT) tags. Tagging occurred two to three times a week from April 28 through July 15, 2011; therefore, only the Chinook parr and coho smolt 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 579 natural-origin Chinook parr and 1,738 coho smolts were tagged (Table 12). This tag group comprised 5.8% of the estimated Chinook parr production and 3.3% of the coho smolt production from the Cedar River in 2011.

A total of 113 Chinook PIT tags (19.5%) were detected as they moved through the smolt flumes at the Chittenden Locks while exiting Lake Washington. The first Chinook was detected on May 26, 2011 and the last on August 27, 2011. Median migration date of Chinook detected at the Locks was June 7, 2011. Individual travel times averaged 19.3 days (St. Dev. = 15.1). Although first and last detections of Chinook at the Locks were similar to 2010, median detection date was 16 days earlier and average travel time was 10 days less.

A total of 589 coho PIT tags (33.9%) were detected at the smolt flumes while exiting Lake Washington through the Locks. The first coho was detected on May 10 and the last on July 25, 2011. Median migration date of coho detected at the Locks was June 4, 2011. Individual travel times averaged 13.6 days (St. Dev. = 8.6).

Table 12. Natural-origin Chinook parr and coho smolts PIT tagged and released from the Cedar River screw trap in 2011.

Statistical Week			Chinook							Coho						
			#	Length (mm)			Portion of	# Detected	% of	#	Length (mm)			Portion of	# Detected	% of
#	Start	End	Tagged	Avg	Min	Max	Parr Migration	@ Locks	Tags Detected	Tagged	Avg	Min	Max	Parr Migration	@ Locks	Tags Detected
18	05/02	05/08	3	69.0	65	71				63	105.7	84	141	1.4%	12	19.0%
19	05/09	05/15								422	105.3	84	148	5.6%	113	26.8%
20	05/16	05/22	14	72.4	65	84	3.5%	8	57.1%	300	106.2	84	154	2.4%	89	29.7%
21	05/23	05/29	9	76.7	69	87	1.3%	1	11.1%	290	105.1	85	139	2.5%	103	35.5%
22	05/30	06/05	14	81.0	68	95	1.9%	7	50.0%	299	105.2	85	128	3.9%	128	42.8%
23	06/06	06/12	38	78.7	65	92	4.6%	9	23.7%	193	107.6	88	127	4.1%	85	44.0%
24	06/13	06/19	74	81.2	65	106	4.2%	18	24.3%	131	110.1	86	127	5.2%	50	38.2%
25	06/20	06/26	92	86.5	66	111	7.3%	11	12.0%	36	112.0	84	132	5.4%	9	25.0%
26	06/27	07/03	152	91.1	71	118	6.9%	43	28.3%							
27	07/04	07/10	113	90.5	71	114	10.0%	13	11.5%	1	85.0	85	85	0.5%		
28	07/11	07/17	56	91.4	66	118	7.0%	3	5.4%							
29	07/18	07/24	14	94.8	84	109	8.7%			3	108.0	100	118	4.4%		
Season Total			**579**	**87.3**	**65**	**118**	**5.8%**	**113**	**19.5%**	**1,738**	**106.2**	**84**	**154**	**3.3%**	**589**	**33.9%**

Mortality

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

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

Incidental Catch

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

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

Bear Creek Results

Sockeye

Catch and Estimated Missed Catch

An estimated 492,773 sockeye fry should have been caught had the inclined-plane trap fished the entire period. During inclined-plane trap operations from January 23 to April 22, 260,965 sockeye fry were caught and an additional 231,808 fry estimated for the 40 nights not fished.

Production Estimate

Thirty-four efficiency trials were conducted during the season and aggregated into seven final strata, with capture rates ranging from 3.45% and 10.35% (Appendix C 1). Catches were large enough throughout the whole season that releases were conducted nearly every night.

A total of 8,160,976 ± 1,063,587 (±95% C.I.) sockeye fry were estimated to have migrated from Bear Creek in 2011 (Table 13). The estimate includes migration prior to, during, and following inclined-plane trap operation. During inclined-plane trap operation (January 23 and April 22), 8,137,851 sockeye fry are estimated to have migrated passed the trap (Table 13). An additional 15,217 fry were estimated to have passed the trap between January 1 and January 23 (Table 13). The sockeye fry migration was still underway when the screw trap replaced the inclined-plane trap on April 26. 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 23 and April 30 was estimated to be 7,908 fry.

Migration Timing

The sockeye migration was already under way when trapping began, averaging over 3,000 sockeye a day. Migration continued to increase dramatically to peak on March 14 with over 600,000 sockeye estimated to have migrated on a single night (Figure 13). Migration was 25%, 50%, and 75% completed by March 11, March 15, and March 21, 2011, respectively. Nearly 87% of the sockeye migration occurred during the month of March.

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2010 brood of Bear Creek sockeye was estimated to be 42.4% (Table 14). Survival was based on 8,160,976 fry migrants and a PED of 19.2 million eggs. PED was estimated based on 6,264 females in 2010 (A. Bosworth, Washington Department of Fish and Wildlife, personal communication) and an average fecundity of 3,075 eggs per female (Cuthbertson 2011).

Table 13. Abundance of sockeye fry migrants from Bear Creek in 2011. Table includes abundance of fry migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*).

Period	Dates	Total Estimated Catch	Fry Abundance	*CV*	95% C.I. Low	95% C.I. High
Pre-Trapping	Jan 1-Jan 22		15,217	20.8%	9,006	21,428
Inclined-Plane Trap	January 23-April 22	492,773	8,137,851	6.7%	7,074,282	9,201,419
Post-Trapping	April 23-April 30		7,908	8.5%	6,591	9,225
	Season Totals	**492,773**	**8,160,976**	**6.6%**	**7,097,389**	**9,224,563**

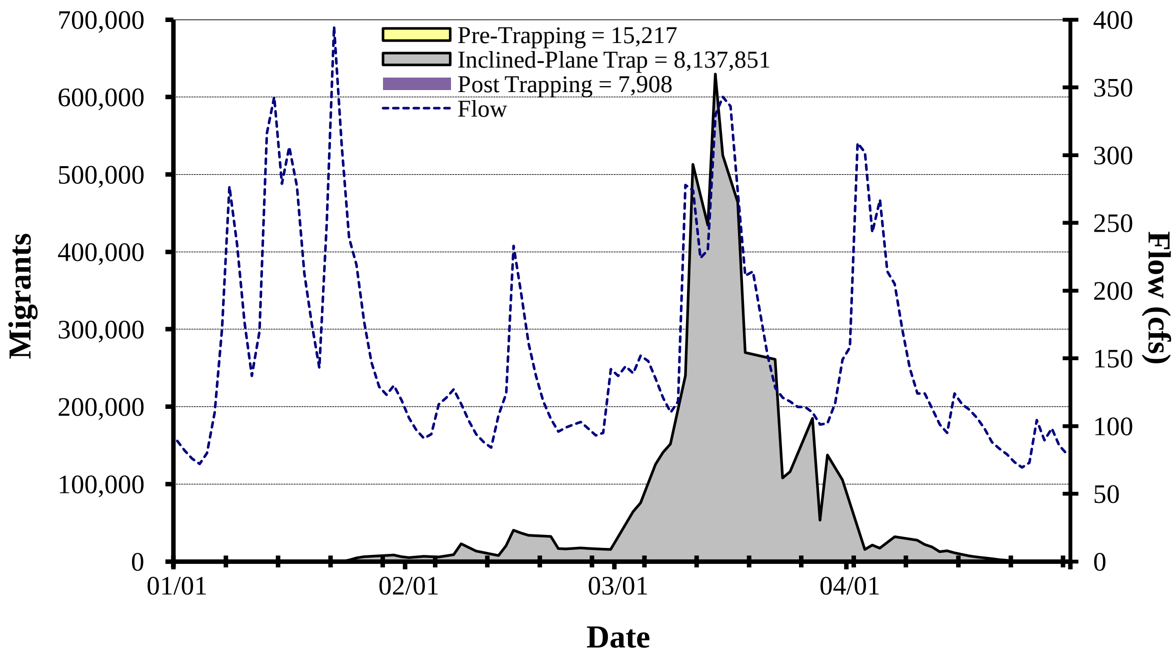

Figure 13. Estimated daily migration of sockeye fry from Bear Creek and daily average flow measured by the King County gage 02a at Union Hill Road in 2011 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Table 14. 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
2010	12,527	6,264	3,075	19,260,263	8,160,976	42.4%	888	12/13/2011

Chinook

Catch and Estimated Missed Catch

Inclined-Plane Trap

An estimated 119 Chinook fry should have been caught had the inclined-plane trap fished the entire period. In total, 49 Chinook fry were captured in the inclined-plane trap and an estimated 70 Chinook fry were missed during the 40 nights not fished. Inclined-plane trap estimates include the period between April 23 to 26 when neither trap was operating.

Screw Trap

A total of 4,677 Chinook should have been caught had the screw trap operated continuously. A total of 4,434 Chinook were caught over the 80 days the screw trap operated and an estimated 243 Chinook were missed during the four occasions (May 19, May 26, June 19, and June 25) when debris stopped the trap.

Production Estimate

Inclined-Plane Trap

A total of 34 efficiency trials were conducted with sockeye fry, ranging in number from 93 to 404 fish. Trials were aggregated into seven strata with trap efficiencies ranging from 3.45% and 10.35%. Chinook migration was estimated to be 1,651 ± 390 (±95% C.I.) between January 23 and April 26 (Table 15, Appendix C 2). Since Chinook were not captured until the third week of trapping and catches thereafter were scarce, migration prior to trapping is assumed to be zero.

Screw Trap

A total of 37 efficiency trials were conducted with Chinook subyearlings, ranging in number from 9 to 100 fish. Trials were aggregated into seven strata; capture rates of these strata ranged between 13.0% and 56.2%. Chinook migration during screw trap operation was estimated to be 16,524 ± 1,641 (±95% C.I.) (Table 15, Appendix C3).

Table 15. Abundance of natural-origin juvenile Chinook emigrating from Bear Creek in 2011. Table includes abundance of juvenile migrants, 95% confidence intervals (C.I.), and coefficient of variation (*CV*). Inclined-plane trap period includes estimated abundance for April 23 through 26 when neither trap was operating.

Gear	**Period**	**Estimated**		**95% C.I.**		***CV***
		Catch	**Abundance**	**Low**	**High**	
Inclined-Plane Trap	January 23 -April 26	119	1,651	1,261	2,040	12.04%
Screw Trap	April 27-July 15	4,677	16,524	14,883	18,165	5.07%
Season Totals		4,796	18,175	16,488	19,862	4.73%

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 18,175 ± 1,687 (±95% C.I.) sub yearlings.

Table 16. 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 2010 brood years.

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

Migration Timing

Chinook migration was bi-modal with 5.1% of the migration emigrating as fry and 94.9% emigrating as parr (Figure 14, Table 16). Peak migration occurred on June 18 with an estimated 858 Chinook passing the trap in one day. Migration was 25%, 50%, and 75% complete by May 24, June 7, and June 17, respectively. The Chinook fry migration was small in magnitude and had two prominent peaks on March 12 of 86 Chinook fry and April 16 of 88 Chinook fry. Chinook parr daily migrations were larger than fry migrations with 65.0% of the Chinook migration occurring between May 15 and June 15.

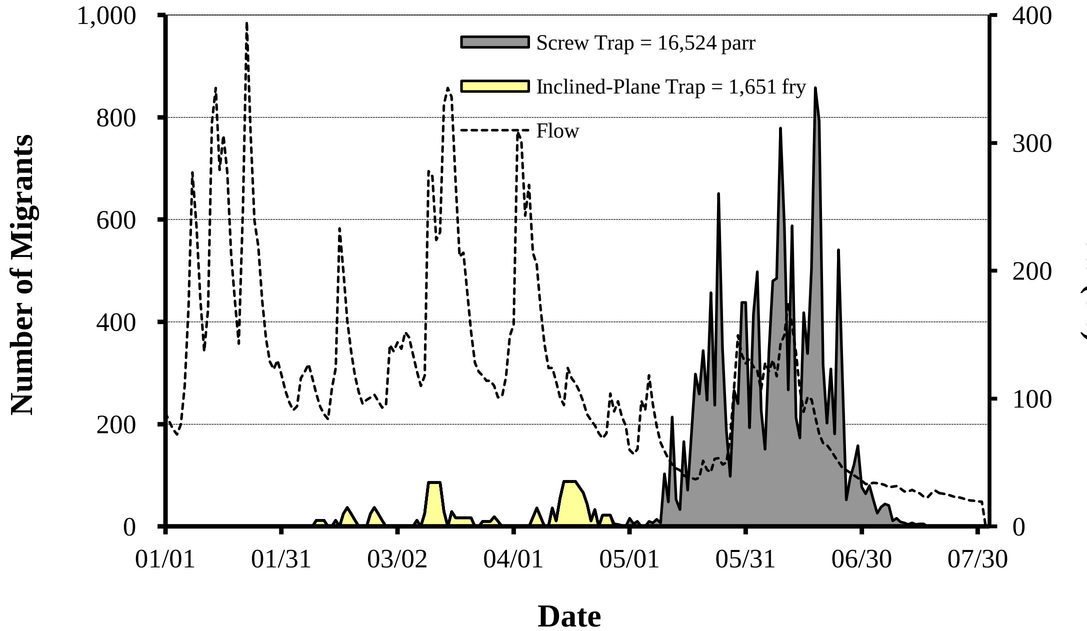

Figure 14. Daily migration of sub yearling Chinook and daily average flow from Bear Creek, 2011. Daily mean flows were measured at King County gage 02a at Union Hill Road in 2011 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2010 brood of Bear Creek Chinook was estimated to be 6.7% (Table 16). Survival was based on 18,175 sub yearling migrants and a PED of 270,000 eggs. The PED was estimated based on 60 female spawners (A. Bosworth, Washington Department of Fish and Wildlife, personal communication) and an assumed fecundity of 4,500 eggs per female.

Size

From early February through mid- April, Chinook fry captured in the inclined-plane trap averaged 42.3-mm FL and ranged from 38-mm to 54-mm FL (Table 17).

Fork lengths of Chinook caught in the screw trap ranged from 42-mm to 107-mm, averaged 79.3-mm FL, and increased over the season. In late-April, the Chinook weekly average length was 58.8-mm FL, with the weekly average quickly growing to be larger than 70-mm FL mid-May. By late June, weekly average lengths reached 80-mm FL (Table 17, Figure 15). The average fry and parr length in 2011 was the second largest and the parr length the third largest observed in the previous ten years (Table 18).

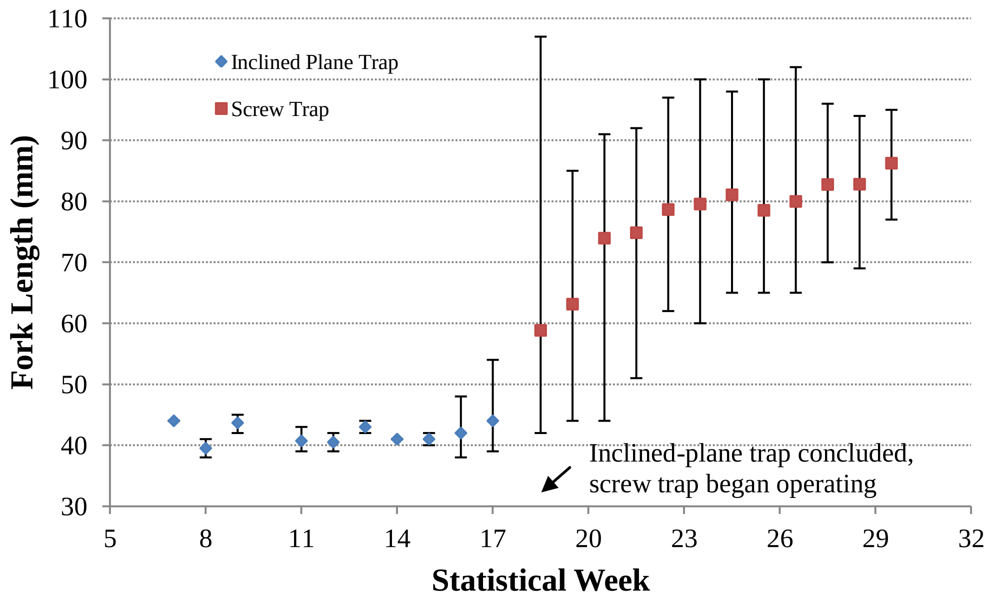

Figure 15. Fork lengths of sub yearling Chinook sampled from Bear Creek in 2011. Data are mean, minimum, and maximum lengths for each statistical week.

Table 17. Fork lengths of juvenile Chinook and coho captured in the Bear Creek inclined-plane and screw traps in 2011. 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	02/07	02/13	7	44.0	n/a	44	44	1	1						
	02/14	02/20	8	39.5	1.29	38	41	4	4						
	02/21	02/27	9	43.7	1.53	42	45	3	3						
	02/28	03/06	10						0						
	03/07	03/13	11	40.7	1.38	39	43	7	7						
	03/14	03/20	12	40.5	2.12	39	42	2	2						
	03/21	03/27	13	43.0	1.41	42	44	2	3						
	03/28	04/03	14	41.0	n/a	41	41	1	1						
	04/04	04/10	15	41.0	1.41	40	42	2	2						
	04/11	04/17	16	42.0	3.82	38	48	11	11						
	04/18	04/24	17	44.0	3.89	39	54	15	15						
	04/25	05/01	18												
			Totals	42.3	3.27	38	54	48	49						
Screw Trap	04/25	05/01	18	58.8	24.58	42	107	6	12	122.8	11.14	99	161	144	331
	05/02	05/08	19	63.1	12.62	44	85	15	19	119.7	9.19	86	151	362	588
	05/09	05/15	20	74.0	8.83	44	91	104	260	116.0	10.16	84	142	462	1,395
	05/16	05/22	21	74.8	9.39	51	92	176	394	114.5	8.87	92	147	278	1,306
	05/23	05/29	22	78.6	6.20	62	97	437	718	107.9	8.26	80	141	310	614
	05/30	06/05	23	79.6	6.83	60	100	370	773	106.5	7.11	88	127	191	326
	06/06	06/12	24	81.1	6.69	65	98	412	793	108.1	9.58	92	133	32	41
	06/13	06/19	25	78.5	6.71	65	100	402	560	109.8	11.23	89	122	6	12
	06/20	06/26	26	80.0	6.50	65	102	498	572	109.0	5.29	104	116	4	10
	06/27	07/03	27	82.8	5.43	70	96	193	225	122.7	19.43	106	144	3	4
	07/04	07/10	28	82.8	5.86	69	94	81	90	94.0	n/a	94	94	1	1
	07/11	07/17	29	86.3	3.73	77	95	20	18						
			Totals	79.3	7.39	42	107	2,714	4,434	114.5	10.61	80	161	1,793	4,628

Table 18. Fork lengths of natural-origin Chinook measured over ten years (brood years 2000-2010) at the Bear Creek 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	41.1	1.97	34	47	39	63	73.4	11.60	38	105	622	5,131
2001	38.9	3.80	34	52	70	278	81.5	10.83	42	110	885	6,880
2002	40.9	3.20	34	54	78	86	75.9	11.20	35	106	709	8,182
2003	41.6	4.99	38	60	70	102	73.6	11.52	40	107	874	10,613
2004	40.6	2.29	38	47	46	102	78.7	7.06	40	102	1,766	4,612
2005	41.4	4.10	37	64	117	264	76.0	8.82	44	100	907	8,180
2006	41.7	3.30	38	55	75	106	79.8	6.80	40	118	2,978	5,320
2007	41.0	2.01	36	46	52	57	71.1	8.95	37	116	1,748	2,774
2008	43.4	4.57	32	61	227	1,014	67.3	11.85	38	99	921	8,613
2009	41.2	3.59	34	52	51	54	75.3	8.94	48	99	952	1,267
2010	42.3	3.27	38	54	48	49	79.3	7.39	42	107	2,714	4,434

Coho

Catch

A total of 4,628 coho smolts were caught in the screw trap over the 80-day trapping season. If the trap had fished without interruptions, a total of 4,872 coho are estimated to have been caught between April 27 and July 17.

Production Estimate

Abundance of coho smolts was based on catch and 24 efficiency trials, which were aggregated into nine strata. Capture rates of efficiency strata ranged from 4.0% to 27.4%. Coho production was estimated to be 34,513 ± 8,813 (±95% C.I.) smolts (Figure 16, Appendix C 4).

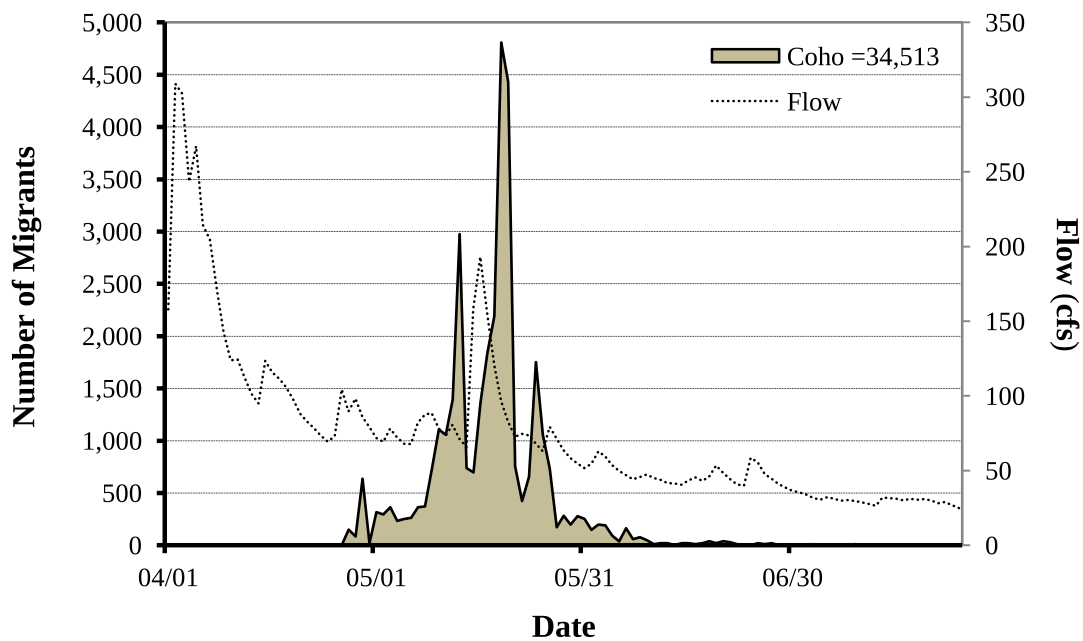

Figure 16. Daily migration of coho smolts in Bear Creek from April 27 to July 17, 2011. Graph also shows mean daily flows during this period. Flow data were measured at King County gage 02a at Union Hill Road in 2010 (http://green.kingcounty.gov/wlr/waterres/hydrology).

Table 19. Catch and abundance of Bear Creek juvenile coho migrants, brood years 1997-2009.

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

Migration Timing

Migration of coho smolts was 25%, 50%, and 75% completed by May 13, May 18, and May 20, 2012, respectively (Figure 16). Migration peaked on May 19 with 4,807 coho smolts estimated to have migrated passed the trap.

Size

Over the trapping period, fork lengths ranged from 80-mm to 161-mm FL and averaged 114.5-mm FL (Figure 17). Weekly mean lengths ranged from 94.0-mm to 122.8-mm FL during screw trap operation (Table 17). Average coho length was near the median observed in previous years of study (Table 20).

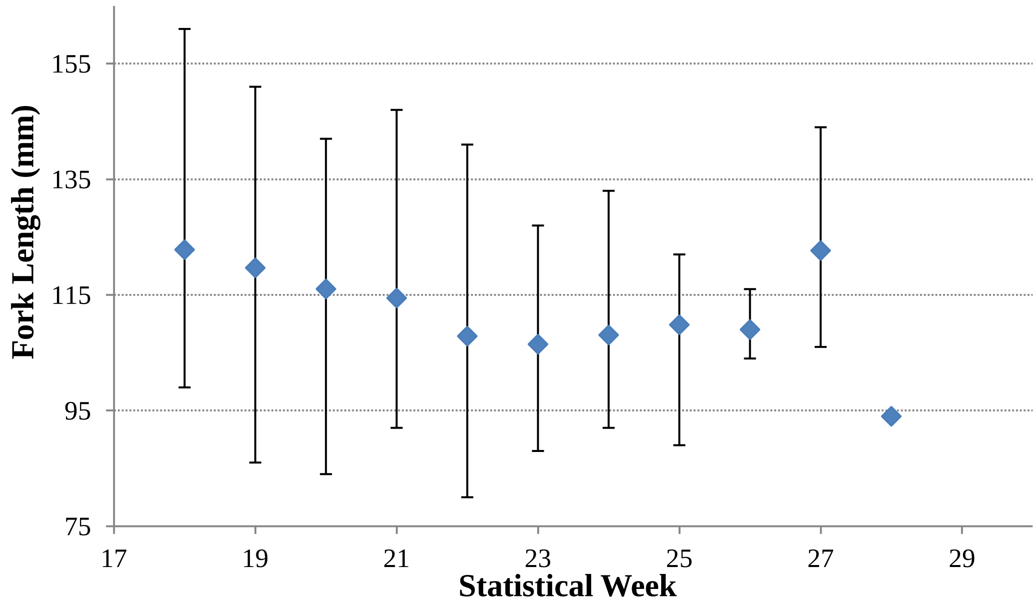

Figure 17. Fork lengths of migrating coho smolts caught at the Bear Creek screw trap in 2011. Data are statistical week mean, minimum, and maximum lengths.

Table 20. Fork lengths of natural-origin coho smolts in Bear Creek over migration years (2002-2011).

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
2011	114.5	10.61	80	161	1,793	4,628

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 2011 trapping season in Bear Creek.

A total of 634 cutthroat trout were captured in the screw trap in 2011. Results from Marshall et al. (2006), suggest that some Bear Creek fish identified by phenotype to be cutthroat trout may be rainbow cutthroat hybrids. From April 27 to May 31, catches totaled 80% of the entire season's catch. Thereafter, catches were intermittent with seven cutthroat being the largest daily catch.

Seventeen different efficiency trials of cutthroat were conducted over the season, ranging from 8 to 42 cutthroat per release. Trials were aggregated into one stratum with a capture rate of 14.1%. Migration was estimated to be 4,569 ± 1,403 (±95% C.I.) cutthroat, with a coefficient of variation of 14.4% (

Figure 18, Appendix C 5) for the trapping period (April 27 through July 17). 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 27. If this time allocation for the migration is applied to cutthroat estimates from the 2011 trapping season, a total 6,168 are estimated to have migrated from Bear Creek.

Cutthroat trout fork lengths averaged 161.1mm FL and ranged between 106-mm and 315-mm FL throughout the trapping season (Table 21). Average fork lengths showed no consistent trend across weeks.

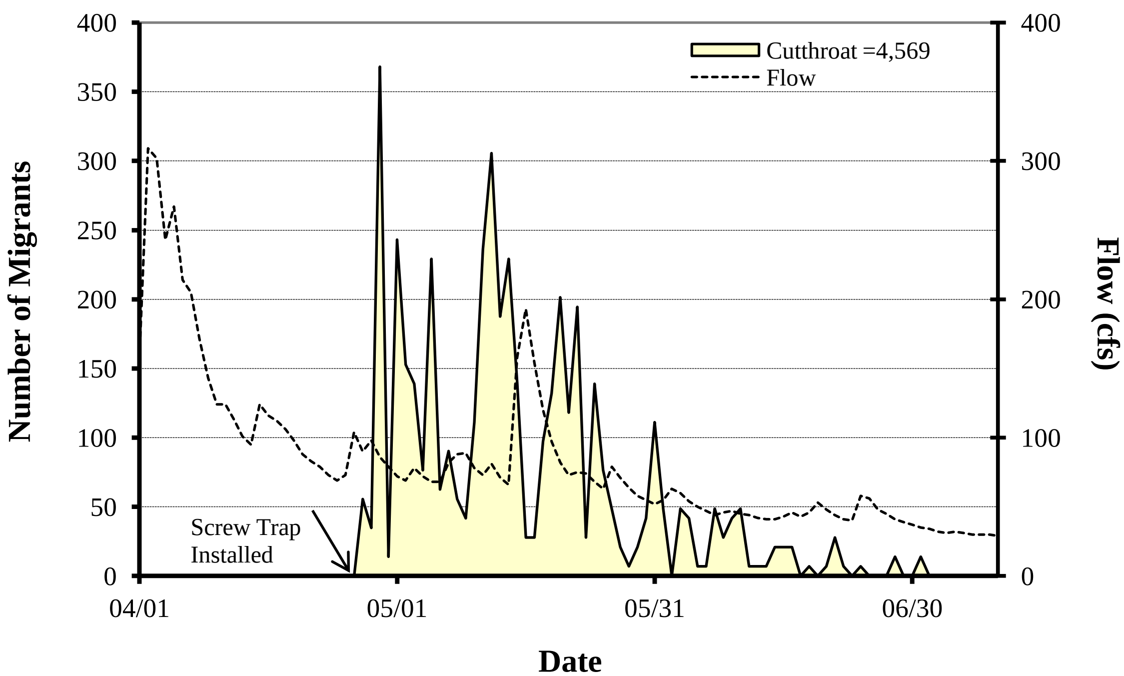

Figure 18. Daily migration of cutthroat trout passing the Bear Creek screw trap in 2011. Flow data were measured at the King County gauging station at Union Hill Road.

Table 21. Cutthroat fork length (mm), standard deviation (s.d.), range, sample size (n), and catch by statistical week in the Bear Creek screw trap, 2011.

Statistical Week			Avg.	s.d.	Range		n	Catch
No.	Begin	End			Min	Max		
18	04/25	05/01	176.1	31.77	119	287	63	103
19	05/02	05/08	168.6	28.47	112	290	94	116
20	05/09	05/15	161.4	25.93	109	315	160	180
21	05/16	05/22	155.5	20.60	109	200	55	98
22	05/23	05/29	144.1	20.74	106	192	26	42
23	05/30	06/05	150.5	12.42	122	181	46	43
24	06/06	06/12	142.8	14.66	122	167	13	27
25	06/13	06/19	140.8	21.04	121	168	5	11
26	06/20	06/26	128.0	14.14	118	138	2	8
27	06/27	07/03	151.0	8.19	142	158	3	4
28	07/04	07/10						
29	07/11	07/17	152.5	16.26	141	164	2	2
Season Totals			**161.1**	**26.69**	**106**	**315**	**469**	**634**

PIT Tagging

As part of an ongoing multi-agency monitoring of Chinook and coho migrating from the Lake Washington system, both species in Bear Creek were PIT tagged and released in 2011. Tagging began on April 28 and occurred three times a week through July 15. Fish were often held overnight to increase the number tagged per day. Over the season, 2,316 natural-origin Chinook were PIT tagged. A total of 336 Bear Creek PIT tagged Chinook (14.5%) were detected moving through the smolt flumes at the Chittenden Locks (Table 22). This tag group comprised 26.3% of the estimated Chinook parr production. The first fish was detected on May 23 and the last on July 29, 2011. Median migration date of fish detected at the Locks was June 5, 2011. Individual travel times averaged 15.1 days (St. Dev. = 8.0).

A total of 1,344 natural-origin coho were PIT tagged in Bear Creek throughout the season (Table 22). A total of 412 Bear Creek PIT tagged coho (30.7%) were detected moving through the smolt flumes at the Chittenden Locks. The first fish was detected on May 8 and the last on July 10, 2011. Median migration date of fish detected at the Locks was June 3, 2011. Individual travel times averaged 10.2 days (St. Dev. = 7.2).

Table 22. Natural-origin Chinook parr and coho smolts PIT tagged and released from the Bear Creek screw trap in 2011.

Statistical Week			Chinook							Coho						
			#	Length (mm)			Portion of	# Detected	% of	#	Length (mm)			Portion of	# Detected	% of
#	Start	End	Tagged	Avg	Min	Max	Parr Migration	@ Locks	Tags Detected	Tagged	Avg	Min	Max	Parr Migration	@ Locks	Tags Detected
18	05/02	05/08								58	124.5	101	152	4.8%	9	15.5%
19	05/09	05/15								349	119.8	86	151	16.4%	65	18.6%
20	05/16	05/22	70	75.7	65	87	11.2%	20	28.6%	300	117.5	93	142	3.5%	62	20.7%
21	05/23	05/29	53	76.9	66	92	2.8%	16	30.2%	204	116.1	92	147	1.3%	75	36.8%
22	05/30	06/05	380	78.6	65	97	18.7%	119	31.3%	259	108.0	80	135	5.4%	130	50.2%
23	06/06	06/12	323	80.0	67	100	13.7%	61	18.9%	156	106.6	93	127	13.1%	64	41.0%
24	06/13	06/19	357	81.4	66	98	10.1%	85	23.8%	18	107.8	95	133	4.6%	7	38.9%
25	06/20	06/26	364	78.4	65	98	11.0%	25	6.9%							
26	06/27	07/03	498	80.0	65	102	26.3%	10	2.0%							
27	07/04	07/10	187	82.7	70	96										
28	07/11	07/17	68	82.9	69	94										
29	07/18	07/24	16	86.4	77	95										
Season Total			**2,316**	**79.9**	**65**	**102**	**26.3%**	**336**	**14.5%**	**1,344**	**115.0**	**80**	**152**	**3.9%**	**412**	**30.7%**

Mortality

Twenty-two Chinook parr mortalities occurred in the screw trap; eight of these were PIT tagged Chinook and the others were a result of heavy debris in the live box.

Incidental Species

In addition to sockeye and Chinook fry, 2 coho fry, 1 coho smolt, and 35 cutthroat were also caught in the inclined-plane trap. Other species included lamprey (*Lampetra spp.*), sculpin (*Cottus spp.*), yellow perch (*Perca flavescens)*, pumpkinseed (*Lepomis gibbosus)*, green sunfish (*Lepomis cyanellus*), and three-spine stickleback (*Gasterosterus aculeatus*).

In addition to target species, the screw trap captured 1 coho fry, 1 hatchery coho 1+, 74 sockeye fry, 16 trout fry, 5 sockeye smolts or kokanee, 12 hatchery trout plants from Cottage Lake and 1 cutthroat adults. Other species caught included lamprey, three-spine stickleback, sculpin, pumpkinseed, green sunfish, whitefish (*Prosopium spp.*), peamouth (*Mylocheilus caurinus*), speckled dace (*Rhinichthys osculus*), bluegill (*Lepomis macrochirus*), large-scale suckers (*Catostomus macrocheilus*), and brown bullhead catfish (*Ameriurus nebulosus*).

Discussion

The 2011 sockeye fry production from the Cedar River and Bear Creek differed with respect to long-term average production from these sub-basins. Cedar River sockeye fry production from the 2010 brood year was low; limited by a low numbers of adult spawners and the second lowest egg-to-migrant survival since monitoring began (brood year 1991). Unlike the Cedar River, Bear Creek juvenile sockeye fry production from the 2010 brood year was the largest since monitoring began (brood year 2000), in excess of nearly 2 million sockeye. Although Bear Creek adult sockeye returns in 2010 were only moderate, a 42.4% egg-to-migrant survival was the highest observed since monitoring began.

Chinook in both sub-basins experienced favorable conditions resulting in higher than average egg-to-migrant survival. Adult Chinook returns to the Cedar River in 2010 were moderate, however a 15.7% egg-to-migrant survival of the 2010 brood was the third highest observed in the thirteen-year average of the dataset, resulting in a production slightly higher than the long-term average. Adult Chinook returns to Bear Creek in 2010 were the second lowest adult return in since 1999. However Chinook survival from egg deposition to migration (6.7%) was the second highest observed over this same time period, resulting in juvenile production that was near the long-term median.

In addition to sockeye and Chinook salmon, in 2011 capture rates of coho and cutthroat smolts in the Cedar River and Bear Creek juvenile traps were high enough o derive abundance estimates for both species. Furthermore, the 2011 trap season was the first year since 2007 that hatchery sockeye were released above the Cedar River juvenile trap. As the hatchery and natural-origin sockeye fry were not visibly different, they could not be directly sorted in the nightly catches. Therefore, survival of the hatchery releases was examined using several indirect methods. These indirect methods introduced uncertainty into both the hatchery and natural-origin production estimates.

The study protocols used to evaluate Lake Washington juvenile salmon production in 2011 were designed to meet the assumptions of the Petersen mark-recapture estimator (Seber 1973, Volkhardt et al. 2007). The measures taken to meet these assumptions are described below and the resulting estimates are considered to be unbiased. Precision of juvenile sockeye and Chinook estimates had a coefficient of variation less than 18%, slightly higher than the level of precision (CV < 15%) recommended by the National Oceanic Atmospheric Administration (Crawford and Rumsey 2011). In addition, we developed and tested assumption associated with the protocols used for specific traps. On the Cedar River inclined-plane 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. An approach was also developed to estimate the hatchery and natural-origin portion of sockeye fry catches on hatchery release nights. On Bear Creek, the assumption that there is little or no day-time movement of sockeye and Chinook fry was tested in 2011. Further detail on these assumptions and the tests used to validate them are described below.

Estimator Assumptions

The 2011 trap season provided an opportunity to test a number of assumptions associated with estimating the abundance of juvenile migrants. The following estimator assumptions were tested for both the Bear Creek and Cedar River screw traps:

(1) All fish have an equal probability of being captured,
(2) Marked and unmarked fish have equal probabilities of capture (adequate mixing prior to recapture),
(3) Marks do not affect capture rates, and
(4) Marks are retained between the time of release and recapture.

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. This assumption was tested by statistically comparing the recapture rates of marked fish over time (i.e., *G*-test). In order to accommodate differences in capture rates due to changing river conditions, the data were stratified into time strata as determined by the *G*-test comparison of recapture rates.

Another possible violation of the equal probability of capture assumption is that larger fish are more powerful swimmers than small fish and may be able to avoid capture in screw traps unless the velocity of the water column is greater than the fish swimming abilities.

In 2010, the assumption that large and small fish of the same species have an equal probability of being captured was assessed for both the Cedar River and Bear Creek screw traps. This assumption was tested again in 2011 for Chinook and coho in both watersheds, and for cutthroat in Bear Creek. Cutthroat catches and recaptures were too low in the Cedar River for 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 (α= 0.05).

Unlike 2010, length did not differ between fish that were captured and recaptured for all species at both trap sites. In the Cedar River screw trap, mean length of maiden Chinook was 5.1-mm larger than recaptured Chinook and mean length of maiden coho was 0.7-mm smaller than the mean length of recaptured coho. In the Bear Creek screw trap, mean length of maiden Chinook was 0.3-mm smaller than the mean length of recaptured Chinook. Mean length of maiden coho was 1.4-mm larger than mean length of recaptured coho (Table 23). Mean length of maiden cutthroat were 6.88-mm larger than recaptured cutthroat. None of these differences were statistically different.

Table 23. Sample size, average length, minimum and maximum lengths, and *P* values from a Kolmogorov-Smirnov comparison of maiden and recapture fish in Cedar River and Bear Creek traps. Size-selectivity tests were conducted for Chinook, coho, and cutthroat in 2011.

Cedar River					
	Sample Size	Average Length	Min	Max	*P* Value
Chinook					
Maiden	538	87.7	65	118	0.06
Recapture	30	82.6	65	100	
Coho					
Maiden	1,119	106.8	84	154	0.21
Recapture	78	107.5	88	135	
Bear Creek					
	Sample Size	Average Length	Min	Max	*P* Value
Chinook					
Maiden	1,580	79.3	42	100	0.86
Recapture	495	79.6	54	99	
Coho					
Maiden	1,053	113.86	80	161	0.32
Recapture	273	112.42	92	151	
Cutthroat					
Maiden	434	161.62	106	315	0.34
Recapture	35	154.74	121	212	

Equal Capture Probability of Marked and Unmarked Fish

A second assumption of mark recapture studies is that there is adequate mixing of marked and unmarked fish from release to recapture location. There are varying distances and stream-type segments that are thought to provide opportunity for adequate mixing of marked fish into the unmarked population between release and recapture points. This is an important assumption to validate as artificially inflating or deflating capture rates due to inadequate mixing can bias production estimates. One way to assess this assumption is by releasing paired efficiency trials using two separate locations with identifying marks. One trial is released at the standard efficiency trial release site, while the other is released farther upstream (test release site). The test release site was chosen based on distance from the standard release site as well as river access. Upon recapture, the number of marked and unmarked fish are enumerated and the G-test is used to compare the ratio of seen:unseen fish of each mark from the different location on a given night. In 2011, this approach was taken to assess whether release locations in both Cedar River and Bear Creek, for all species and traps, are adequate distance to allow for mixing to occur.

Due to concerns of applying fin clips as a mark to fry during inclined plane trapping, only Bismarck Brown was available to mark fish. As a result, we were unable to conduct paired releases of sockeye and Chinook fry on the same night. However, if river conditions were similar on two successive nights, a group of marked fish was released at the test site the second night and recapture rates were compared between nights. This approach was taken to assess both Bear Creek and Cedar River sockeye during the inclined-plane trap period. During screw trapping at both sites fish were large enough to implant a PIT tag as a mark. One group mark was PIT tagged and released at the standard location and a PIT tagged and fin clipped group was released at the test location.

During inclined-plane trapping on the Cedar River, the standard release site is the Logan Street Bridge at R.M. 1.1, roughly 0.3 miles upstream of the trap. The test release site was at the Williams Street Bridge roughly 0.5 miles upstream of the trap (R.M. 1.3). Sockeye catches were low and flows on the Cedar River were erratic, making it difficult to conducted releases with similar size groups and river conditions. Only two trials were conducted, one March 2 and 3 consisting of 885 sockeye in each group, and March 6 and 7 with 886 sockeye fry in each group. Recapture rates did not differ between release sites for either paired efficiency trial (P = 0.46, P = 0.47 respectively). Both trials released at the standard site had recaptures rate of less than 1.0% greater than those released at the test release site. Additional years of testing will be necessary to confidently draw conclusions concerning the efficiency trial release location for sockeye fry.

In the Cedar River, too few Chinook were captured to perform paired release trials during the inclined-plane and screw trap operations. However, ten paired coho releases were conducted throughout the month of May (Table 24). The standard release location for coho smolts is at the Riviera Apartments near river mile (R.M. 2.1), roughly 0.5 miles upstream from the screw trap. The test release site was located roughly 2.6 RM upstream from the screw trap at the Highway 169 Bridge over the Cedar River (R.M. 4.7). There were no significant difference detected between recapture rates of fish released at the standard release site and the test site, nor was one release site consistently higher than another (t_9 = 1.11, P = 0.29).

Table 24. Paired releases of coho smolts in the Cedar River. Data are releases and recaptures (i.e. “seen”), and trap efficiency measured from the standard location (Riviera Apartments) and the test location (Highway 169 Bridge).

		Standard Location Release				Test Location Releases			
Date	**P value**	**# Released**	**Seen**	**Unseen**	**Efficiency**	**# Released**	**Seen**	**Unseen**	**Efficiency**
05/03/2011	0.82	89	8	81	8.99%	90	8	82	8.89%
05/05/2011	0.60	65	7	58	10.77%	65	10	55	15.38%
05/07/2011	1.00	50	2	48	4.00%	50	1	49	2.00%
05/10/2011	0.99	49	2	47	4.08%	50	1	49	2.00%
05/11/2011	0.43	50	5	45	10.00%	50	2	48	4.00%
05/18/2011	0.47	52	2	50	3.85%	52	0	52	0.00%
05/19/2011	0.74	50	4	46	8.00%	50	6	44	12.00%
05/24/2011	0.23	50	9	41	18.00%	50	4	46	8.00%
05/25/2011	0.77	50	7	43	14.00%	50	7	43	14.00%
05/27/2011	0.71	50	4	46	8.00%	50	4	46	8.00%

In Bear Creek, paired releases were conducted for both Chinook and coho in 2011. In Bear Creek the standard release site is 100 yards upstream at the Redmond Way Bridge. The test release site was roughly 0.5 miles upstream from the trap at the Northeast Union Hill Road Bridge. During inclined-plane trap operations, twelve paired sockeye releases were conducted at the test site. Because sockeye fry were abundant and flows were stable, test releases were scheduled between two nights of releases at the standard location, increasing the number of paired releases. Release groups were 399 or 400 in size. Only two of the releases were statistically different, a paired release on March 23 and 24 and on April 11 and 12 (P = 0.04, and P= 0.02, respectively). All but one release at the test site had higher capture rates than those released at the standard site by as much as 4.25% higher. A paired t-test indicates that recapture rates of sockeye released at the standard site (Redmond Way) are consistently significantly higher than those released at the test site (N.E. Union Hill Road)(t_{11}= 4.27, *P*= 0.001). Although few paired trials were statistically significantly different, higher recapture rates at the standard release site may indicate inadequate mixing of fish released from the standard site or potentially higher predation rates of fish released from the test site. An additional year of paired releases from these two sites will be used to further test this conclusion and modify trapping protocols accordingly.

Eleven paired Chinook parr releases were conducted at Bear Creek from late May to late June. Group sizes ranged from 50 to 75 each. Only one of the releases (June 24) was statistically significantly different (P = 0.041). Capture rates of eight of the eleven releases were higher for test location releases, by as much as 17%. A paired t-test indicated that recapture rates did not differ between releases sites (t_{10} = 1.15, *P* = 0.29). We tentatively conclude that fish are adequately mixing between release from Redmond Way to recapture at the Bear Creek screw trap. Further years of paired releases will be needed to further determine if a release site further upstream is needed to allow for more adequate mixing of Chinook before recapture at the trap.

Table 25. Paired efficiency trial releases of marked Chinook from two separate sites in Bear Creek in 2011. Standard location is Redmond Way Bridge and Test Location is N.E.Union Hill Bridge.

		Standard Location Releases				Test Location Releases			
Date	**P value**	**# Released**	**Seen**	**Unseen**	**Efficiency**	**# Released**	**Seen**	**Unseen**	**Efficiency**
05/24/2011	0.55	50	24	26	48.00%	50	27	23	54.00%
05/25/2011	0.80	50	18	32	36.00%	50	23	27	46.00%
06/02/2011	0.43	50	21	29	42.00%	50	25	25	50.00%
06/04/2011	0.49	56	10	46	17.86%	56	13	43	23.21%
06/09/2011	0.61	50	11	39	22.00%	50	8	42	16.00%
06/13/2011	0.53	75	12	63	16.00%	75	15	60	20.00%
06/15/2011	0.07	49	14	35	28.57%	50	23	27	46.00%
06/17/2011	0.05	56	17	39	30.36%	56	27	29	48.21%
06/20/2011	0.39	50	20	30	40.00%	50	17	33	34.00%
06/22/2011	1.00	50	13	37	26.00%	50	16	34	32.00%
06/24/2011	0.04	60	23	37	38.33%	61	13	48	21.31%

A total of nine coho paired releases were conducted during the month of May. Release group sizes ranged from 50 to 75. Three of the nine releases were statistically different; May 1 (*P* = 0.01), May 5 (*P* = 0.05), and May 25 (*P* = 0.0009). Six of the nine releases from the test site had lower capture rates than those released at the standard site. A paired t-test did not detect a significant difference between recapture rates of fish released from the standard release site and the test release site (t_7 = 1.32, *P* = 0.23).

Table 26. Paired efficiency trial releases of coho at two separate sites in Bear Creek in 2011. Standard location is Redmond Way Bridge and Test Location is Union Hill Bridge.

		Standard Location Releases				Test Location Releases			
Date	P value	# Released	Seen	Unseen	Efficiency	# Released	Seen	Unseen	Efficiency
05/01/2011	0.01	75	17	58	22.67%	75	5	70	6.67%
05/03/2011	0.55	65	18	47	27.69%	65	15	50	23.08%
05/05/2011	0.05	50	19	31	38.00%	50	10	40	20.00%
05/07/2011	0.81	50	12	38	24.00%	50	11	39	22.00%
05/10/2011	0.64	50	13	37	26.00%	50	11	39	22.00%
05/11/2011	0.74	50	6	44	12.00%	50	4	46	8.00%
05/13/2011	0.67	50	2	48	4.00%	50	4	46	8.00%
05/18/2011	0.23	50	4	46	8.00%	50	9	41	18.00%
05/24/2011	0.06	50	6	44	12.00%	36	11	25	30.56%
05/25/2011	8.58E-04	50	2	48	4.00%	50	15	35	30.00%

Mark Does Not Affect Catchability

When conducting mark recapture studies it is important to validate the assumption that the mark applied does not influence the catchability of the species. In 2011 at both Cedar River and Bear Creek screw traps, PIT tags were used as a mark. Implanting a PIT tag can be an invasive procedure for a juvenile salmon to endure, from being anesthetized to the invasion of a foreign object into their peritoneal cavity that can sometimes be as much as 20% the length of the fish. The abilities of a fish may be compromised by such a procedure and affect the recapture rate, violating the assumption that marks do not affect the catchability of the fish. This assumption was tested for Chinook parr and coho smolts in 2011 for both Cedar River and Bear Creek screw trap periods, by comparing the ratio of seen:unseen fish of all clipped groups and PIT tagged groups throughout the season. Although there may be varying environmental or temporal factors that influence releases throughout the season, the comparison of seasonal totals rather than specific paired releases may indicate whether one mark is consistently affecting the ability to recapture a fish. As there is only one option adequate for marking fry (Bismarck Brown dye) without potentially impeding their swimming abilities, this assumption was not validated for sockeye or Chinook fry.

Chinook catches were low during screw trap operations on the Cedar River and efforts were consolidated to PIT tag as many as possible. As a result, only three clip groups were released. All efficiency trial release groups and subsequent recaptures were small and contributed to low power to detect differences in the recapture rates of clipped and PIT tagged Chinook. Coho catches were more abundant, allowing for fifteen clip groups (792 total fish released) and eighteen PIT tag groups (1,028 total fish released) to be released and compared. The seasonal ratio of seen:unseen clipped coho was significantly greater than that of PIT tagged coho (P = 0.026). Clipped coho had a seasonal recapture rate of 10.5% while seasonal recapture rate of PIT tagged coho was 8.1%. Although these two groups were statistically different, the effect of these differences on the production estimate was within the confidence intervals of each production estimate.

In Bear Creek, nine coho clip groups were released (594 fish total) and eleven PIT tagged groups were released (705 fish total). Recapture rates did not differ between clipped and PIT tagged coho in Bear Creek ($P = 0.88$). The seasonal efficiency of the PIT tagged coho was just 0.5% higher than the clipped coho, a magnitude unlikely to affect the production estimate. There were eight clip groups (378 fish total) and twenty-seven PIT tag groups (1,230 fish total) of Chinook released in 2011. Because Chinook are smaller than coho and may be more affected by the body size-to-tag size ratio, the comparison of mark type may have important implications on the Chinook production estimate. However, there was no significant difference between the clipped and PIT tag seen:unseen ratio, although seasonal efficiency of clip group was 9% higher. In future years, we will continue to compare recapture rates of clipped and PIT tagged coho and Chinook migrants in Bear Creek in order to further explore the effects on mark-types of trap efficiency.

Mark Retention

The last assumption tested in 2011 concerns the retention of marks applied to estimate capture rates. Lost marks from point of release to recapture decreases recapture rates and results in overestimating production. The same Chinook and coho efficiency trials used to assess adequate mixing (PIT/clipped) were used to assess mark retention during screw trap operations. Fin clips have been used for decades as reliable, recognizable marks that should remain apparent for the duration of screw trap operation. Atlantic salmon that were caudal clipped and held for observation did not show any fin regeneration until after 50 days, with regeneration being very apparent by day 90 (Dietrich and Cunjak 2006). However, PIT tag retention is dependent on the experience of the tagging staff as well as the length of fish being tagged. Although the initial intention of these mark groups was to assess mixing, they were also used to assess the validity of PIT tags as a mark. Upon releasing double marked fish, the bucket was examined to be sure that no tags were expelled between tagging and release. At every trap check, catch was examined for marks. All recaptured clipped fish were examined for a PIT tag scar and screened with an electronic PIT tag reader to determine if a tag was present. If a clipped fish had a scar but no PIT tag, then it was assumed the fish had lost its tag between release and recapture. This would indicate a tag loss rate and the reliability of PIT tags as a valid mark for efficiency trials. In 2011, no tags were expelled from fish before release, as evident by the lack of loose tags in the bucket. Also none of the recaptured double marked fish showed any signs of tag loss, indicating that PIT tags were a reliable mark and mark retention was 100%.

Dyes are common ways of marking large batches of fish that may be too small to fin clip. During inclined-plane trapping, Bismarck Brown is used to mark sockeye and Chinook fry rather than fin clipping which may impede swimming. Three batches of 30 sockeye were dyed with Bismarck Brown by following the procedures in the Methods section. Test fry were held for 3 days following initial marking and reassessed visually by comparing them to newly dyed fish each day, as well as non-dyed fish. In all three instances, test fish did not appear to have faded when compared to newly dyed fish and when compared to non-dyed fish, test fish were clearly dyed. Test sockeye were not held longer than three days as to not inflict any unnecessary stress on them. Three days was thought to be adequate holding time for assessment. Based on historical data, delayed recaptures of sockeye were minimal and occurred no later than one day after release.

Cedar River Estimate Assumptions

Natural-Origin and Hatchery-Origin Catch Composition

Throughout the 2011 Cedar River sockeye fry migration, hatchery sockeye were released in the Cedar River. A total of four groups were released above the inclined-plane trap on nights that the trap was operating, resulting in an unknown portion of hatchery and natural-origin sockeye in the catch. In previous years, various methods have been used to partition both origins as appropriately as possible, these include the collection of otoliths (hatchery sockeye otoliths are thermally marked); a flow regression model based on historical otolith analysis; interpolation of natural-origin catch; and assessing the nightly migration timing of natural-origin fish to partition natural-origin fish during hours when hatchery fish inundate the trap (Kiyohara and Volkhardt 2008). Of these methods, otolith sampling is the only direct method to estimate hatchery and natural-origin sockeye in nightly catch. However there was no funding for otolith sampling in 2011 so all releases were evaluated using indirect methods listed above.

Interpolation of natural-origin sockeye fry catch was used to indirectly estimate hatchery catches on three of the four hatchery release nights; January 31 and March 1 and 8. With this approach, the catch of natural-origin sockeye fry is estimated as intermediate between the preceding and following nights and catch of hatchery sockeye fry is the difference between total catch and natural-origin estimated catch. Based on this method, hatchery sockeye fry survival was estimated to be 32.2%, 49.9%, and 39.5% respectively. This approach was considered the most precise of indirect methods because it only assumes that natural-origin migration rates were intermediary between those of the day preceding and following the release.

Interpolation was not a valid method to estimate the February 8 hatchery release because this method estimated more natural-origin sockeye than the total fry caught on this night. The alternative method was to examine the nightly timing distribution on nights surrounding the release and apply the hourly proportions to the hatchery release night. Remaining fish from each hour are considered hatchery catch. This assumes that nightly migration timing of naturally produced fish is consistent over several days. We felt this was less certain than the assumption for the interpolation approach. This method also yielded an unreasonable estimate for February 8 release as actual catches were greater than expected for earlier hours and less than expected during hours when hatchery fish would have been expected to arrive at the trap.

Both interpolation and nightly migration timing methods did not provide reasonable estimates for survival of hatchery sockeye released on February 8, 2011, and therefore we assumed that survival was 0%. Possible contributors to this low estimate are errors in either method that assumes natural –origin migrations are intermediary or similar to surrounding nights or poor adjustment of hatchery fry to high flows and turbidity when they were released.

A flow-based regression model used to estimate survival in previous season was considered in 2011 but did not yield reasonable estimates. This model performed poorly for three of the four releases, estimating survival to be over 100% for two releases and estimating a greater catch of fish from both origins than actually observed in entirety on a release night. This method was previously developed using unfed hatchery fry released from Landsburg Hatchery and may not be appropriate to use in 2011 because all fish released were fed prior to release and released at

R.M. 13.5 (Seiler et al. 2005). In 2007, this model was also dismissed as a useful tool to estimate hatchery survival as it yielded unreasonable estimates. In both 2007 and 2011, hatchery fish were fed before release and released at a closer location in the river. Differences in the fish condition and release site location may both be reasons why this model is not performing well.

There were notable differences observed between hatchery and natural-origin sockeye caught in the trap in 2011 which may violate assumptions mentioned above for methods used to estimate hatchery catch and survival. Apparent size differences of sockeye in catches were noted on nights when hatchery fish were released. Natural inclination would be to assign larger sockeye as hatchery-origin as all hatchery sockeye released upstream of the trap were fed prior to release. In addition to the observed size difference, there was also a behavioral difference noted: the larger fish were swimming against the current in the counting trough where the smaller fish were swimming with the current. Natural-origin sockeye likely have smaller energy reserves than fed hatchery sockeye fry and may be inclined to use the natural river flow to carry them downstream after emergence rather than exert unnecessary energy to migrate. After emergence hatchery fish are held and fed in a trough for up to ten days. An additionally important observation based on the noted size difference, was that hatchery fish, defined above by the visual size difference, continued to move past the trap for up to three nights after a release. In the past, a majority of hatchery sockeye appeared to move past the trap on the night of the release. There are no external marks to identify a hatchery or natural-origin sockeye so it is possible that in previous years, when size differences were not noted, hatchery fish were present in subsequent nights catches but not visually apparent.

Based on these observations, the indirect methods used to allot sockeye fry catch into hatchery and natural-origin have added additional uncertainty to the final estimates. Specifically, our estimates of hatchery migration and survival estimates are likely to be low and our estimates of natural-origin sockeye fry abundance are likely to be high on hatchery release nights. Both methods used to estimate hatchery catch assume migration patterns of natural-origin sockeye are consistent on nights previous and following a release. These observations of delayed migration indicate that this assumption may be violated considering the night following release would not mimic the natural migration pattern if hatchery fish are included in the total catch. If hatchery sockeye are larger, they may possess a greater ability to maneuver in the river and may migrate on following nights, like observed in 2011. Currently, only catch on nights of hatchery releases are partitioned in to separate origins. We do not account for the possibility of hatchery fish migrating on subsequent nights. Any hatchery fish that migrate beyond the trapping efforts for a given night are counted as natural-origin sockeye, thus inflating the natural-origin production estimate and decreasing hatchery estimates.

To gain more certainty in hatchery and natural-origin catch composition, direct measure of hatchery proportions in nightly catches following hatchery releases are needed. Otoliths samples will be the most direct approach of acquiring this information. Another potential option is to apply an external mark that would identify hatchery fish, such as a dye or paint mark.

Hatchery and Natural-Origin Efficiency Trials

In 2011, high flows and low catches of natural-origin sockeye fry made it difficult to form reasonably sized efficiency trials throughout the season. As in the past, sockeye from Landsburg

Hatchery were arranged to be used as surrogates for some release groups (ten separate groups), as smaller and fewer release groups can result in less accurate estimates.

As the season proceeded, natural-origin sockeye catches grew stronger and were used, in conjunction, for release groups when possible (19 natural-origin release groups throughout the season). Using both natural-origin and hatchery sockeye for efficiency trial groups allowed some comparision of hatchery and natural-origin sockeye capture rates.

The comparison of recapture rates of natural versus hatchery origin sockeye fry was evaluated using the *G*-test approach (α=0.05) described in the methods section. In this comparison the seen:unseen ratio was compared between natural-origin and hatchery-origin efficiency trials. Efficiency trials were compared using average seasonal capture rates, which was 2.5% for hatchery-origin and 4.8% for natural-origin sockeye. These capture rates of natural-origin and hatchery sockeye were found to be statistically different (P =2.2E-16). Further investigation revealed that eight of the hatchery groups were released on nights when flows were between 1,000 and 2,100 cfs while the majority of natural-origin trials were released at flows below 950 cfs (Figure 19). Additionally, seen:unseen ratio of fish of both origins that were released at flows greater than 1,000 cfs were compared using the G-test and were found not statistically different (P = 0.11). Therefore, the recapture rate differences between natural and hatchery origin sockeye fry was likely an artifact of river discharge which functioned as a covariate to influence recapture rates.

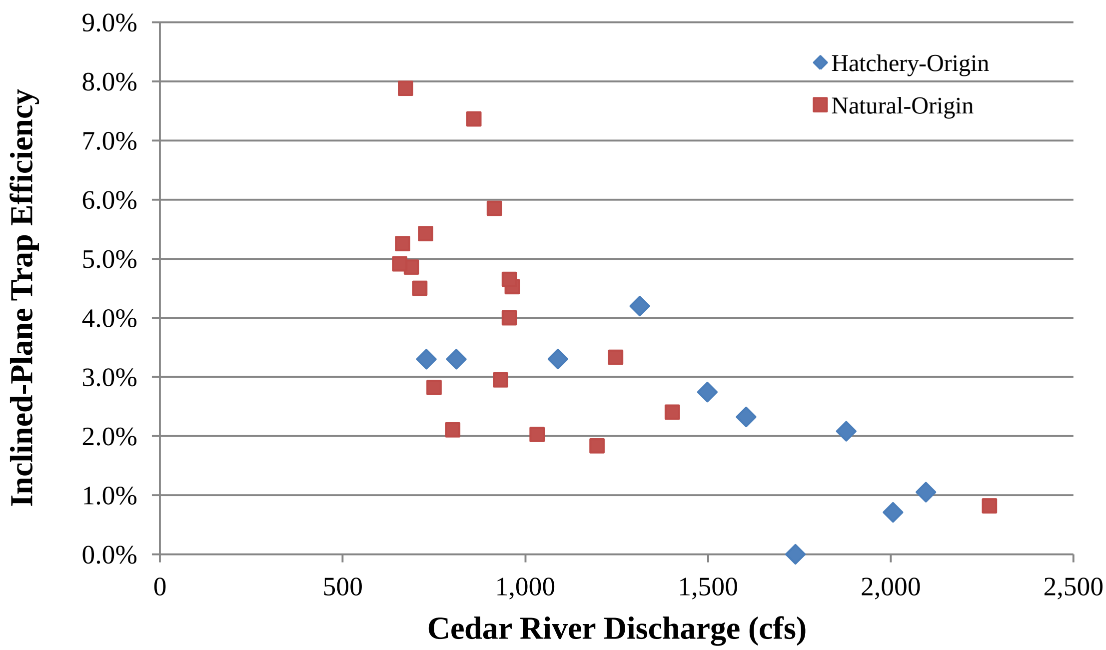

Figure 19. Trap efficiency of the Cedar River inclined-plane trap measured for hatchery and natural-origin sockeye over a range of river discharge levels in 2011. River discharge was measured at USGS gage Station #12119000.

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 production. 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 2011 catches were low, subsequently only two paired releases were conducted to test the assumption that capture rates of sockeye are similar enough to Chinook to be used a surrogates to estimate Chinook fry production. Efficiency trials were conducted in the same manner described in the Methods section for sockeye. Efficiency trial groups consisted of 129 and 148 of each species with an equal number of each species released.

There was no significant difference detected between sockeye and Chinook recapture rates ($p = 0.89$ on March 23 and $p = 0.78$ on March 28). The *G*-test was used to compare each paired release in order to determine if the ratio of seen:unseen differed between species. Therefore, we tentatively conclude that sockeye are an adequate surrogate to estimate trap efficiencies for Cedar River Chinook fry.

In 2010, no significant difference was noted between sockeye and Chinook however, all but three comparison trials suggested that sockeye are recaptured at a higher rate than Chinook. The opposite is noted in 2011. In the two comparison trials conducted in 2011, Chinook were recaptured at a higher rate than sockeye. This may be partially influenced by environmental and temporal factors or density. In 2010, twelve paired trials were released from late January through mid-March with flows ranging from 402 to 810 cfs, perhaps representing a wider time period of the migration as well as a wider range of flows. In 2011, both trials were released in late March with higher flows of 1,032 cfs on March 23 and 956 cfs on March 28. In late March Chinook could be actively moving to acquire suitable habitat for rearing before exiting the river. Higher flows may also force fry downstream.

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

Cedar River Sockeye Median Migration Date

One of the goals identified for this study is to identify environmental variables that influence sockeye migration timing. Although previous reports have demonstrated that total thermal units during the month of February are a good predictor of the sockeye median migration date (Figure 6, R^2=0.58), average temperatures from November through January provide an earlier and better predictor of median migration date (Figure 20, $R^2 = 0.70$). For the 2010 brood, this model predicted median migration on March 22, three days earlier than the observed median. This period, November through January, represents the incubation period when the peak of the adult sockeye return has passed and majority of the eggs have been deposited in the gravel. If temperatures are warmer during the incubation period, the median migration date may occur earlier. Further analysis will evaluate the influence temperature at different stages of egg development have on sockeye and Chinook migration timing in the Cedar River and Bear Creek. Broods 1999 and 2005 were not included in analysis as November and December temperature data were not available for these years. Brood 2000 was not included in analysis due to extreme low flows and a landslide that impeded migration for a portion of the season.

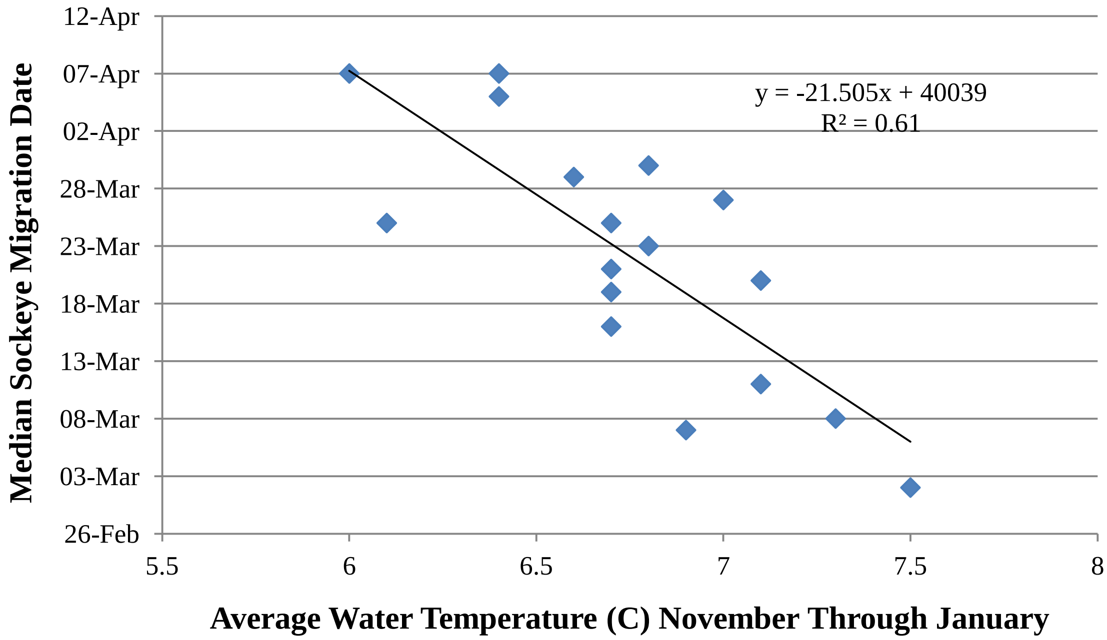

Figure 20. Median migration date for brood years 1993-2008 sockeye as a function of average November through January water temperatures in the Cedar River as measured at the USGS Renton Gage #12119000. Brood years 1999, 2000, and 2005 were not included. Temperature data was not available for brood years 1999 and 2005. Brood year 2000 was treated as an outlier.

Cedar River Coho Migration

In 2010, a notable phenotypic diversity of coho migrants in the Cedar River screw trap led to closer investigation of coho age structure and migration timing (Kiyohara and Zimmerman 2011). At least two age classes of coho smolts were observed in the trap catches, noted by body lengths and a recognizable difference in eye to head proportions – smaller in sub yearling smolts and larger in yearling smolts. 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. In 2011, additional investigation was intended however, notably, there were very few coho that phenotypically appeared to be sub yearlings. Only one coho was visually classified as a sub yearling coho and PIT tagged. Additional years of study will be necessary to identify and understand the contribution of zero-age smolts to the freshwater production.

Day-time Migration in Bear Creek

During the 2000-2002 trap seasons, day-time movement of sockeye and Chinook fry in Bear Creek were evaluated and found to be minimal (Seiler et al 2003, 2004a, and 2004b). 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, this assumption was re-evaluated by trapping five day-time intervals and concluded that day-time movement of sockeye was minimal (contributed an additional 1.2% to the total production) while Chinook day-time movement accounted for 23.9% of the total production during inclined-plane trap operation period. Movement of fish can be influenced by available rearing space, including temporary rearing space, and total production of either or both species. Juvenile Chinook salmon have been noted to select difference habitats as they grow, even within a short temporal period (Holecek, D., et al 2009). In 2010, catches and migrations of both sockeye and Chinook were the lowest observed since trapping began and may not accurately represent either species' movements in larger return years. In 2011, the Bear Creek sockeye production was the largest since trapping began and the Chinook production was near the median. Day-time monitoring in 2011 may more accurately capture day-time migrations of both sockeye and Chinook.

In 2011, the Bear Creek inclined-plane trap operated during five day-time intervals (February 1 and 15, and March 4, 15, and 29) to assess day-time fry movement. A total 192 sockeye were caught during the day periods. No Chinook were caught. A day-to-night ratio was calculated using the same methods described for Cedar River. Sockeye day-to-night ratios ranged from 0.08% to 3.55% (Table 27) and increased total catch by 1,990 and abundance by 37,272 sockeye. While the day-time catches of sockeye may seem to be significant, it consists of a small portion of the total production (0.46%) and surprisingly a smaller proportion of the total production measured in 2010 (1.2%) which was the smallest sockeye juvenile production noted since monitoring began. Validating this assumption in 2010 and 2011, during one of the smallest and largest sockeye migrations noted, has reaffirmed that there are few sockeye moving during day-time hours on Bear Creek. Chinook day-time migrations in 2010 were greater than assumed even though it was the smallest Chinook production estimated since monitoring began. However in 2011, the migration was near the median yet no Chinook were caught during day-time hours. Although day-time migration during the inclined-plane trap operation could have a large impact on the sockeye fry estimate for Bear Creek, daytime, migration should have less of an impact on the Chinook outmigrant estimate because the majority of Chinook migrants leave the system as larger parr after the screw trap has been installed and is fishing 24-hours each day.

Table 27. Day-to-night capture ratios for sockeye fry in the Bear Creek inclined-plane trap, 2011.

Night				Day				D:N
Date	Catch	Time Fished (hr)	catch/hr	Date	Catch	Time Fished (hr)	catch/hr	
31-Jan	514	15		01-Feb	3	9	0.33	**1.08%**
01-Feb	415	15						
	929	30	30.97					
14-Feb	1,676	15		15-Feb	52	9	5.78	**3.55%**
15-Feb	3,211	15						
	4,887	30	162.90					
03-Mar	5,198	13		04-Mar	3	11	0.27	**0.06%**
04-Mar	6,111	13						
	11,309	26	434.96					
14-Mar	22,099	13		15-Mar	127	11	11.55	**0.74%**
15-Mar	18,285	13						
	40,384	26	1,553.23					
28-Mar	5,548	13		29-Mar	7	11	0.64	**0.08%**
29-Mar	14,300	13						
	19,848	26	763.38					

Recommendations

Two of three recommendations for 2011 were addressed during the trap season. During the trap season we assessed day-time movement of juvenile Chinook and sockeye and the use of sockeye fry as surrogates for Chinook fry capture rates. We were unable to address the usefulness of coho eye size as a field tool for classifying coho smolt age due to limited numbers of small-eyed coho in the 2011 trap catches. In 2012, the second and third recommendations will continue to be investigated; however day-time movement in Bear Creek has been evaluated during two years when juvenile sockeye production was at both extremes and thought to be a good representation of the range over the data set.

Furthermore, when evaluating 2011 data for both systems, the uncertainty of a number of assumptions associated with our estimates became apparent. In particular, we recommend using a more direct method for estimating hatchery migration and survival in the 2012 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: Improve natural and hatchery origin catch composition by incorporating otolith sampling on nights when hatchery releases occur above the Cedar River inclined-plane trap. In 2011, hatchery migration and survival was estimated for four hatchery releases conducted above the trap. Visual observations and historical methods used to estimate hatchery and natural-origin components of catch on release nights have indicated that there are flaws to some degree in the approaches that are taken to estimate migrations. Survival ranged from 0% to 49.9%, however three different methods were used to determine hatchery and natural-origin catch composition and hatchery survival for lack of one method providing reasonable estimates for all releases. To reduce uncertainty and assess hatchery fry migration more concretely, developing a sampling plan that incorporates otolith sampling would provide the most direct measure of hatchery proportions in catches.

Recommendation 2: Test assumptions affiliated with mark recapture studies. In 2011, a variety of tests were conducted to assess the quality of our production estimates by validating assumptions. These assumptions include verifying that all fish have equal probability of being captured and recaptured, marks do not affect the ability of a fish to be captured and marks are retained from point of release to recapture. Continued testing will reveal areas of uncertainty in juvenile production estimates. In particular, the release site used for Bear Creek trap will be examined in order to better address whether marked and unmarked fish are adequately mixing prior to recapture.

Recommendation 3: Test the assumption that sockeye are adequate surrogates for estimating Chinook fry capture rates of the Cedar River inclined-plane trap. This assumption has been made based on the similar physical states (i.e., recently emerged fry) of each species. Chinook fry movement has been assumed to be comparable to that of sockeye fry. As a result, the abundance of Chinook fry migrants was derived based on sockeye capture rates. In part, this strategy was developed to minimize handling of the natural-origin Chinook fry, which are 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. In 2011, flows were variable however catches were not abundant enough to form many paired releases. Therefore, paired releases of sockeye and Chinook fry will be conducted in 2012 over as wide a range of flows as possible given available catch and river conditions.

Recommendation 4. 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 migrations by using PIT tags to track migration through the Hiram Chittenden Locks. 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, only 1 coho was visually identified as an age 0 coho. If catches are more abundant, in 2012, 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.

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

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

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

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

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

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

where

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

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

Derivation:

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

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

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, 2011.

Appendix B 1. Catch and migration by strata for Cedar River natural-origin sockeye fry, 2011.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	01/30/2011	02/07/2011	853	2.74%	29,496	8.02E+07
2	02/08/2011	02/10/2011	289	1.05%	26,334	2.58E+08
3	02/11/2011	02/14/2011	862	2.20%	38,413	1.09E+08
4	02/15/2011	03/06/2011	52,884	4.56%	1,156,160	5.07E+09
5	03/07/2011	03/07/2011	5,509	7.88%	68,979	7.25E+07
6	03/08/2011	03/08/2011	3,580	5.25%	67,125	9.07E+07
7	03/09/2011	03/24/2011	20,427	2.85%	711,140	5.66E+09
8	03/25/2011	03/31/2011	12,702	4.35%	285,352	1.92E+09
9	04/01/2011	05/01/2011	14,247	0.72%	1,856,859	2.48E+11
10	05/02/2011	05/04/2011	2,127	7.36%	28,360	1.98E+07
11	05/05/2011	05/25/2011	8,653	5.12%	162,743	9.91E+08
		Total	**122,133**		**4,430,961**	**2.62E+11**

Appendix B 2. Catch and migration by strata for Cedar River natural-origin Chinook fry, 2011.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	01/30/2011	02/07/2011	161	2.74%	5,567	8.66E+06
2	02/08/2011	02/10/2011	45	1.05%	4,106	3.66E+07
3	02/11/2011	02/14/2011	91	2.20%	4,055	8.71E+06
4	02/15/2011	03/06/2011	2,164	4.56%	47,310	3.12E+07
5	03/07/2011	03/07/2011	72	7.88%	902	1.64E+05
6	03/08/2011	03/08/2011	28	5.25%	525	2.00E+05
7	03/09/2011	03/24/2011	1,579	2.85%	54,971	9.76E+07
8	03/25/2011	03/31/2011	766	4.35%	17,208	1.57E+07
9	04/01/2011	05/01/2011	315	0.72%	41,055	8.50E+08
10	05/02/2011	05/04/2011	6	7.36%	80	1.56E+04
11	05/05/2011	05/09/2011	12	5.12%	226	8.84E+04
		Total	**5,239**		**176,005**	**1.05E+09**

Appendix B 3. Catch and migration by strata for Cedar River natural-origin Chinook parr, 2011.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	05/10/2011	07/16/2011	797	7.84%	9,909	2.50E+06
		Total	**797**		**9,909**	**2.50E+06**

Appendix B 4. Catch and migration by strata for Cedar River natural-origin coho migrants, 2011.

Strata	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	04/27/2011	04/30/2011	201	5.76%	3127	9.56E+05
2	05/01/2011	05/14/2011	1674	8.50%	19362	6.54E+06
3	05/15/2011	05/17/2011	1013	16.23%	6078	9.62E+05
4	05/18/2011	05/23/2011	700	7.29%	9195	3.50E+06
5	05/24/2011	05/31/2011	726	9.67%	7284	1.60E+06
6	06/01/2011	06/03/2011	219	31.25%	621	3.66E+04
7	06/04/2011	07/16/2011	397	5.56%	6791	2.29E+06
Total			**4,930**		**52,458**	**1.59E+07**

Appendix C

Catch and Migration Estimates by Strata for Bear Creek
Sockeye, Chinook, Coho Salmon, and Cutthroat Trout, 2011.

Appendix C 1. Catch and migration by strata for Bear Creek sockeye, 2011.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	01/24/11	02/14/11	16,434	8.25%	198,391	1.63E+08
2	02/15/11	03/10/11	122,473	8.05%	1,517,149	8.85E+09
3	03/11/11	03/17/11	124,031	3.45%	3,534,884	2.12E+11
4	03/18/11	03/22/11	79,478	5.75%	1,327,945	6.63E+10
5	03/23/11	04/03/11	131,458	10.35%	1,264,651	6.87E+09
6	04/04/11	04/12/11	12,392	5.50%	222,917	5.81E+08
7	04/13/11	04/22/11	6,507	8.99%	71,914	3.79E+07
		Total	**492,773**		**8,137,851**	**2.94E+11**

Appendix C 2. Catch and migration by strata for Bear Creek natural-origin Chinook fry, 2011.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	01/23/2011	02/13/2011	3	8.25%	36	4.77E+02
2	02/14/2011	03/09/2011	20	8.05%	248	5.57E+03
3	03/10/2011	03/16/2011	14	3.45%	399	1.37E+04
4	03/17/2011	03/21/2011	5	5.75%	84	2.68E+03
5	03/22/2011	04/02/2011	6	10.35%	58	5.30E+02
6	04/03/2011	04/11/2011	6	5.50%	108	2.59E+03
7	04/12/2011	04/26/2011	65	8.99%	718	1.40E+04
		Total	**119**		**1,651**	**3.95E+04**

Appendix C 3. Catch and migration by strata for Bear Creek natural-origin Chinook parr, 2011.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/26/2011	05/15/2011	291	40.85%	698	1.01E+04
2	05/16/2011	05/22/2011	444	23.38%	1,860	7.77E+04
3	05/23/2011	06/02/2011	1,363	38.66%	3,509	7.66E+04
4	06/03/2011	06/17/2011	1,360	22.31%	6,051	2.79E+05
5	06/18/2011	06/19/2011	229	13.00%	1,652	1.82E+05
6	06/20/2011	07/05/2011	904	34.58%	2,602	7.56E+04
7	07/06/2011	07/15/2011	86	56.25%	151	3.70E+02
		Total	**4,677**		**16,524**	**7.01E+05**

Appendix C 4. Catch and migration by strata for Bear Creek natural-origin coho smolts, 2011.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/27/2011	05/10/2011	1,425	27.35%	5,169	2.17E+05
2	05/11/2011	05/12/2011	436	17.00%	2,446	2.70E+05
3	05/13/2011	05/13/2011	175	4.00%	2,975	2.12E+06
4	05/14/2011	05/15/2011	278	19.00%	1,433	4.72E+04
5	05/16/2011	05/20/2011	1,162	7.33%	14,622	1.60E+07
6	05/21/2011	05/23/2011	507	27.00%	1,829	8.80E+04
7	05/24/2011	05/26/2011	315	8.00%	3,535	1.32E+06
8	05/27/2011	06/05/2011	504	27.14%	1,839	3.75E+04
9	06/06/2011	07/16/2011	70	5.56%	665	1.36E+05
		Total	**4,872**		**34,513**	**2.02E+07**

Appendix C 5. Catch and migration by strata for Bear Creek cutthroat migrants, 2011.

Strata	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/27/2011	07/16/2011	685	14.05%	4,569	5.13E+05
		Total	**685**		**4,569**	**5.13E+05**

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