Evaluation of Downstream Migrant Salmon Production in 2007 from the Cedar River and Bear Creek

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March 2008

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

Acknowledgements

The evaluations of downstream migrant salmon production in the Cedar River in 2007 was made possible by City of Seattle Public Utilities (SPU), who funded the operations of the sockeye fry trap. King Conservation District and King County Department of Natural Resources and Parks provided funding for trapping in Bear Creek, the Cedar River screw trap, and PIT tagging in both systems.

The success of these projects relied on the hard work of a number of dedicated permanent and temporary WDFW personnel. The Hatcheries Program successfully collected adult sockeye broodstock and incubated eggs, releasing over 11.8 million sockeye fry into the Cedar River. Escapement data were collected and estimates were developed by a number of individuals representing several agencies: Steve Foley and Larry Lowe, WDFW; Mike Leslie and Brian Footen, Muckelshoot Tribe; Karl Burton, SPU; and Hans Berge, Mistie Hammer, Kollin Higgins, and Jim Lissa, King County DNRP. WDFW Scientific Technicians Paul Lorenz, Dan Estell, and Kelsey Kropp worked long hours, usually at night, operating the traps, marking, identifying and counting fish. WDFW Biologists Mike Ackley and Pete Topping provided valuable experience and logistical support. Project management was provided by Paul Faulds from SPU, and Hans Berge and Frank Leonetti from King County.

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

Cedar River

The Boeing Company provided electrical power and a level of security for our fry trap.
The Renton Municipal Airport provided security for the fry trap and other equipment housed at the airport.
The City of Renton Parks Department provided access and allowed us to attach anchor cables to their property.
The United States Geological Survey provided continuous flow monitoring.
Seattle Public Utilities communicated flow changes.

Bear Creek

Blockbuster Video provided electrical power.
The City of Redmond Police Department provided a measure of security for the crew and trap.
King County Department of Natural Resources and Parks (DNRP) provided continuous flow monitoring.

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Executive Summary

This report provides the results of monitoring five salmonid species as downstream migrants in 2007 from two of the more heavily spawned tributaries in the Lake Washington basin: the Cedar River and Bear Creek. Monitoring sockeye fry production in the Cedar River began in 1992 to investigate the causes of low adult sockeye returns. This annual trapping program, which continued through 2007, was expanded in 1999 with the addition of a second downstream migrant trap to estimate the production of juvenile Chinook salmon. With this trap, the production of coho, steelhead and cutthroat smolts were also estimated.

In addition to the Cedar River, downstream migrant production is also measured in the Sammamish basin. A trap was operated in the Sammamish River in 1997 and 1998 to estimate sockeye fry production. This monitoring program was moved to Bear Creek in 1999 to concurrently assess Chinook and sockeye production. Since 1999, as in the Cedar River, this trapping operation has also estimated the populations of coho, steelhead and cutthroat smolts.

Cedar River

Declining adult sockeye salmon returns in the late 1980s and early 1990s prompted an effort to investigate causes for this decline. To determine which life-stages were experiencing poor survival, an evaluation of fry production was undertaken in the Cedar River beginning in 1992. Assessing the sockeye population, at this location and life-stage, separates freshwater production into river and lake components. This report documents our evaluation during 2007, the sixteenth year of this project. The primary study goal was to estimate the season total migration of natural-origin Cedar River sockeye fry into Lake Washington. This estimate enables calculation of a survival rate for the 2006 brood from egg deposition to lake entry, and provides data to calculate other live stage components such as survival from lake entry to smolts and adult return.

Beginning in January and continuing through early June, a floating inclined-plane screen (fry) trap located at river mile (R.M.) 0.7 in the Cedar River was operated to capture a portion of the sockeye fry migrating into Lake Washington (Figure 1). Had the trap fished continuously from January 18 through June 7, total catch was estimated at 326,773 sockeye. Trap efficiency was estimated by releasing dye-marked fry upstream of the trap on 60 nights during trapping season. Capture rates ranged from 1.2% to 11.5%. Total migration for 2007 was estimated at 9.25 million natural-origin sockeye fry. Survival of natural-origin fry from egg deposition to lake entry was estimated at 5.9%, the third lowest observed since this study began. This rate is the ratio of 9.25 million natural-origin fry to an estimated deposition of 155.6 million eggs.

Over the season, 11.8 million hatchery-produced sockeye fry were released into the Cedar River from three locations. A portion of these fry (8.4 million) was released below the fry trap at the Cedar River Trail Park. Survival of hatchery fry released at the Cedar River Trail Park was assumed to be 100%. The remaining 3.4 million fry were released at two different sites upstream of the trap, 2.3 million released at R.M. 13.5 and 1.1 million released at R.M. 21.8. Survival of the fry released above the trap was estimated using three different approaches and ranged from 5.61% to 148%. We estimated 1.9 million survived to the trap. With the addition of hatchery sockeye fry, we estimate a total of 19.6 million sockeye fry entered Lake Washington in 2007.

Median migration timing for natural-origin fry in 2007 was only one day later than average. February stream temperatures averaged 7.0°C in 2007, slightly warmer than the 15-year average (6.2° C), which in turn produced a median migration date fairly close to the 15-year average median migration date. The median migration date for natural-origin fry was March 23, 35 days later than that of the hatchery fry. This difference was only one day earlier than average.

In response to the listing of the Puget Sound Chinook Evolutionary Significant Unit (ESU) under the Endangered Species Act as a threatened species, the existing sockeye fry monitoring program was expanded in 1999 to include an assessment of the natural-origin Chinook production in the Cedar River. The gear operated each year, starting in January, to assess sockeye fry production also captures Chinook fry. To capture the larger, later migrating Chinook, a screw trap was installed at R.M. 0.9 in mid-April, and operated through July. Total catch was estimated at 2,670 Chinook fry. From the start of the season in January through the middle of April, mark-recapture data generated with releases of marked sockeye were used to estimate fry trap efficiencies for Chinook migrants. Abundance was estimated at 109,511 Chinook for the period of January 1 through April 17.

Chinook catch from the screw trap totaled 878 parr. Screw trap efficiency was estimated by releasing groups of fin-marked or PIT tagged Chinook parr above the trap. Capture rates ranged from 3.0% to 12.3%. Total migration from April 18 through July 20, was estimated at 14,225 Chinook parr.

Age 0+ Chinook production from the Cedar River was estimated at 123,736 in 2007. Timing was bi-modal with fry emigrating in January through mid-April comprising 88% of the total migration. Egg-to-migrant survival was estimated at 4.7%. Over the season, age 0+ Chinook increased in size from 34 mm in January to 125 mm by the end of the season.

Over the season, natural-origin coho migration was estimated at 33,994 smolts. Estimates of production were not made for steelhead and cutthroat in 2007 due to low catches (1 steelhead and 4 cutthroat smolts).

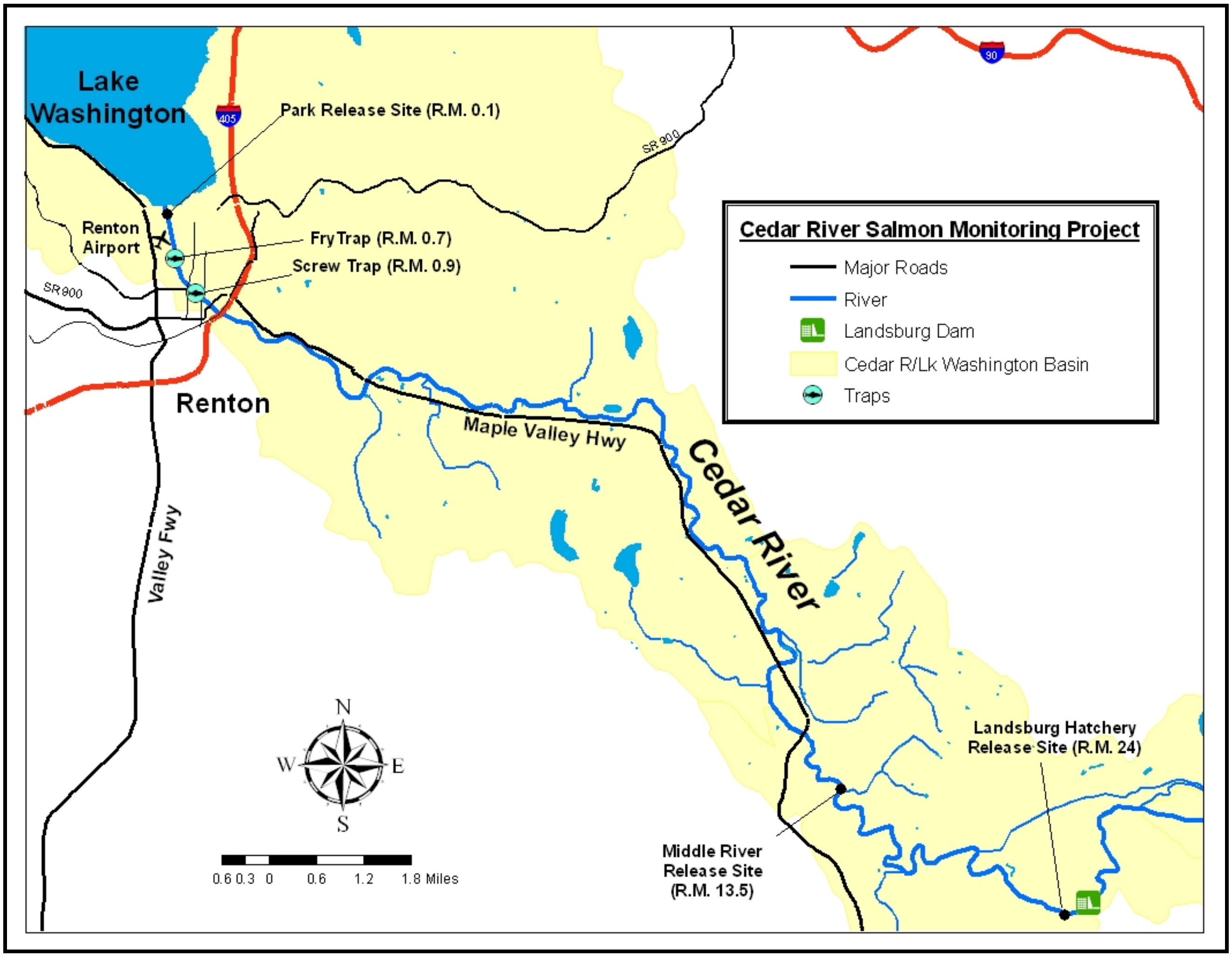

Figure 1. Site map of the lower Cedar River watershed depicting the fry and screw trap locations, hatchery sockeye release sites, and trap efficiency test release sites for the 2007 trapping season.

Bear Creek

A fry trap was installed on Big Bear Creek 100 yards downstream of the Redmond Way Bridge and operated from February through mid April. In April, it was replaced with a screw trap that fished until July 11. Downstream migrant production was estimated for natural-origin sockeye fry, age 0+ Chinook, coho and cutthroat smolts. Steelhead production was not assessed due to insufficient catch.

Throughout the fry-trapping season, 36 mark groups were released using sockeye fry. Total catch was estimated at 377,314 sockeye fry. Capture rates ranged from 1.5% to 12.5% and total sockeye production was estimated at 5,983,651 fry, more than twice the previously observed high production. Relating this production to the estimated deposition of 33.9 million eggs yielded a survival rate of 17.7%, the second highest survival estimated since trapping began in 1998.

Migration of age 0+ Chinook during fry trap operation was estimated using sockeye fry mark-recapture data. Total catch was estimated at 166 Chinook fry. Total abundance was estimated at 4,054 Chinook fry. During screw trap operation, 5,276 Chinook parr were caught. Efficiency for the screw trap was estimated by releasing mark groups above the trap. Capture rates ranged from 28.6% to 52.3%. Chinook abundance during screw trap operation was estimated at 12,816 parr.

Total production of age 0+ Chinook was estimated at 16,870 in 2007. Migration timing was bimodal with roughly 24% emigrating as fry between February and April; the remaining emigrated as parr between May and June. Weekly Chinook fork lengths averaged 38.0 mm in February, and grew to average over 80 mm by mid-May. Egg-to-migrant survival was estimated at 2.9%.

Coho production was estimated at 25,143 smolts and cutthroat production at 3,869 smolts. During the 2007 trapping season, only one steelhead was caught in the Bear Creek screw trap.

Introduction

The decline of sockeye salmon returns to Lake Washington from the mid 1980s to 1991 prompted managers to begin investigating the cause(s). Although over 500,000 fish returned in 1988, by 1991 less than 100,000 sockeye returned through the Ballard Locks. In 1991, a broad-based group was formed to address this decline. Resource managers developed a program involving population monitoring in combination with an artificial production program. Information generated by these efforts, which continued through 2007, will be used to improve management of Lake Washington sockeye salmon.

Sockeye life history can be partitioned into a freshwater incubation and rearing phase and a marine rearing phase. Existing management information indicated that marine survival had averaged 11%, varying eight-fold (2.6% to 21.4%), for the 1967 to 1993 broods with no apparent decline over the data set (WDFW unpublished data). In contrast, survival in freshwater, as measured by smolts per spawner rates, declined over this same period.

During the freshwater phase, the majority of sockeye production involves two freshwater habitats: the stream, where spawning, egg incubation, fry emergence, and migration to the lake occurs; and the lake, where virtually all of the juveniles rear for one year before emigrating to the ocean as smolts. Measuring survival rates in both of these habitats will help explain causes for population variation. In 1992, trapping gear and methodology were developed to estimate natural-origin and hatchery sockeye fry production from the Cedar River and monitoring began. To assess sockeye fry production on a basin scale, monitoring sockeye fry production in the Sammamish Slough began in 1997 and since 1999 has continued in Bear Creek.

The National Marine Fisheries Service listed the Puget Sound Chinook ESU under the Endangered Species Act as a threatened species in March 1999. In the Lake Washington watershed, it was evident that recovery-planning efforts would be more effective if more were known about the habitat requirements, early life history, freshwater productivity, and survival of Chinook salmon. Baseline information was available on the number of spawners, but adult counts provide little insight into survival during specific life stages. Estimating the number of juvenile migrants facilitates separating survival into two components: egg-to-migrant (freshwater) and migrant-to-returning adult. In the Lake Washington system, this later stage includes passage through the lake, Ship Canal, Ballard Locks, and the marine environment. This provides a more direct accounting of the role that stream habitats play in regulating salmon production (Seiler *et al.* 1981, Cramer *et al.* 1999).

The downstream migrant evaluations conducted in the Cedar River and Bear Creek in 1999 were the first in the Lake Washington basin directed at estimating the production of natural-origin juvenile Chinook (Seiler et al. 2003). Since the Chinook migration includes newly emerged fry and later, larger parr, two different gear types were employed. The fry trap gently captures fry but larger migrants can avoid it. For the later-timed parr migration a rotary screw trap was installed.

Cedar River

Since 1992, we have operated a floating inclined-plane (fry) trap in the lower Cedar River to evaluate the production of natural-origin and hatchery sockeye fry. Production of sockeye fry at the Landsburg Hatchery on the Cedar River began with the 1991 brood. Released in 1992, this brood and all subsequent sockeye incubated at this hatchery, have been identified with thermally-induced otolith-marks (Volk *et al.* 1990). In 1995, we evaluated the effect of flow on survival by releasing ten hatchery groups over a range of flows. Results demonstrated that in-river fry survival is largely a function of flow (Seiler and Kishimoto 1996).

We have also determined that over the sixteen broods measured, survival from egg deposition to fry emigration is largely a function of the severity of peak flows in the Cedar River during the egg incubation period. Therefore, over the range of spawning population levels that have been evaluated thus far, the numbers of natural-origin sockeye fry entering Lake Washington are the product of the number of eggs deposited and the flow-affected survival rates during incubation and migration.

In Summer 1998, the lower Cedar River was dredged to reduce the flooding potential (USACE 1997). This project lowered the streambed and created a wider and deeper channel, which reduced the velocity to near zero where the fry trap was located (R.M. 0.25). This dramatic change in the channel required moving the trap location upstream in 1999 and 2000. In addition, the trapping program was extended in 1999 to also evaluate the production of juvenile Chinook (Seiler *et al.* 2003). To effectively capture larger Chinook, in addition to the fry trap, a different gear type (a screw trap) was operated in faster water. Concurrent operation of the fry and screw traps assessed the capture and size biases of each trap.

Bear Creek

In 1997 and 1998, a downstream migrant trap was operated in the Sammamish Slough at Bothell to estimate the contribution of sockeye fry to Lake Washington from the Sammamish portion of the watershed. While this operation successfully estimated sockeye fry production, velocities in the Sammamish were too low to capture migrants larger than sockeye fry. Therefore, assessing the production of Chinook and other migrants required selecting a trapping location with sufficient velocity.

Big Bear Creek, also referred to as Bear Creek, is the most heavily spawned tributary in the Sammamish watershed. In past years, sockeye have returned in excess of 50,000 spawners. In more recent years, since trapping began, escapement has ranged from 1,449 to 60,000 spawners, with a median return of 8,170 sockeye. Therefore, in 1999, the migrant trapping operation was moved downstream to the lower end of this stream where velocities were high enough to capture larger migrants. In addition to estimating Chinook and sockeye production, higher velocities also enabled estimating the production of coho, steelhead and cutthroat smolts.

Goals and Objectives

The overall goal of this project is to quantify the downstream migrant populations of sockeye, Chinook and coho salmon and steelhead and cutthroat trout from the Cedar River and Bear Creek. In addition to estimating the daily migration for each species, describing their size at time and collecting additional biological data will enable accomplishing the following objectives.

Chinook

1. **Estimate in-river survival.** Relating total migrant production to the estimated egg deposition estimates in-river (egg-to-migrant) survival. Over time, we will correlate this rate among broods with such factors as spawner abundance, flows, and habitat condition.
2. **Estimate fry and smolt productions.** Relating the proportions of fry and parr to brood specific factors will identify production determinants.
3. **Estimate lake/marine survival of natural production.** Relating subsequent adult returns to a brood's juvenile production will estimate survival through the lake, the Ballard Locks, and the marine environment.
4. **Tag natural-origin Chinook.** Tagging natural-origin Chinook emigrating from the Cedar River and Bear Creek with PIT tags will assess survival through the lake system.

Sockeye

1. **Estimate survival of natural production.** Relating the estimate of natural-origin fry produced to the estimated egg deposition measures the overall success of natural spawning. Significant variation in this rate among broods, as a function of spawner abundance, predator populations, and flows will be evaluated to assess stream carrying capacity and the relative importance of production determinants.
2. **Estimate the season total of fry entering the lake.** Relating the combined estimate of natural-origin and hatchery fry to the smolt production the following spring will measure rearing survival within the lake. Over time this information will help assess predation rates and the lake's carrying capacity. Relating brood year adult returns to the total fry production measures overall survival through the lake and marine environments.
3. **Estimate incidence of hatchery fry in the population at lake entry (Cedar River).** Comparing this rate with the incidence of hatchery fish in the population at later life stages (smolts and adults) will assess relative hatchery and natural-origin survival rates.
4. **Develop migration timing of natural-origin and hatchery fry.** Comparing the difference between natural-origin timing and hatchery fry releases with subsequent survival to return rates will contribute to the adaptive management process guiding Cedar River Hatchery sockeye fry production.

Coho, Cutthroat and Steelhead

Quantifying the annual production of these smolt populations will help measure the ecosystem health of the Cedar River and Bear Creek. Population levels and ratios between these species are indicative of habitat condition and performance of fisheries management.

Methods

Trapping Gear and Operation

Cedar River

In each year since 1999, two traps were operated in the lower Cedar River during the spring out-migration period. A small floating inclined-plane (fry) trap was operated in late winter through spring to capture a proportion of the migrating sockeye and Chinook fry emigrating during this period. The size and placement of this trap was chosen to avoid capturing yearling migrants and to avoid predation in the trap. A floating rotary screw trap was operated during the early spring to summer months to assess the migration of Chinook, coho, steelhead, and cutthroat. Because this trap was employed to capture larger migrants that would prey on sockeye fry, the live box was designed so as not to retain sockeye fry. Together, these traps enabled estimating the production of each species while minimizing mortality.

Fry Trap

The fry 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 40x13 ft steel pontoon barge. Fish are separated from the water via a perforated aluminum plate (33 - 1/8 in. holes per in^2). The structure resembles the larger traps we use to capture juvenile salmonids in the Chehalis and Skagit rivers, which are described in Seiler *et al.* 1981. Lowered to a depth of 16 inches, each scoop trap screens a cross-sectional area of 4 ft^2. The trap was positioned at RM 0.7, just downstream of the South Boeing Bridge. The fry trap was fished off the east bank, between the shoreline and eight feet from the bank similar to the 2006 season. Two scoop traps were fished throughout the season except during 21 nights when only one trap fished due to high flows and debris loads.

Trap operation began on January 18, and operated 93 nights from mid-January to mid-June. During each night of operation, trapping began before dusk and continued past dawn. Although most of the downstream migration occurred at night, trapping was conducted during several daylight intervals to assess daytime movement. Captured fish were removed from the trap, identified by species, and counted each hour. Large sockeye fry catches were counted using an electronic counter. The electronic count was divided by an adjustment factor (96.4%) to estimate the actual catch. As in previous years, this adjustment factor was found through calibration testing.

Screw Trap

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). The trap was located approximately 300 yds downstream of the Logan Street Bridge (approximately RM 0.9), similar to 2006. In previous years, the trap had been positioned just upstream of the Logan Street Bridge. Bed aggradations during fall flow events in 2006 made this location unsuitable for trap operation. Although this site did not provide for efficient trapping in 2006, after surveying the lower river, this site still afforded the best combination of trapping conditions, security, and safety available for effective trap operation. The screw trap was operated nearly continuously from mid-April through May with one brief period when trapping was suspended for repair, and three separate periods (April 19, May 29 and June 4), when debris stopped the trap. From May 30 through July, trapping was suspended during the daylight hours due to low catch rates. The catches were enumerated at dusk and in the early morning in order to discern diel movements. Spring flows were low and due to the bed aggradations, there was no defined channel to trap in resulting in extremely low catches. On May 30, four 4x8 feet perforated plate panels were placed in the river leading upstream off the east pontoon at roughly a 15-degree angle in attempt to increase catch and water velocity flowing into the trap. On June 6, a wire mesh screen was installed on the west side of the trap, in a similar fashion as the east side, in attempted to further lead fish into the trap. Higher flows on June 13 caused two of the east side panels to wash downstream. They were replaced the following day, however, the other two panels washed out the same night. The trap fished with two panels until June 19, when all panels were washed out. Two panels were reinstalled on June 20, and the trap fished this way for the rest of the season. All Chinook, coho, steelhead, and cutthroat smolts were enumerated by species and randomly sampled for size (fork length).

Bear Creek

As with the Cedar River, out-migrating salmonids were captured using two traps in lower Bear Creek. A fry trap was used to capture sockeye and Chinook fry early in the trapping season. This trap was replaced with a screw trap in early April to capture Chinook, coho, steelhead, and cutthroat.

Fry Trap

The fry trap used in Bear Creek was identical to that employed in the Cedar River. A single scoop trap was suspended from a 30x12 ft steel pontoon barge positioned approximately 100 yds downstream of Redmond Way, below the railroad trestle in the middle of the channel. Trapping began in early February and ended in mid-April. On nearly every date the trap was operated, trapping began before dusk and continued past dawn. Captured fish were removed from the trap at hourly to several hour intervals, depending on migration rates, and counted.

Screw Trap

On April 15, the fry trap was replaced with a 5 ft diameter screw trap. Screw trap operation began on April 16, and operated continuously through July 10, except for one outage due to debris on May 19. Catches were usually enumerated at dusk and in the early morning. All Chinook, coho, steelhead, and cutthroat smolts were enumerated by species and randomly sampled for size (fork length).

Mark Recapture Groups

Cedar River

Fry Trap

Capture rates for sockeye fry in the Cedar River fry trap were estimated by marking, releasing, and recovering marked fry. Groups varying between 134 and 2,998 marked sockeye fry were released at the Logan Street Bridge (R.M. 1.1) over 60 nights throughout the season. Fry captured the previous night or in the early hours of the night were marked in a solution of Bismarck brown dye (14 ppm for 1.5 hours). Marked fry were distributed across the middle of the channel from the bridge.

Screw Trap

Chinook parr and coho smolts were estimated using mark-recapture data from groups released upstream of the trap. Trap efficiency tests were conducted by aggregating marked fish released and recovered over weekly or longer time strata. Due to low catches, adequate numbers of fish were not available for large releases as done in previous years. Within each stratum, releases occurred over multiple-, one- or two-day intervals, varying from 1 to 201 juveniles of each species per release. Fish were anesthetized in a solution of MS-222 and marked with alternating partial upper and lower vertical and horizontal partial-caudal fin-clips or tagged with PIT tags (Chinook and coho). Marks were changed at weekly intervals. Marked fish were allowed to recover from the anesthetic during the day in perforated buckets suspended in calm river water. In the evening, the groups were released from the Williams Avenue Bridge located roughly 550-yds upstream. During trap checks, catches were examined for marks or tags.

Bear Creek

Fry Trap

In Bear Creek, fry trap capture rates for sockeye were estimated by releasing groups of marked sockeye fry, ranging from 100 to 470 sockeye, from the Redmond Way Bridge on 36 nights over the season. As in the Cedar River, fry captured the previous night or in the early hours of the night were marked in a solution of Bismarck brown dye (14 ppm for 1.5 hours).

Screw Trap

Capture efficiency for the screw trap was estimated for Chinook, coho, and cutthroat smolts using the same approach described for the Cedar River screw trap. Mark groups ranged from 1 to 75 of each species and were released from the Redmond Way Bridge.

Production Estimate

Production estimates for most species were made using stratified mark-recapture approaches. The Petersen estimate, modified by Chapman (1951), is often used to estimate juvenile salmonid abundance. Abundance during time period *i* is estimated by;

$$\hat{U}_i = \frac{(u_i + 1)(M_i + 1)}{(m_i + 1)} - 1 \qquad \text{Equation 1}$$

where:

U_i = Migration of unmarked fish past the trap during time period i,

u_i = Catch of unmarked fish during time period i,

M_i = Marked fish released above the trap during time period i, and

m_i = Marked fish recaptured during time period i.

Seber (1982) provides an approximate unbiased estimate of the variance:

$$V(\hat{U}_i) = \frac{(M+1)(u+1)(M-m)(u-m)}{(m+1)^2(m+2)} \qquad \text{Equation 2}$$

Total production over the entire juvenile salmonid outmigration is estimated by;

$$\hat{N} = \sum_{i-1}^{n} \hat{U}_i$$

Equation 3

Similarly, the variance of N is estimated by the sum of the variances for U_i. The normal confidence interval about N was calculated using:

$$\hat{N}_{95\%ci} = \hat{N} \pm 1.96\sqrt{V(\hat{N})}$$

Equation 4

This approach assumes that marked fish and unmarked fish have the same probability of capture during each fishing period. In some cases, however, recaptures of marked fish may occur during a relatively short period (e.g. a few hours after release), whereas the unmarked catches they represent may occur over a longer period. If trapping is suspended during the period when only unmarked fish are passing the trap, the catch of unmarked fish must be estimated for the abundance estimator to be valid. In this case $\hat{u}_i$ is substituted for u_i in Equation 1. The variance, $V(\hat{U}_i)$, is now estimated using (Ryding pers comm.2006, see Appendix A for derivation);

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

Equation 5

In other cases, the recapture of marked fish occurred over a prolonged period; including subsequent fishing periods (e.g. *i+1, i+2*, etc.). Where this occurred, the outmigration data was analyzed using the maximum likelihood estimator for stratified populations developed by Darroch (1961) as illustrated by Seber (1982). The software used in this analysis is a program called DARR (Darroch Analysis with Rank Reduction) developed by Bjorkstedt (2000). DARR 2.0 was used in this analysis and is an improved version of the original program (Bjorkstedt 2005).

In a temporally stratified study fish are marked and released in s tagging strata, and marked and unmarked fish are recovered in t recovery strata. The probability that a fish tagged in the i^{th} period, will be captured in the j^{th} period, is the joint probability (π_{ij}) that an individual released in period i will resume migration and is susceptible to capture during period j (migration probability θ_{ij}) and is captured during period j (capture probability p_j). The joint probability is $\pi_{ij} = \theta_{ij}\, p_j$. Darroch (1961) provided a maximum likelihood estimator for obtaining the number of emigrating juvenile fish during the *jth* recovery period, n_j, where $s = t$ and the rows of $\mathbf{m},\{m_i\}$, are mutually independent and

m_i ~ multinomial (M_i, π_{ij})
u_j ~ binomial (n_j, p_j)

where $i = 1, 2, 3, \ldots s$, and $j = 1,2,3,\ldots t$.

Data are arranged in matrices as

$$\mathbf{u} = \begin{bmatrix} u_1 \\ u_2 \\ u_3 \\ u_4 \end{bmatrix}, \quad \mathbf{M} = \begin{bmatrix} M_1 \\ M_2 \\ M_3 \\ M_4 \end{bmatrix}, \quad \mathbf{m} = \begin{pmatrix} m_{11} & m_{12} & \dots & m_{1t} \\ 0 & m_{22} & \dots & m_{2t} \\ \dots & \dots & \dots & \dots \\ 0 & \dots & 0 & m_{st} \end{pmatrix}$$

The capture probability or the trap efficiency for each period is estimated as the proportion of marked fish that are recaptured from the matrices :

$$P = p^{-1} = m^{-1}M$$

Equation 6

Counts of unmarked fish are expanded to estimates of abundance

$$\hat{U} = D_u P$$

Equation 7

where:

m^{-1} = the matrix inverse of the recapture matrix,
D_u = the matrix with elements u arranged along the diagonal with zeros elsewhere, and
$\hat{U}$ = the number of unmarked fish passing the trap during the recovery stratum.

The total abundance is estimated by summing the estimated number of unmarked individuals.

$$\hat{N} = \sum \hat{U}_i$$

Equation 8

The matrix Θ, which describes the probability that an individual marked and released during one period will resume migration during that or another period, is estimated by;

$$\hat{\Theta} = D_M^{-1} m D_{\hat{p}}$$

Equation 9

The variance-covariance matrix for ***U*** is approximated by:

$$Cov(\hat{U}) \approx D_u \Theta^{-1} D_\mu D_m^{-1} (\theta')^{-1} D_u + D_u (D_p - I)$$

Equation 10

where:

D_μ = a diagonal matrix with elements $\mu_i = \sum_j \left(\Theta_{ij} / p_j\right) - 1$, and

I = an identity matrix

The estimated variance is for the total population estimate and is obtained by summing the elements of the variance-covariance matrix for the stratum estimates. Normal confidence limits were calculated from Equation 4.

Initial data inputs to DARR consisted of a matrix of marks released, recaptures, and captures by week. DARR 2.0 applies a series of algorithms to aggregate data to yield an admissible estimate of abundance while preserving as much of the data structure as possible (Bjorkstedt 2005).

Cedar River

Fry Trap

Sockeye

Sockeye mark recaptures always occurred within hours of their release, yet these efficiency tests were used to represent longer fishing periods that often included periods of suspended trapping; therefore, migration during each stratum was estimated using Chapman's modification of the Petersen estimate. Equations 2 and 5 were used for the variance estimates.

To estimate nighttime catch that would have occurred when trapping was suspended, straight-line interpolation based on the catch from adjacent nights was used. Where the estimate was made for only a single night, the variance was estimated by the variance of the mean (i.e., the interpolated catch) (Equation 11). However if one or both nightly catches, u_i, used to interpolate the catch during the unfished period also were estimated then Equation 12 was used.

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

Equation 11

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

Equation 12

where:

n = Number of sample nights used in the interpolation,

u_i = Nightly catches of unmarked fish used to estimate the un-fished interval,

$\bar{u}_i$ = Interpolated nightly catch estimate, and

$\hat{u}_i$ = Estimated nightly catches of unmarked fish used to estimate the un-fished interval.

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

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

Equation 13

Sockeye catch was also estimated when the trap was not operated continuously through the entire nighttime period. Where the trap was operated intermittently through the night, catch during the un-fished interval(s) ($\hat{u}_u$) was (were) estimated by;

$$\hat{u}_z = T_z \overline{R}$$

Equation 14

where;

T_z = Hours during non-fishing period z, and

$\overline{R}$ = Mean Catch Rate (fish/hour) from adjacent fished periods.

The variance was estimated by;

$$Var(\hat{u}_z) = T_z^{\ 2} Var(\overline{R})$$

Equation 15

The total catch of unmarked fish on night *i* was estimated by the sum of the catches from the fished periods, *f*, and un-fished periods, *z*. The variance of the nightly catch was estimated by the sum of the variances for the un-fished periods, *z*, and during night *i*.

Hatchery And Natural-Origin Catch Composition

On hatchery release nights that were fished, natural-origin and hatchery sockeye fry catches were estimated based on one of three methods, listed below in their order of preference (accuracy):

1. During hatchery releases on February 26, March 8 and 12, otolith samples were taken. The number of hatchery sockeye in the nightly catch was estimated by:

   $$\hat{u}_{hi} = O_{hi} u_i$$

   Equation 16

   where:

   $\hat{u}_{hi}$ = Estimated number of hatchery sockeye caught during night i, and

   O_{hi} = The proportion of otolith marked hatchery sockeye in the sample from night i.

   Natural-origin sockeye were estimated by subtracting the estimated hatchery catch, $\hat{u}_{hi}$, from the actual catch of unmarked sockeye, u_i.

2. For hatchery release nights when otolith sampling was not conducted, the catch of natural-origin sockeye from the previous and following nights were used to interpolate the natural-origin catch on the hatchery release night. Hatchery catch was then estimated by subtracting natural-origin catch from the total nightly catch. This approach was used where natural-origin sockeye catches were generally consistent from night to night and estimates of

hatchery catch were greater than zero. This method was applied to hatchery releases occurring on February 7, 8, and 16.

3. Where straight-line interpolation yielded hatchery catches less than zero, we estimated hatchery and natural-origin catch by comparing the nightly timing distributions between hatchery release nights and the surrounding nights when only natural-origin fish were migrating. Recognizing that there is a delay between when the nightly migration of natural-origin fish began to when the hatchery fish reached the trap, we compared the early evening catch of natural-origin sockeye to the total catch of natural-origin sockeye from nights adjacent to the hatchery release night. This proportion was applied to the early evening natural-origin sockeye catches on hatchery release nights to estimate the expected nightly catch of natural-origin sockeye. The catch of hatchery sockeye was estimated by subtracting the estimated natural-origin catch from the actual total nightly catch. This approach was taken on February 20 and 21.

Recognized that the survival of hatchery sockeye is affected by stream discharge (Seiler and Kishimoto 1996), we also evaluated survival using a flow-based hatchery release survival model developed from previous years data (1995, 2001-2003) when intensive otolith sampling was conducted to estimate hatchery fry survival. The final results yielded were not used as it produced erroneous estimated hatchery and natural-origin catches, likely due to such extreme flows experienced during release nights.

Day:Night Catch Rates

Daytime sockeye catches were estimated by multiplying the nighttime catch by the proportion of the 24-hour catch estimated to have been caught during the day. Previously the day catch rate was estimated by averaging the rates measured during the current season. During the 2007 trapping season, flows were extremely high compared to previous seasons trapped and are believed to have greatly influenced the range of our day catch ratios. Thus, we chose to stratify by flow and average day catch rates from the 2001 to 2007 trapping season and applying the appropriate day catch rate to the daily catch based on the daily average flow. This proportion, (F_d), was found by;

$$F_d = \frac{T_d}{\overline{Q}_d^{-1} T_n + T_d} \qquad \text{Equation 17}$$

and its variance by;

$$Var(F_d) = \frac{Var(\overline{Q}_d) T_n^{\,2} T_d^{\,2}}{\overline{Q}_d^{4} \left(\overline{Q}_d^{-1} T_n + T_d \right)} \qquad \text{Equation 18}$$

where;

T_n = Hours of night during 24 hour period,

T_d = Hours of day during 24 hour period, and

$\overline{Q}_d$ =Flow based average day/night catch ratio.

The variance for each daytime catch was estimated using the delta method (Goodman 1960);

$$Var(\hat{u}_d) = \hat{u}_i^{\,2} Var(F_d) + Var(\hat{u}_i) F_d^{\,2} - Var(\hat{u}_i) Var(F_d)$$

Equation 19

Survival of Cedar River naturally-produced sockeye fry-to-lake entry is the ratio of the natural-origin fry migration estimate to an estimate of potential egg deposition (PED).

Chinook

Efficiency tests conducted with sockeye fry were used to estimate efficiencies for Chinook catches in the fry trap. Therefore, procedures used to estimate the juvenile Chinook migration during fry trap operation were identical to those described for sockeye fry.

Screw Trap

Chinook, Coho, and Trout

Trap efficiency tests were conducted using marked or tagged Chinook, coho, and trout. Since these tests were conducted on a daily or nearly daily schedule and recoveries were protracted over periods of up to two weeks, we used Darroch's maximum likelihood estimator for stratified populations to estimate abundances for these species. Alternating upper and lower caudal vertical and horizontal clips were changed at approximately weekly intervals until early May. On May 7, we began PIT tagging Chinook three days per week and fin marking on the other days. Beginning June 6, PIT tags were placed in coho as well. The PIT tags enabled identification of individually tagged fish enabling stratification to be evaluated post-season.

Mark groups were stratified by clip prior to developing matrices for input into DARR 2.0. We allowed DARR to aggregate (re-stratify) data itself. The final matrices were developed by adjusting strata to reflect periods of similar river discharge. Production estimates and their variances were developed using Equations 6 – 10.

Bear Creek

Procedures used to estimate downstream migrant production for the fry trap and screw trap were nearly identical to those used on the Cedar River. Differences applied only to estimating the daytime catch. Whereas day catches in the Cedar River were estimated using day:night catch ratios ($\overline{Q}$), day catches in the Bear Creek fry trap were minimal and not estimated. The variances of interpolated catches from the fry trap were estimated using Equation 11 or 12.

Cedar River Results

Sockeye

Trap Operation

Fry trap operation began on January 18, and operated on 93 nights through the season until the last night of trapping on June 7. Five daytime trapping intervals were fished on March 13, 20, 27 and April 4 and 10.

On seven of the scheduled trapping nights, the trap did not operate continuously through the night due to excessive debris or stream flow. During those nights, the trap was operated at 10-minute intervals each hour.

Catch

During the first night of trap operation (January 18), 70 sockeye fry we caught during the fourteen hours trapped. Nightly catches increased and natural-origin catch peaked on February 11, with 12,110 natural-origin sockeye fry caught. Catches decreased thereafter, until the last night of trapping (June 7), when 40 fry were caught. The combined nightly catches of natural-origin sockeye for the season totaled 215,946 fry.

Diel Migration

While the vast majority of sockeye fry migrate at night, daytime trapping indicated small numbers of fry migrated during daylight. This season, there were five daylight intervals trapped to evaluate daytime migration: March 13, 20, 27, and April 4 and 10. An estimated 4,981 fry would have been captured had the trap fished during the day, a mere 1.5% of the season's total estimated catch. Flows were extremely high during these periods ranging from 950 cfs to 2,910 cfs and resulted in day catch rates ranging from 2.77% to 76.71%. Two of those days fished are believed to be inaccurate, either because they followed a hatchery release night or the surrounding nights and day were only partially fished due to high flows, therefore they were not included in our analysis. From past years, we believe that the range in catch rates this season did not reflect typical catch rates and were likely influenced by flow. Instead of using the average day catch rate measured this season, we stratified and averaged day catch rates from 2001 to 2007 by flow; 0-999cfs (0.83%), 1000-1,499 cfs (2.25%), and 1,500 cfs and greater (12.35%), and applied the appropriate stratum average to nightly catches based on daily average flow (Figure 2).

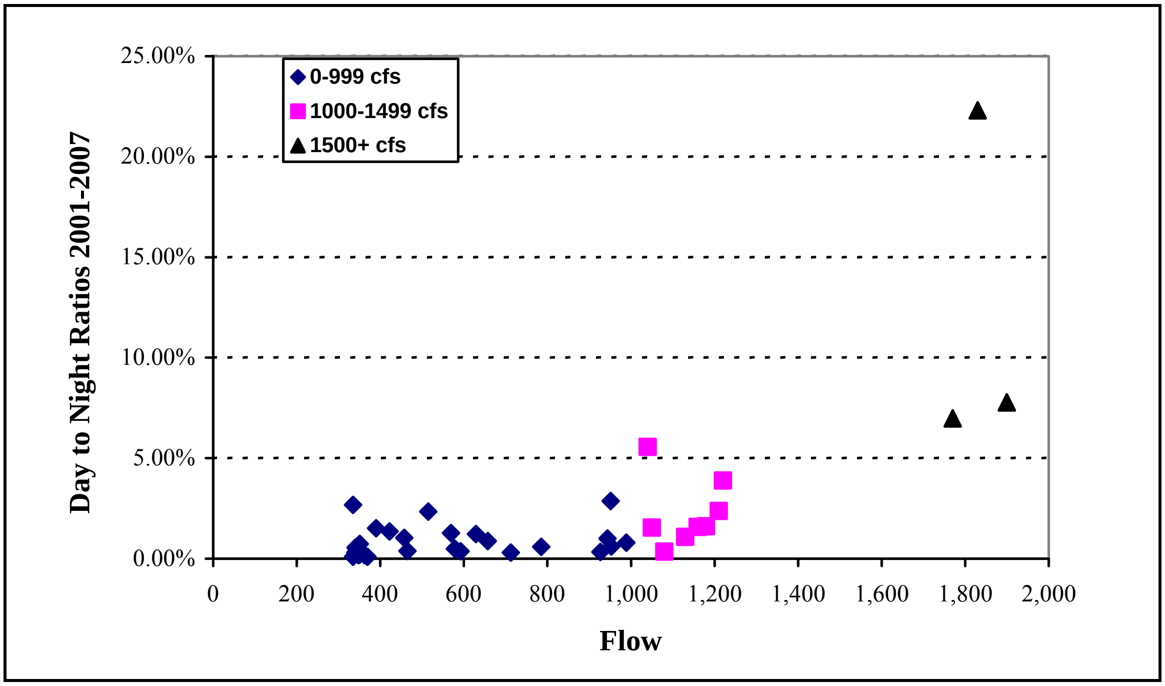

Figure 2. Day-to-night catch rate ratios of sockeye fry estimated using the night before and the night after the daytime interval, Cedar River fry trap, 2001-2007.

Catch Expansion

An estimate was made for the number of sockeye that may have been caught for the day and night periods not fished. Nights not fished were estimated by interpolation and day periods not fished were estimated using the day to night ratios explained above. Due to large amounts of debris, partial catches were expanded on seven nights. Had the trap fished continuously (day and night) from January 18 through June 7, we estimate an additional 110,826 fry would have been caught. With the addition of these fish to the actual catches, season catch total is projected at 326,773 sockeye in the fry trap.

Production Estimate

We calculated 19.57 million sockeye fry entered Lake Washington from the Cedar River in 2007 (Table 1, Figure 3). The total included 9.25 million natural-origin fry and 10.32 million hatchery-produced fry. Capture rates ranged from 1.2% to 11.5%. Logarithmic extrapolation was used to estimate fry migration before trapping started, January 1 to January 18, which resulted in an additional 14,198 natural-origin sockeye fry. Addition of this estimate accounts for approximately 0.2% of the total natural-origin estimate. Logarithmic extrapolation was also used to estimate migration through July 31, which totaled 14,610 fry, only 0.2% of the total natural-origin estimate. Our estimated coefficient of variation (CV) for the natural-origin migration was 3.9% with a 95% confidence interval of 8,538,229 to 9,954,238 sockeye fry.

Table 1. Estimated 2007 Cedar River natural-origin and hatchery sockeye fry migrations entering Lake Washington with 95% confidence intervals.

Component	Period	Dates	Estimated Migration	CI 95% Low	CI 95% High	CV	Proportion of Total
Natural Origin	Before Trapping	January 1 - 17	14,198	11,652	16,743	9.1%	0.2%
	During Trapping	January 18- June 7	9,217,426	8,509,426	9,925,425	3.9%	99.7%
	After Trapping	June 8- June 30	14,610	13,956	15,265	2.3%	0.2%
		Subtotal	**9,246,234**	**8,538,229**	**9,954,238**	**3.9%**	
Hatchery	Above Trap	February 7 - March 7	1,959,463				
	Below Trap	January 31 - March 19	8,364,000				
		Subtotal	**10,323,463**				
		Total	**19,569,697**				

Natural-Origin And Hatchery Timing

Releases of hatchery fry began on January 31, and continued through March 19 (Table 3). The median migration date for hatchery fry released upstream of the fry trap was February 16. The natural-origin fry migration was under way when trapping began on January 18. A number of migration peaks also occurred on February 9, February 17, March 8 and April 9. After another peak on April 22, the migration declined to low levels in May and June when trapping ended (Figure 4, Table 2). Median migration dates for natural-origin fry occurred on March 23.

Stream temperatures influence the length of the incubation period. After evaluating temperature data throughout the period of fry incubation and migration, it appears February stream temperatures best explain observed variation in migration timing ($r^2 = 0.58$) (Figure 5). February stream temperatures averaged 7.0° C in 2007, somewhat warmer than the 15-year average (6.2° C), which in turn produced a median migration date fairly close to the 15-year average median migration date (Table 2, Figure 5). The 2001 fry migration was treated as an outlier due to extreme low flows that facilitated predation and an earthquake, which triggered a landslide that temporarily blocked flow and may have caused a significant mortality in the later-timed portion of the fry production.

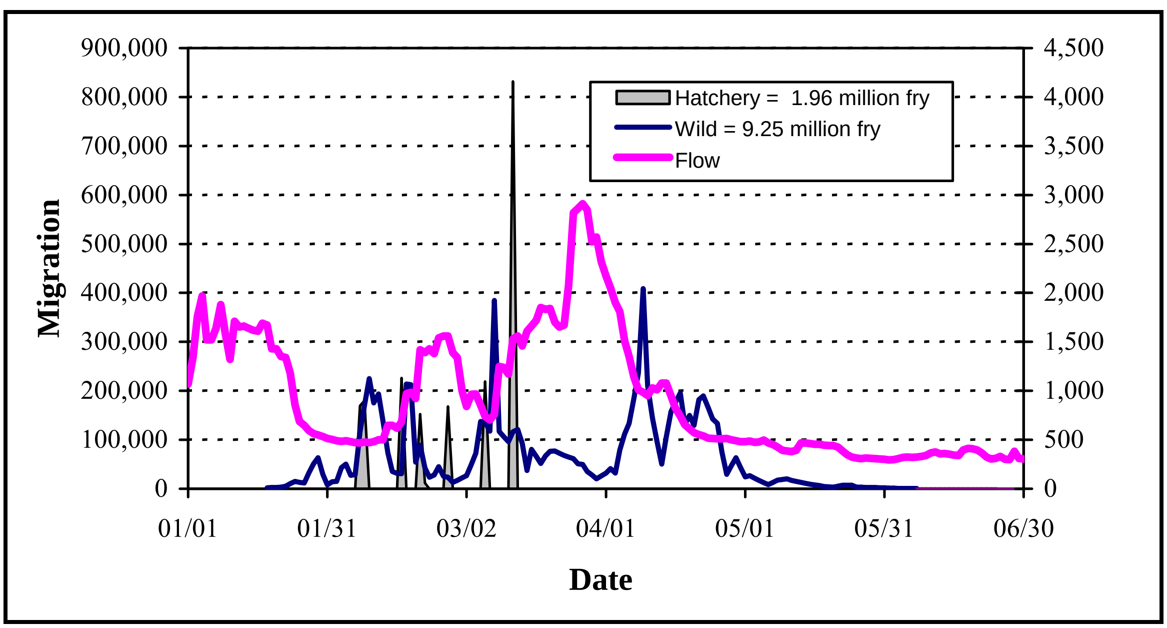

Figure 3. Estimated daily migration of natural-origin and hatchery Cedar River sockeye fry into Lake Washington and daily average flow, 2007.

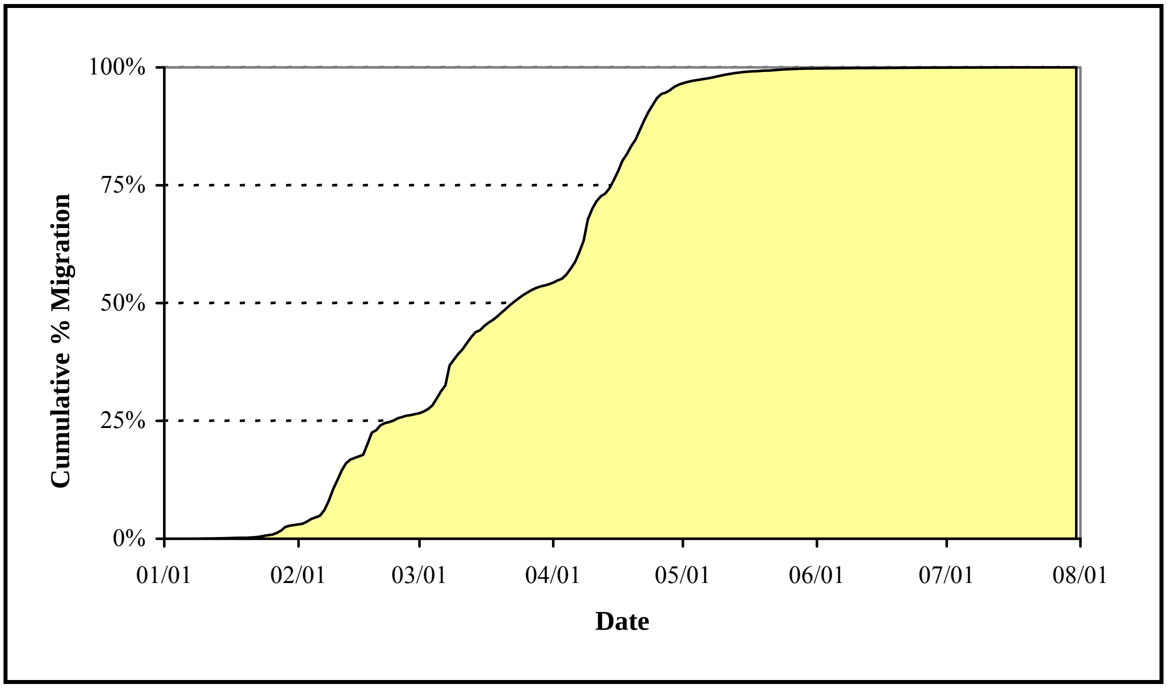

Figure 4. Cumulative natural-origin sockeye fry migration timing, Cedar River 2007.

Table 2. Median migration dates of natural-origin, hatchery and total (combined) sockeye fry populations, Cedar River.

Brood Year i	Trap Year i+1	Median Migration Date Wild	Hatchery	Combined	Difference (days) W-H
1991	1992	03/18	02/28	03/12	19
1992	1993	03/27	03/07	03/25	20
1993	1994	03/29	03/21	03/26	8
1994	1995	04/05	03/17	03/29	19
1995	1996	04/07	02/26	02/28	41
1996	1997	04/07	02/20	03/16	46
1997	1998	03/11	02/23	03/06	16
1998	1999	03/30	03/03	03/15	27
1999	2000	03/27	02/23	03/20	32
2000	2001	03/10	02/23	03/08	15
2001	2002	03/25	03/04	03/19	21
2002	2003	03/08	02/24	03/03	12
2003	2004	03/21	02/23	03/15	26
2004	2005	03/02	02/01	02/28	29
2005	2006	03/20	02/23	03/14	25
2006	2007	03/23	02/16	03/12	35
	Average	03/22	02/26	03/13	24

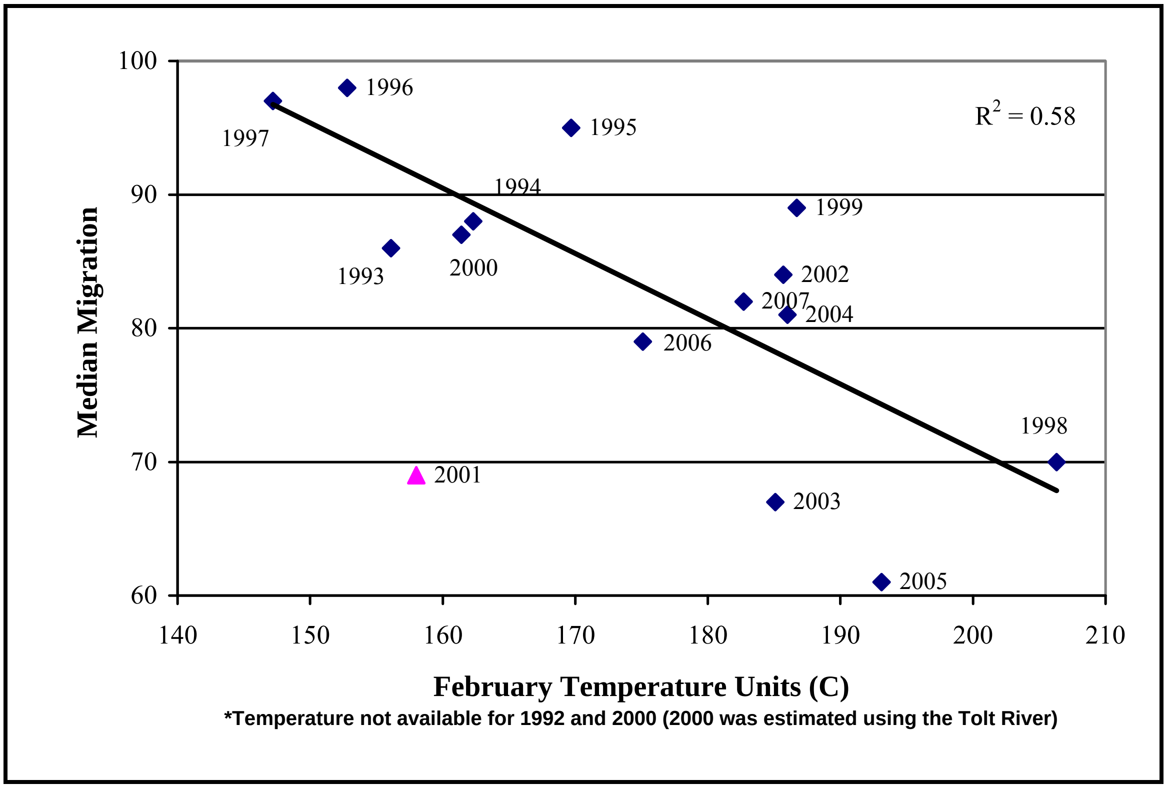

Figure 5. Linear regression of median migration Julian Calendar date for natural-origin Cedar River sockeye fry as a function of the sum of daily average temperatures from February 1-28 (USGS Renton Gaging Station #12119000) for migration years 1993-2007, with 2001 as an outlier.

Survival of Hatchery Release Groups

Over the season, 11,832,000 hatchery-produced sockeye fry were released into the Cedar River (Table 3). On six nights between February 7 and March 12, 2,369,000 sockeye fry were released from a train trestle at R.M.13.5. Releases at Landsburg (R.M 21.8) occurred on two nights, from February 8 to March 20, totaling 1,099,000 sockeye fry. The remaining 8,364,000 sockeye fry were released in eleven separate releases below the trap at R.M. 0.1.

Survival rates estimated for the groups of fry released above the trap ranged from 5.61% to 148.83%, and averaged 61.07% (Table 4). The average, without survivals greater than 100%, is 40.61%. All but one of the releases (February 16) above the trap consisted of fed fry. Flows were extremely high throughout the season and greatly affected our trap efficiency and ability to estimate survival of hatchery releases. Other factors that may also have contributed to the poor performance of these groups include poor condition or inaccurate counts at release, inaccurate estimation of hatchery and natural-origin catch composition, or poor adjustment of hatchery fry to the dynamic, high-energy environment into which they were released.

Table 3. Hatchery sockeye fry released into the Cedar River in 2007.

Release Date	Number Released by Site Mid-River (RM 13.5)	Landsburg (RM 21.8)	Below Trap (RM 0.1)
01/31/2007			786,000
02/01/2007			1,023,000
02/07/2007	545,000		
02/08/2007		579,000	
02/12/2007			1,038,000
02/13/2007			1,021,000
02/15/2007			508,000
02/16/2007	508,000		
02/20/2007		520,000	1,021,000
02/21/2007	212,000		1,055,000
02/26/2007	231,000		
02/27/2007			536,000
03/05/2007			513,000
03/06/2007	314,000		
03/07/2007			793,000
03/12/2007	559,000		
03/19/2007			70,000
Total	**2,369,000**	**1,099,000**	**8,364,000**

Table 4. In-river survival estimates of hatchery sockeye fry released above the trap, Cedar River 2007.

Release Date	Sockeye Released	Daily Avg. Flow	Estimated Daily Migration	Survival
02/07/2007[a]	545,000	467	169,537	31.1%
02/08/2007[a]	579,000	479	179,733	31.0%
02/16/2007[a]	508,000	682	226,494	44.6%
02/20/2007[b]	520,000	1,420	152,646	29.4%
02/21/2007[b]	212,000	1,390	11,888	5.6%
02/26/2007[c]	231,000	1,560	168,166	72.8%
03/06/2007[c]	314,000	738	219,039	69.8%
03/12/2007[c]	559,000	1,530	831,960	148.8%
Sum	3,468,000		1,959,463	
Average				54.1%

<u>**Note**</u>: [a] Survival estimated using interpolation
[b] Survival estimated using nightly timing migrations
[c] Survival estimated using otolith samples

A variety of methods were used to estimate the number of hatchery fry in the nightly catch (Table 5). Otolith sampling was the best method. It directly estimates hatchery and natural-origin fish in the catch. However, funding was not sufficient to analyze otolith samples for every release. For releases where otolith analysis was not conducted, we used the most precise indirect method available that provided a plausible estimate (e.g. survival between zero and about 100%).

Table 5. Different methods for estimating survival of hatchery sockeye fry releases from Landsburg Hatchery, Cedar River 2007.

			Daily Interpolation			Regression			Nightly timing			Otolith		
	Prelim.	Total	Estimated Catch		Hat.	Estimated Catch		Hat.	Estimated Catch		Hat.	Estimated Catch		Hat.
Date	Flow	Est. Catch	Wild	Hat.	Survival	Wild	Hat.	Survival	Wild	Hat.	Survival	Wild	Hat.	Survival
2/5	480	1,780												
2/6	472	2,669												
2/7	467	20,812	5,055	15,757	31.11%	127	20,685	40.84%	12,799	8,013	15.82%			
2/8	479	15,321	7,442	7,879	31.04%	4,672	10,649	41.96%						
2/9	470	9,829												
2/10	480	10,970												
2/11	499	12,110												
2/12	499	12,080												
2/13	649	5,445												
2/14	649	2,587												
2/15	619	12,001	2,574											
2/16	682	21,414	2,561	18,853	44.59%	-2,919	24,333	57.54%	12,410	9,004	21.29%			
2/17	970	11,975	2,548											
2/18	986	2,536												
2/19	921	620												
2/20	1,420	3,496	635	2,861	34.33%	-3,996	7,492	89.90%	1,050	2,446	29.36%			
2/21	1,390	596	666	-70	-4.08%	-932	1,528	88.96%	500	96	5.61%			
2/22	1,430	654	689											
2/23	1,380	712												
2/24	1,540	496												
2/25	1,560	279												
2/26	1,560	2,313	528	1,785	63.34%	-338	2,651	94.05%	779	1,534	54.43%	261	2,052	72.80%
2/27	1,390	777												
2/28	1,340	1,023												
3/1	1,000	1,327												
3/2	839	1,631												
3/3	964	3,014												
3/4	967	4,397												
3/5	853	9,132												
3/6	738	17,087	9,758	7,329	48.26%	7,819	9,268	61.03%	11,461	5,626	37.05%	6,493	10,594	69.76%
3/7	704	10,384												
3/8	759	6,109												
3/9	1,250	1,834												
3/10	1,240	1,671												
3/11	1,170	1,507												
3/12	1,530	5,114	1,496	3,618	157.86%	2,978	2,136	93.19%	3,574	1,540	67.19%	1,703	3,411	148.83%
3/13	1,560	1,484												
3/14	1,460	1,461												
3/15	1,610	541												

Note: Highlighted values are preferred methods for estimating hatchery survival on those dates.

The most accurate approach, otolith sampling, was used for the fed fry releases on February 26, March 6 and 12 (see Hatchery And Natural-Origin Catch Composition: Method 1). Survival was estimated at 72.80%, 69.76%, and 148.83%, respectively with nearly all of the fed fry emigrating on the night of release. The estimated survival of the March 12 release is likely a factor of low trap efficiency (0.41%), due to high flows. If the efficiency releases conducted during similarly high flows as those experienced on March 12 were averaged (0.80%) and applied to this release, survival would be lower and more comparable to those at similar flows (76.28%).

Interpolation of the natural-origin catch was used on three nights, February 7, 8, and 16, and estimated the survival of those hatchery releases at 31.11%, 31.04% and 44.59%, respectively (see Hatchery And Natural-Origin Catch Composition: Method 2). This approach was considered the most precise of the indirect methods, as it only assumed natural-origin migration rates were intermediary between those of the day preceding and following the release.

Estimating natural-origin and hatchery components through analysis of the nightly migration timing distribution was applied to data for two nights, February 20 and 21 (see Hatchery And Natural-Origin

Catch Composition: Method 3). This approach estimated survival of hatchery fish at 29.36% and 5.61%, respectively. This approach assumed the nightly hourly migration timing of naturally-produced fish was consistent over several days, which we felt was less certain than the assumption for the interpolation approach.

A flow-based regression model used to estimate survival in previous season was considered in estimating survival for releases but did not yield reasonable estimates for this season, possibly due to the extremely high flows experienced during hatchery releases. While this model was developed using otolith estimated survival rates, it performed poorly with some of the catch data from this year (e.g. actual catch less than predicted catch); therefore, we preferred using the in-season data rather than the model for most hatchery survival estimates.

Survival of hatchery releases below the trap was assumed to be 100%.

Egg-to-Migrant Survival of Naturally-Produced Fry

Overall egg-to-migrant survival of the 2006 brood sockeye was estimated at 5.9 % (Table 6). This rate is the ratio of 9.2 million natural-origin fry to an estimated potential egg deposition (PED) of 155.6 million eggs. This PED is based on an escapement estimate of 106,961 spawners (Steve Foley[a], pers comm), an assumed even sex ratio and an average fecundity of 2,910 (Figure 6). The estimate of fecundity was derived from the average number of eggs per female estimated during broodstock collection. This is the lowest fecundity observed since survival was estimated beginning 1991. In 2006, returning sockeye collected for broodstock appeared less fit. They were smaller, skinnier, and some females exhibited partial egg development in their skeins. It is likely that poor ocean conditions are to blame for the decrease in fecundity (Antipa pers. comm.).

The 2006 brood experienced the third lowest survival since 1991, likely a result of high flows during the incubation period. Regressing the survival estimates on peak brood year incubation flow resulted in a R^2 of 0.55 (Figure 6). The best fit for this data series was derived from fitting the data to an exponential equation ($y = ba^x$). This function generally describes an exponential decay in egg-to-migrant survival with increasing peak stream flow during the incubation period. As additional data are generated, we will continue to assess this model and others, to increase our understanding of the factors affecting natural-origin sockeye fry production from the Cedar River.

Table 6. Estimated egg-to-migrant survival of naturally-produced sockeye fry (using the AUC method to estimate spawners) in the Cedar River relative to peak mean daily flows during the incubation period as measured at the USGS Renton gage, brood years 1991-2006.

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

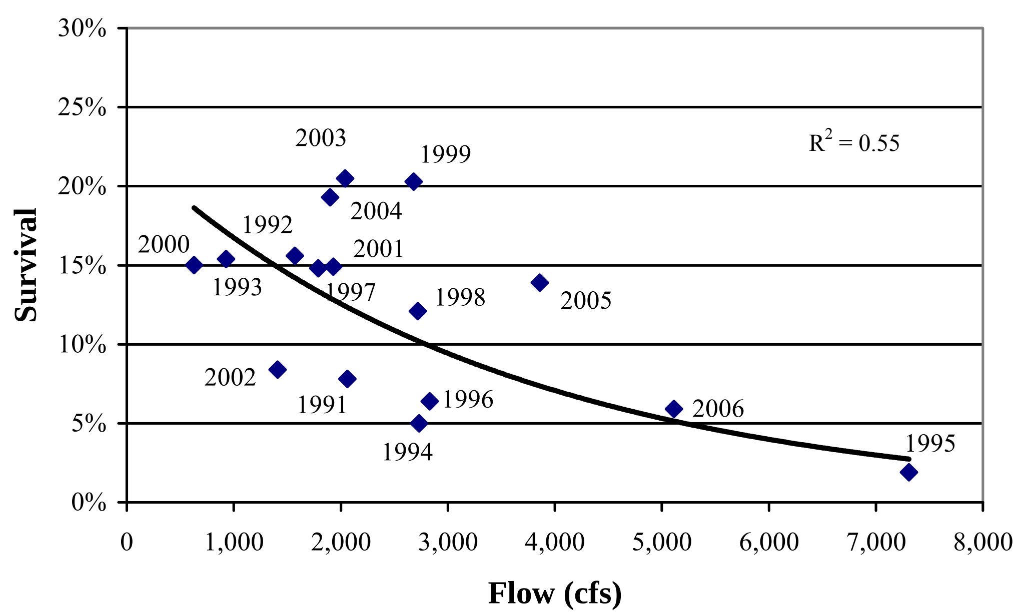

Figure 6. Exponential regression of natural-origin sockeye egg-to-migrant survival from brood years 1991 to 2006 as a function of peak flow during the winter egg incubation period, Cedar River.

Chinook

Catch

Fry Trap

On the first night of fry trap operation (January 18), 2 Chinook fry were caught. Catches increased quickly to peak at 113 fry on February 1, and then again at 161 fry on February 16. Thereafter, catch declined to average less than 27 Chinook fry per day for the remainder of the season. Five daytime intervals were fished throughout the season. Day to night catch rate ratios ranged from 0% to 15.48% and averaged 7.06% (Table 7). Over the season, a total of 1,743 Chinook were captured in the fry trap.

Screw Trap

Over the 97-day interval that the screw trap operated (April 18 through July 20), 878 unmarked natural-origin and 174 adipose fin-clipped (ad-marked) hatchery Chinook were caught. Only natural-origin Chinook catches were used to make the production estimate. From the first night of trapping to May 31 (six weeks), only 162 Chinook were captured, comprising 18% of the season total. However, in the first three weeks of June, 614 natural-origin Chinook parr were caught (71% of the season total). Nightly catches peaked on June 7 when 122 Chinook parr were caught. The remaining 12% of Chinook parr were caught between the last week of June and the end July.

Table 7. Day to night catch rate ratios of Chinook fry estimated at the Cedar River fry trap, 2007.

Nighttime					Daytime						
Start Date	Start Time	Hours	Catch	Catch/Hr	Start Date	Start Time	Hours	Catch	Catch/Hr	D:N Ratio	Flow (cfs)
12-Mar	1900	13	42	3.23	13-Mar	800	10	5	0.50	15.48%	1530
19-Mar	1900	13	13	1.00	20-Mar	800	11	0	0.00	0.00%	1830
20-Mar	1900	13	21	1.62							
Sum/Average		26	34	1.31							
26-Mar	2000	11	0	0.00	27-Mar	800	11	0	0.00	0.00%	2910
27-Mar	2000	11	20	1.82							
Sum/Average		22	20	0.91							
03-Apr	1900	12	4	0.33	04-Apr	700	12	2	0.17	10.81%	1900
04-Apr	1900	12	33	2.75							
Sum/Average		24	37	1.54							
09-Apr	2000	11	43	3.91	10-Apr	700	12	4	0.33	9.02%	951
10-Apr	1900	12	42	3.50							
Sum/Average		23	85	3.70							
									Average	7.06%	
									Variance	9.42E-04	

Catch Expansion

Fry Trap

An estimate was made for the number of Chinook that may have been caught for the day and night periods not fished. Daytime migration was estimated by using the average (7.06%) ratio of day/night catch rates measured during operation of the fry trap. Due to large amounts of debris, partial catches were expanded on seven nights. Had the trap fished continuously (day and night) from January 18 through June 7, an estimated 971 additional fry would have been caught. With the addition of these fish to the actual catches, season catch total is projected at 2,714 Chinook in the fry trap. Total catch used to calculate migration from January 18 through April 17, was estimated at 2,670 fry.

Production Estimate

Fry Trap

Capture rates for Chinook fry were assumed to be equivalent to that of marked sockeye fry released upstream of the trap, therefore sockeye mark-recapture data was used to estimate Chinook fry migration. As in the sockeye fry estimate, estimated catches, $\hat{u}$, were substituted for u in the equation. Fry migration was estimated at 109,016 Chinook fry for the period of January 18 through April 17 (Appendix B 2).

The fry trap and screw trap ran concurrently between April 18 and June 7, which provided independent daily estimates of Chinook migration. Daily estimates from each trap were summed by week and tested for equality using a Z-test. During the weeks of concurrent operation, differences were significant beginning week 18 and screw trap migration estimates were larger for all but week 16 ($\alpha = 0.05$) (Table 8). However, the mean fork length of Chinook caught in the screw trap during week 16 were significantly larger (2 sample t-test, α=0.05) (Figure 7) than those caught in the fry trap, which is less efficient for larger-sized migrants. Due to these differences we elected to use screw trap migration estimates beginning week 16 when the screw trap was installed, through the remainder of the season.

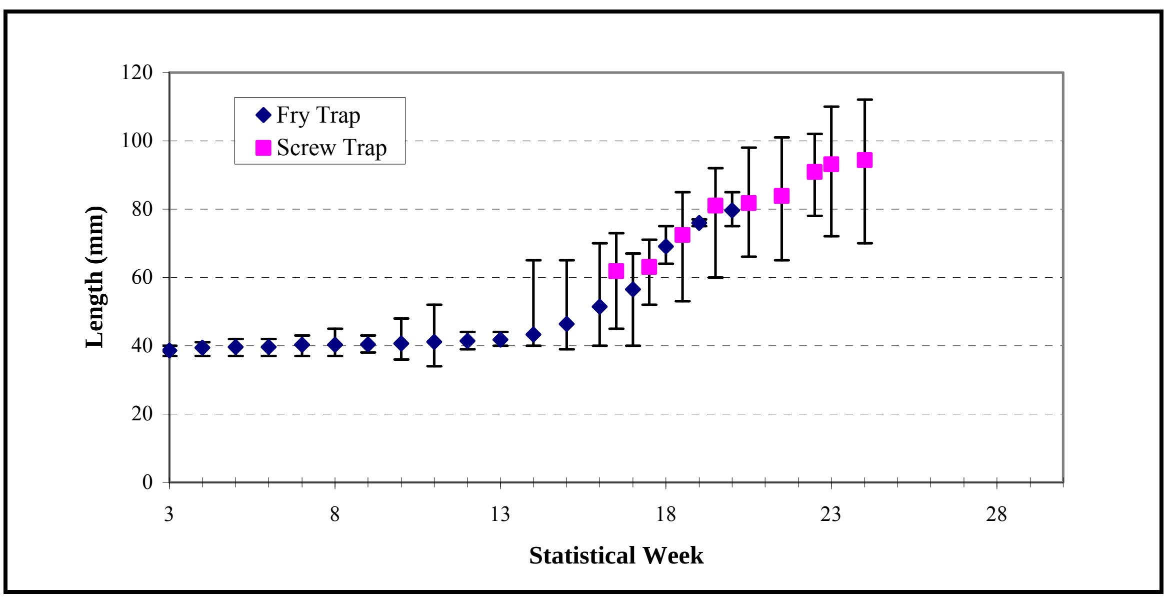

Figure 7. Average and range of fork lengths of Chinook sampled from the Cedar River, 2007.

Screw Trap

Over the entire season 33 mark groups were released. Groups were marked with either upper or lower horizontal or vertical partial caudal clips or PIT tags. There were no significant differences in recapture rates of clipped fish and PIT tagged fish, as well as no differences between recapture rates of groups that were released when no panels, two panels and four panels were in place to increase catch (2 sample T-test, α=0.05).

Many of these mark groups were small with few or no recaptures; therefore, the original groups were aggregated by mark into statistical weeks and regrouped by DARR 2.0 into four final strata. Each of the final strata had at least two recaptures. Capture rates for the four groups ranged from 3.0% to 12.3% (Appendix B 3). Migration during screw trap operation was estimated at 14,225 Chinook parr.

Combining the Chinook production estimated from the fry trap for January 18 through April 17 and the estimate from the screw trap for April 18 through July 20, a total migration over this interval was estimated at 123,241 age 0+ Chinook (Table 9). Migration prior to fry trap operation was estimated by logarithmic extrapolation from January 1 to 17, adding 495 migrants for a total migration of 123,736 Chinook.

Table 8. Independent weekly estimates of Chinook migration, N_w, from the fry and screw traps with results from a Z-test comparison of the weekly estimates, Cedar River 2007.

Statistical Week			Fry Trap		Screw Trap		Significant Difference? (Yes/No)
Begin	End	Number	Estimated Migration (N_w)	$V(N_w)$	Estimated Migration (N_w)	$V(N_w)$	
04/16	04/22	16	275	1.78E+03	266	2.55E+03	n
04/23	04/29	17	82	3.97E+02	167	1.01E+03	n
04/30	05/06	18	167	6.53E+02	499	3.88E+03	y
05/07	05/13	19	56	2.12E+02	1,232	7.74E+04	y
05/14	05/20	20	56	9.80E+01	1,233	3.25E+04	y
05/21	05/27	21	0	0.00E+00	1,400	2.12E+04	y
05/28	06/03	22	0	0.00E+00	1,170	3.25E+04	y
06/04	06/10	23	0	0.00E+00	3,256	3.57E+05	y

Table 9. Natural-origin Cedar River juvenile Chinook production estimate and confidence intervals, 2007.

Gear	Period	Estimated		95% CI		CV
		Catch	Migration	Low	High	
Pre-Trapping	January 1 - 17		495	329	661	17.12%
Fry Trap	January 18- April 17	2,670	109,016	93,044	124,989	7.48%
Screw Trap	April 18 - July 20	878	14,225	8,669	19,781	19.93%
	Season Total		**123,736**	**106,824**	**140,649**	**6.97%**

As in the previous six seasons, emigration timing was clearly bi-modal (Figure 8). We estimate that the migration was 25%, 50%, and 75% complete by February 19, March 14, and April 4, respectively (Figure 9). Juvenile Chinook emigrated mostly as fry, contributing to 88% of the total migration. Only 16% of the total migration were parr. This is the greatest proportion of fry since we began trapping in 1998 (Table 10). This large proportion of fry is likely due to high flows during fry trapping that may have forced juveniles downstream earlier than previously years.

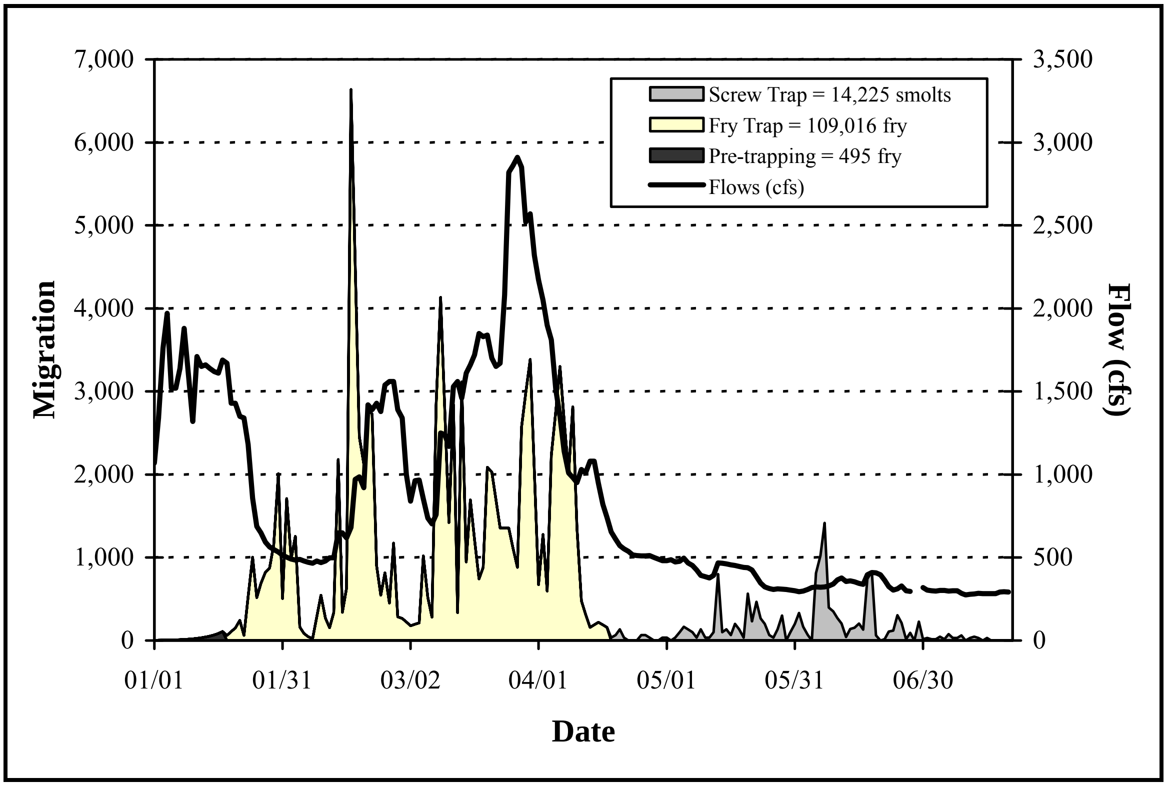

Figure 8. Estimated daily Cedar River Chinook migration from fry and screw trap estimates and flow (USGS Renton Gage), 2007.

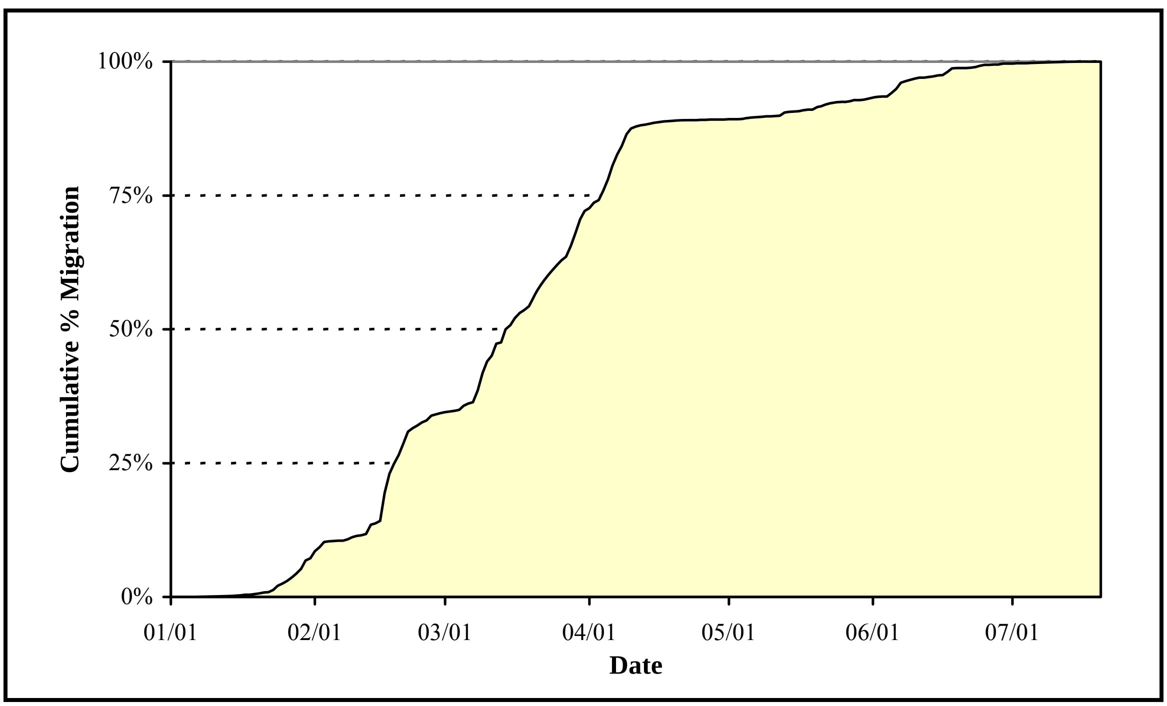

Figure 9. Cumulative percent migration of age 0+ Chinook, Cedar River 2007.

Table 10. Comparison of fry and parr components and survival between brood years for natural-origin Chinook production, standardized by assuming a January 1 to April 15 fry migration and April 16 through July 13 parr migration, Cedar River broods 1998 to 2006.

Brood	Estimated Migration			% Migration		Est.	PED	Production/Female			Survival Rates		
Year	Fry	Parr	Total	Fry	Parr	Females		Fry	Parr	Total	Fry	Parr	Total
1998	67,293	12,811	80,104	84.0%	16.0%	173	778,500	389	74	463	8.6%	1.6%	10.3%
1999	45,906	18,817	64,723	70.9%	29.1%	180	810,000	255	105	360	5.7%	2.3%	8.0%
2000	10,994	21,157	32,151	34.2%	65.8%	53	238,500	207	399	607	4.6%	8.9%	13.5%
2001	79,813	39,326	119,139	67.0%	33.0%	398	1,791,000	201	99	299	4.5%	2.2%	6.7%
2002	194,135	41,262	235,397	82.5%	17.5%	281	1,264,500	691	147	838	15.4%	3.3%	18.6%
2003	65,875	54,929	120,804	54.5%	45.5%	337	1,516,500	195	163	358	4.3%	3.6%	8.0%
2004	74,292	60,006	134,298	55.3%	44.7%	511	2,299,500	145	117	263	3.2%	2.6%	5.8%
2005	98,085	19,474	117,559	83.4%	16.6%	339	1,525,500	289	57	347	6.4%	1.3%	7.7%
2006	107,796	14,613	122,409	88.1%	11.9%	587	2,641,500	184	25	209	4.1%	0.6%	4.7%

Egg-to-Migrant Survival

Relating juvenile Chinook production from the Cedar River to estimates of annual egg deposition yields brood year egg-to-migrant survival rates (Table 10). For the 2006 brood, the natural-origin Chinook egg-to-migrant survival rate was estimated at 4.7% based on an escapement of 587 females (Steve Foley[b], pers comm) and an assumed fecundity of 4,500 eggs per female. Fall 2006 produced the largest Chinook return to the Cedar River on record. However, survival was the lowest recorded since 1998, likely the effects of scouring during high flow events in November 2006. The effect of this low survival rate on the 2006 brood is further exacerbated by the high proportion of fry vs. parr out-migrants. Survival of fry migrants moving through Lake Washington is likely much lower than for the larger parr migrants.

Size

From January through mid April, the weekly mean fork lengths of Chinook fry caught in the fry trap averaged 41 mm, and increased in size less than 8 mm (Table 11, Figure 7). By Week 17 (April 23-29), the weekly average increased to over 60 mm, however, the smallest Chinook fry captured each week remained consistently less than 40 mm. Beginning Week 18 (April 30 – May 6), and for the remainder of the season, the minimum fork length of Chinook captured in both traps measured over 50 mm, and averaged well over 60 mm, likely indicating that the fry migration was over.

Chinook caught in the screw trap increased in size from a weekly average fork length of 61.9 mm in mid-April to 115 mm near the end of trapping (Table 11). During screw trap operation, sizes ranged from 45 mm to 125 mm and averaged 91.7 mm. In comparison to 2006, fry were much smaller in 2007, while parr size was considerably larger (Table 12).

Table 11. Mean natural-origin Chinook fork length (mm), standard deviation, range, sample size, and catches in the Cedar River fry and screw traps, 2007.

Statistical Week			FRY TRAP						SCREW TRAP					
Begin	End	No.	Avg.	s.d.	Range Min	Range Max	n	Catch	Avg.	s.d.	Range Min	Range Max	n	Catch
01/15	01/21	3	38.6	1.18	37	40	15	20						
01/22	01/28	4	39.5	0.97	37	41	62	237						
01/29	02/04	5	39.6	0.89	37	42	103	416						
02/05	02/11	6	39.6	1.35	37	42	29	74						
02/12	02/18	7	40.3	1.35	37	43	73	432						
02/19	02/25	8	40.3	1.59	37	45	36	145						
02/26	03/04	9	40.4	1.08	38	43	25	97						
03/05	03/11	10	40.6	1.98	36	48	47	297						
03/12	03/18	11	41.2	2.90	34	52	46	174						
03/19	03/25	12	41.5	1.43	39	44	20	172						
03/26	04/01	13	41.8	1.62	40	44	10	218						
04/02	04/08	14	43.3	5.45	40	65	34	238						
04/09	04/15	15	46.4	8.63	39	65	39	138						
04/16	04/22	16	51.4	9.72	40	70	15	29	61.9	9.06	45	73	7	8
04/23	04/29	17	56.5	12.12	40	67	4	7	63.0	7.31	52	71	5	5
04/30	05/06	18	69.0	4.90	64	75	5	11	72.4	9.23	53	85	16	15
05/07	05/13	19	76.0	1.41	75	77	2	5	81.0	6.98	60	92	39	37
05/14	05/20	20	79.7	5.03	75	85	3	3	81.8	8.95	66	98	39	37
05/21	05/27	21							83.8	7.02	65	101	39	42
05/28	06/03	22							90.8	6.94	78	102	32	39
06/04	06/10	23							93.1	7.32	72	110	357	377
06/11	06/17	24							94.3	7.58	70	112	66	156
06/18	06/24	25							95.7	7.12	75	118	153	95
06/25	07/01	26							99.5	8.69	84	122	36	39
07/02	07/08	27							107.2	9.25	87	118	10	15
07/09	07/15	28							115.0	10.10	101	125	4	13
07/16	07/22	29											0	0
		Season Totals	41.8	6.20	34	85	568	2,714	91.7	10.1	45	125	803	878

Table 12. Comparison of natural-origin Chinook sizes measured over seven years (2001-2007) at the Cedar River fry and screw traps.

	Fry						Parr					
Date	Avg	s.d.	Min	Max	n	Catch	Avg	s.d.	Min	Max	n	Catch
2001	40.3	4.18	34	75	287	687	81.3	14.91	40	121	379	2,872
2002	41.3	7.47	32	92	634	3,781	78.1	21.19	32	131	997	2,592
2003	44.3	10.79	34	90	563	7,186	91.0	13.69	42	128	1,782	3,675
2004	41.9	7.09	34	91	629	2,918	87.4	13.82	42	126	812	6,156
2005	44.7	9.00	36	110	416	4,640	95.7	10.80	42	138	2,260	4,524
2006	45.0	10.70	34	82	496	1,975	82.8	10.92	38	116	701	879
2007	41.8	6.20	34	85	568	2,714	91.7	10.10	45	125	803	878

Coho

Catch

A total of 482 natural-origin coho smolts were caught in the screw trap between April 18 and July 20. Catch distribution was variable throughout the season with approximately 61% of the migration passing the trap in May. Due to a trap outage, catches on April 19 (4 coho), were not included in the final analysis. A total of 478 coho were used to estimate migration.

Production Estimate

Mark groups were released almost daily with fin marks rotating weekly. A total of 11 mark groups ranging in size from 2 to 104 coho were released. Mark groups had few to no recaptures; therefore the original groups were aggregated into three strata. Capture rates for the final strata ranged from 1.3% to 2.9% (Appendix B 4).

Coho production over the trapping season was estimated at 32,103 smolts using Darroch's maximum likelihood estimator (Appendix B 4). Assuming a starting migration date of April 1, 891 additional smolts were estimated to have migrated before trapping began on April 18, using linear extrapolation. Total coho production was estimated at 33,994 smolts with a coefficient of variation of 40.8% and a 95% confidence interval of 8,291 to 59,697 smolts (Figure 10). The poor precision measured for this estimate was primarily the result of poor capture rates experience at this site.

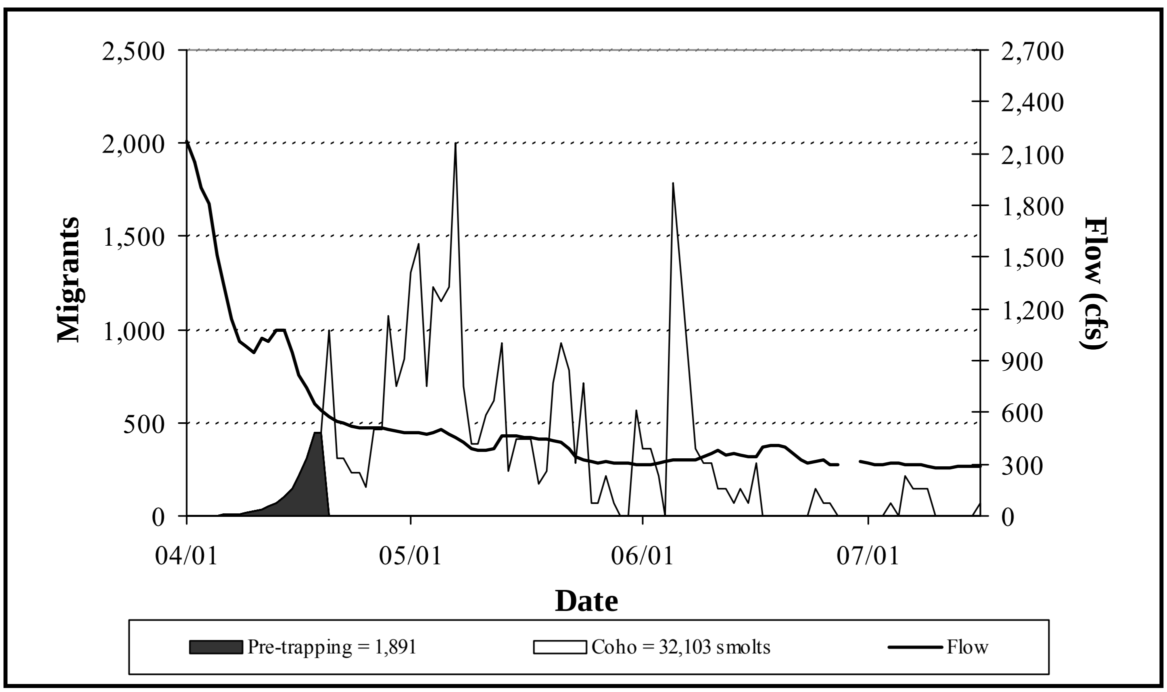

Figure 10. Estimate of daily coho smolt migration and daily average flow, Cedar River screw trap, 2007.

Size

Over the season, weekly coho smolt fork lengths averaged 109.0 mm and individuals ranged from 86 mm to 148 mm (Table 13, Figure 11). Weekly mean size ranged from 107.3 mm to 138.5 mm.

Table 13. Weekly mean fork length (mm), standard deviation, range, sample size and catches for coho smolts from the Cedar River screw trap, 2007.

Statistical Week			Avg.	s.d.	Range		n	Catch
Begin	End	No.			Min	Max		
04/16	04/22	16	108.6	11.02	93	135	24	21
04/23	04/29	17	108.9	9.67	88	131	39	38
04/30	05/06	18	105.9	9.64	86	133	82	96
05/07	05/13	19	109.2	8.93	90	135	59	76
05/14	05/20	20	109.0	8.36	89	139	53	82
05/21	05/27	21	107.3	8.79	93	135	34	50
05/28	06/03	22	110.6	9.51	100	131	16	22
06/04	06/10	23	110.3	10.07	91	131	71	66
06/11	06/17	24	109.4	7.95	100	119	8	16
06/18	06/24	25	113.8	11.79	100	128	4	0
06/25	07/01	26	112.0	7.94	106	121	3	4
07/02	07/08	27	122.3	13.31	110	148	7	6
07/09	07/15	28	138.5	3.54	136	141	2	4
07/16	07/22	29	138.0	n/a	138	138	1	1
		Season Totals	109.0	10.00	86	148	403	482

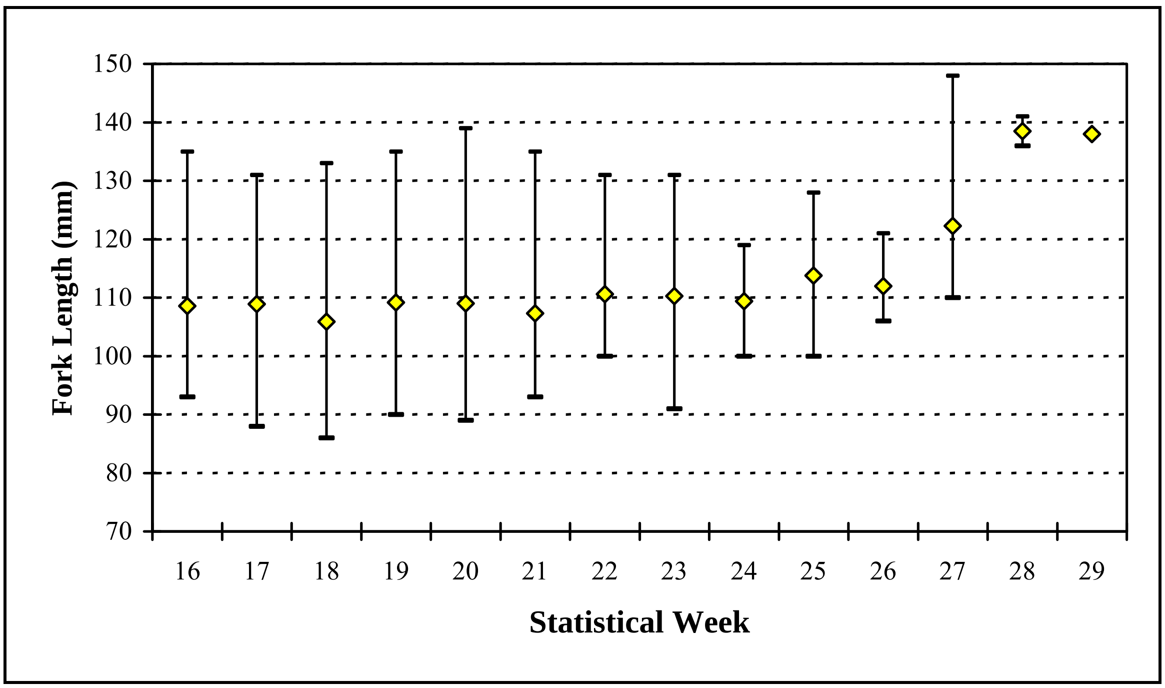

Figure 11. Weekly ranges and mean fork lengths for coho smolts captured in the Cedar River screw trap, 2007.

Trout

The variety of life history strategies used by trout in the Cedar River may include anadromous, ad-fluvial, and resident forms. For simplicity, the catches and estimates reported herein are for trout that were visually identified in the field as either cutthroat or steelhead. We acknowledge that cutthroat-rainbow hybrids are included in the reported cutthroat numbers. Furthermore, we are uncertain whether the reported steelhead were truly the anadromous life-form; yet we reported these separately from the resident rainbows described in the Incidental Catch section, below, since they appeared smolted.

Throughout the season, only 1 steelhead migrant and 4 cutthroat trout were captured. Catches were too small to develop migration estimates. Cutthroat fork lengths ranged from 124 to 187 mm, and averaged 153 mm.

PIT Tagging

To support the ongoing, multi-agency evaluation of salmonid survival within the Lake Washington basin, we began tagging natural-origin Chinook with passive integrated transponder (PIT) tags on May 7. Due to lower than usual trap efficiency and lower numbers of fish, tagging only occurred three times a week through June 30. Chinook were held from the previous day in order to increase the number tagged per day. Over the season a total of 743 natural-origin Chinook parr were tagged (Table 14). This tag group comprised only 5.2% of the estimated Chinook parr production from the Cedar River in 2007. Beginning June 7, as a result of such low numbers of Chinook to tag, we began tagging natural-origin coho as well. A total of 75 natural-origin coho were tagged in 2007.

Table 14. Natural-origin Chinook parr and coho PIT tagged and released from the Cedar River screw trap, 2007.

Stat Week			Wild	Length			Portion of	Wild	Length			Portion of
#	Start	End	Chinook	Avg	Min	Max	Migration Tagged	Coho	Avg	Min	Max	Migration Tagged
19	05/07	05/13	18	78.1	66	90	1.5%					
20	05/14	05/20	42	81.8	69	94	3.4%					
21	05/21	05/27	51	85.1	70	98	3.6%					
22	05/28	06/03	15	90.5	78	100	1.3%					
23	06/04	06/10	309	93.1	72	110	7.2%	54	111.3	91	130	1.1%
24	06/11	06/17	121	94.0	70	112	7.5%	14	109.5	96	131	1.6%
25	06/18	06/24	128	95.0	75	118	8.9%	2	113.5	110	117	1.4%
26	06/25	07/01	59	99.5	84	122	10.0%	5	111.0	100	128	7.0%
Season Totals			743	92.5	66	122	5.2%	75	111.0	91	131	0.2%

Mortality

There were no Chinook mortalities while operating the fry trap.

During screw trap operations, 5 Chinook mortalities resulted from PIT tagging.

Incidental Catch

Incidental catches in the fry trap included 23 coho fry, 312 coho smolts, 204 chum fry, and 6 cutthroat smolts. Other species caught included three-spine stickleback, sculpin, lamprey, largescale suckers, long-fin smelt fry, dace and catfish.

Other salmonids caught in the screw trap include 174 ad-marked hatchery Chinook parr, 48 sockeye smolts, and 1 unmarked cutthroat adult. Other species caught included three-spine stickleback, sculpin, lamprey, large-scale suckers (adult and fry), peamouth, dace, and a bullhead catfish.

Bear Creek Results

Sockeye

Catch

On the first night of trapping, February 2, 47 sockeye fry were caught in the fry trap. Thereafter, through the morning of April 16, the trap fished two to four nights a week for a total of 41 nights. Catches peaked on the night of March 19, when 33,291 fry were caught. When trapping concluded on the morning of April 16, catches totaled 221,080 sockeye fry.

Expanding catches for the 32 nights not fished estimates that there would have been an additional 156,234 sockeye fry caught during those nights. The total expanded catch from February 2 to April 16, is estimated at 377,314 fry. In previous years no sockeye fry were caught during daylight intervals fished. Therefore, migration during daylight hours was considered minimal and not estimated.

Production Estimate

Thirty-six mark groups were released, nearly every night that the trap was fished, above the trap over the season. Since recaptures were sufficient for all mark-release groups, no aggregating of the efficiency strata was necessary. Capture rates ranging from 1.5% to 13.3% (Appendix C 1). During the period of fry trap operation (February 2 through April 16), we estimate 5.95 million sockeye fry passed the trap. The sockeye fry migration appeared to be underway when trapping began. Logarithmic extrapolation was used to estimate what may have passed the trap prior to February 2, contributing 18,688 fry to our total estimated migration. The sockeye fry migration was still underway when the screw trap replaced the fry trap on April 16. Rather than attempting to calibrate the screw trap, the tail end of the migration was estimated using logarithmic extrapolation. Migration from April 16 to April 30, was estimated at 17,997 fry. A total of 5,983,651 sockeye fry was estimated to have migrated from Bear Creek in 2007 with a CV of 10.9% and a 95% confidence interval of 4,708,018 to 7,259,284 (Table 15). The production measured in 2007 was over two-times higher than the previously measured peak abundance.

Egg-to-migrant survival of the 2006 brood was estimated at 19.4% (Table 16). This rate is the ratio of 5,983,651 fry to an estimate of 30.8 million eggs potentially deposited. Egg deposition is based on an estimated 21,172 adult sockeye in Bear Creek (Steve Foley[a] pers comm), an even sex ratio, and the assumption that Bear Creek sockeye have the same fecundity as Cedar River sockeye (2,910 eggs per female). In previous years, we have calculated survival using an assumed fecundity of 3,200 egss per female. This year, we have chosen to examine survival based on fecundity measured each year in the Cedar River at the broodstock collection facility; annual survival rates changed by no more than +/- 0.8%. This is the highest survival since trapping began at this location in 1999.

Table 15. Estimated 2007 Bear Creek sockeye fry migration entering Lake Washington with 95% confidence intervals.

Period	Dates	Est. Migration	CV	95% CI	
				Low	High
Pre-Trapping	January 1-February 1	18,688	3.8%	17,302	20,074
Fry Trap	February 2-April 15	5,946,966	10.9%	4,671,337	7,222,595
Post-Trapping	April 16-April 30	17,997	7.1%	15,510	20,484
	Season Totals	5,983,651	10.9%	4,708,018	7,259,284

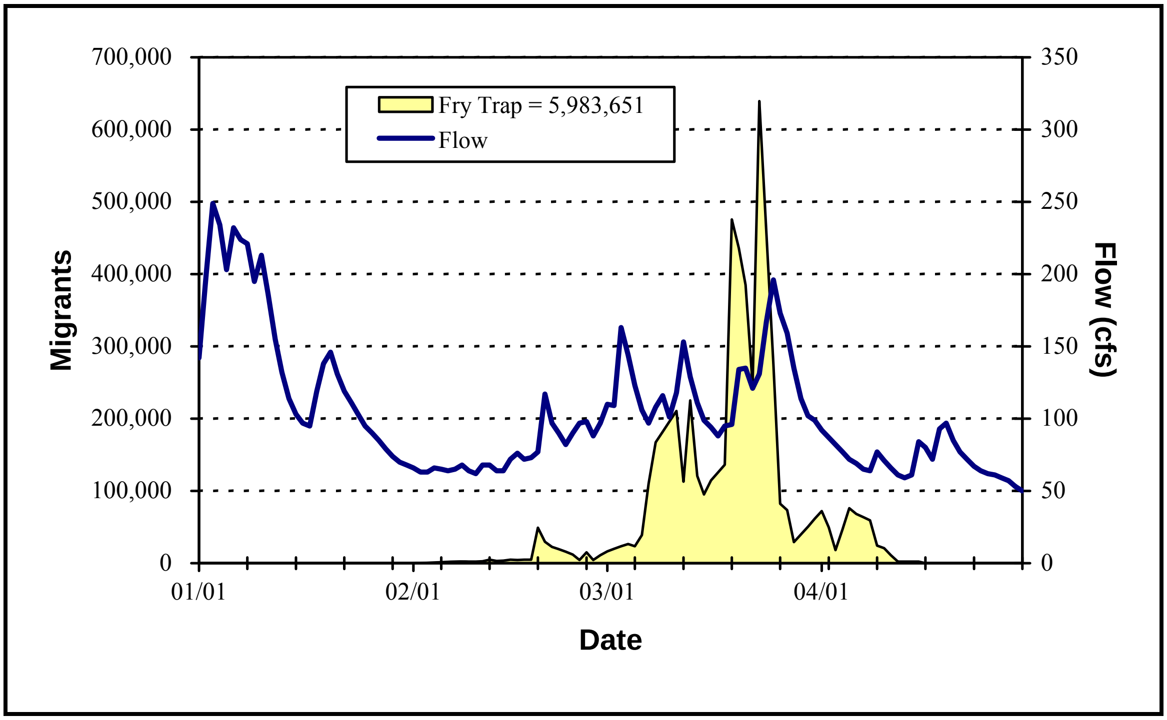

Figure 12. Estimated daily migration of sockeye fry from Bear Creek and daily average flow, 2007.

Table 16. Sockeye egg-to-migrant survival rates by brood year in Bear Creek, based on annually-measured sockeye fecundity in the Cedar River.

Brood Year	Spawners	Females (@50%)	Fecundity	PED	Fry Production	Survival Rate	Peak Incubation Flow	
							(cfs)	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

Chinook

Catch

Fry Trap

On the first night of trapping, February 2, 1 Chinook fry was captured. Catches peaked on the night of March 19, with 44 Chinook fry captured. In total, 106 Chinook fry were captured in the fry trap by the time trapping ended on the morning of April 16.

Catch expansion for the 32 nights not fished resulted in an additional estimated catch of 60 Chinook fry, bringing the total estimated catch to 166 Chinook fry caught in the fry trap.

Screw Trap

The fry trap was replaced with the screw trap on April 15, and began fishing April 16. It fished continuously through the morning of July 11. On the first night of trapping, only 4 Chinook were caught, and daily migrations through the rest of April averaged 4 Chinook per day. By early May catches began to increase and peaked on May 13, when 436 Chinook were caught. Catches then sharply declined to average 17 Chinook per day for the remainder of the season. A total of 5,320 Chinook were caught over the 86 days trapped. However, because of a trap outage, catch on May 19 (44 Chinook) was not included in the final analysis. A total of 5,276 Chinook were used to estimate production.

Production Estimate

Fry Trap

Chinook migration timing, as indicated by catch, suggested most Chinook reared upstream of the trap before migrating. Too few Chinook fry were captured during fry trapping to directly estimate efficiency. Therefore, fry trap capture rates for marked sockeye were assumed to be equivalent to that of Chinook fry and were used to estimate Chinook fry migration. Since trap efficiency tests using sockeye fry were instantaneous measurements of efficiency, estimated catches of unmarked Chinook fry were used to calculate abundance during each fishing stratum. Over the entire fry migration period, abundance was estimated at 3,976 Chinook (Appendix C 2). When we began trapping operations, the Chinook fry migration was already underway. We estimated that 78 Chinook fry migrated passed the trap prior to February 2. Total abundance for the fry trapping period was estimated at 4,054 Chinook fry.

Screw Trap

Fifty-three Chinook mark groups were released with fin marks rotating weekly during screw trap operation. Originally, 11 different fin-mark groups were released. Due to low recaptures in one stratum, DARR 2.0 aggregated these into 10 strata and produced capture rates between 28.6% and 52.3%. Migration during screw trap operation was estimated at 12,816 Chinook (Appendix C 2). Combining the fry and screw trap estimates develops a total production of 16,870 juvenile Chinook, with a coefficient of variation of 6.03% and a 95% confidence interval of 14,876 to 18,863 juveniles. As in the past, migration is clearly bi-modal with 24% of the migration emigrating as fry and the remaining 76% emigrating as parr (Figure 13) (Table 18).

Egg-to-migrant survival of the 2006 brood was estimated at 2.8% (Table 18). This rate is the ratio of 16,870 Chinook to an estimate of 589,500 eggs deposited. Egg deposition is based on 131 spawning females in Bear Creek and an assumed fecundity of 4,500 eggs per female. In addition, based on carcass recovery, hatchery-produced Chinook comprised 77.8% of the spawners sampled (Steve Foley[b] pers comm).

Table 17. Bear Creek juvenile Chinook production estimate and confidence intervals, 2007.

Gear	Period	Estimated Catch	Estimated Migration	95% CI Low	95% CI High	CV
Pre-Trapping	January 1- February 1		78	47	109	20.38%
Fry Trap	February 2 - April 15	166	3,976	2,358	5,594	20.76%
Screw Trap	April 16 - July 10	5,276	12,816	11,651	13,981	4.64%
	Season Totals	5,442	16,870	14,876	18,863	6.03%

Table 18. Comparison of fry and parr components and survival between brood years for natural-origin Chinook production, standardized by assuming a February 1 to April 8 fry migration and April 9 through June 30 parr migration, Bear Creek broods 2000 to 2006.

Brood Year	Estimated Migration Fry	Estimated Migration Parr	Estimated Migration Total	% Migration Fry	% Migration Parr	Est. Females	PED	Production/Female Fry	Production/Female Parr	Production/Female Total	Survival Rates Fry	Survival Rates Parr	Survival Rates 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%	276	1,242,000	20	58	77	0.4%	1.3%	1.7%
2002	645	16,636	17,281	3.7%	96.3%	144	648,000	4	116	120	0.1%	2.6%	2.7%
2003	2,089	21,558	23,647	8.8%	91.2%	105	472,500	20	205	225	0.4%	4.6%	5.0%
2004	1,178	8,092	9,270	12.7%	87.3%	76	342,000	16	106	122	0.3%	2.4%	2.7%
2005	5,764	16,598	22,362	25.8%	74.2%	128	576,000	45	130	175	1.0%	2.9%	3.9%
2006	3,452	13,077	16,529	20.9%	79.1%	131	589,500	26	100	126	0.6%	2.2%	2.8%

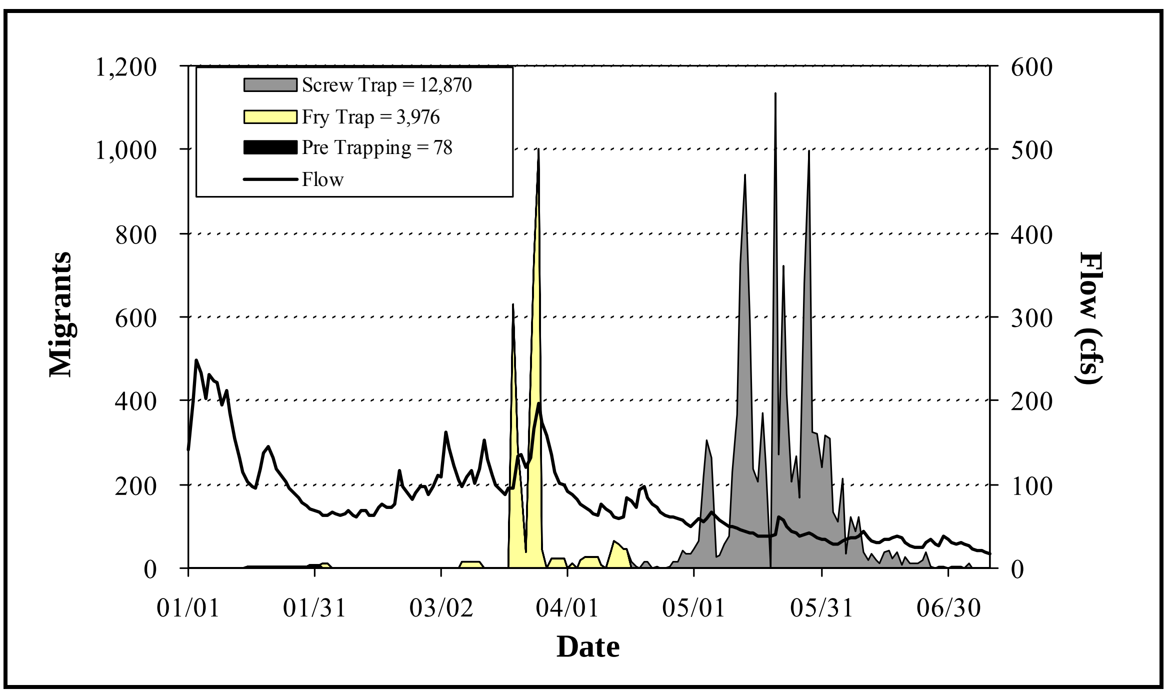

Figure 13. Estimated daily Chinook 0+ migration and daily average flow from Bear Creek, 2007.

Size

From early February through mid- April, the sizes of Chinook fry captured in the fry trap ranged from only 38 mm to 55 mm, and averaged 41.7 mm (Table 19).

Weekly average fork lengths during screw trap operation increased throughout the season. Chinook averaged 58.8 mm in early April, and grew to average 80.0 mm by late May through the remainder of the season (Table 19, Figure 14). Fork lengths over the screw trapping period ranged from 40 mm to 118 mm and averaged 79.8 mm for the season. Average fry and parr sizes measured in 2007 are much larger than those observed in the previous six years (Table 20).

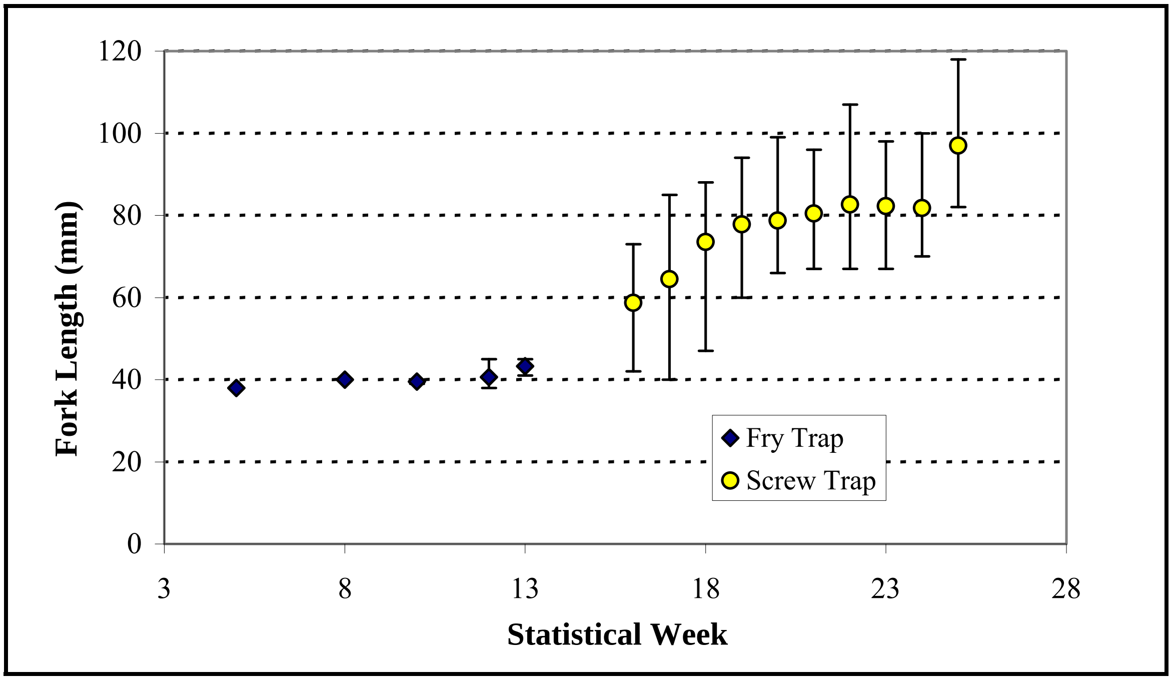

Figure 14. Average and range of Chinook 0+ fork lengths sampled from Bear Creek, 2007.

Table 19. Juvenile Chinook and coho mean fork lengths (mm), standard deviations, ranges, sample sizes, and catches in the Bear Creek fry and screw traps, 2007.

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
Fry Trap	01/29	02/04	5	38.0	n/a	38	38	1	1						
	02/05	02/11	6						0						
	02/12	02/18	7						0						
	02/19	02/25	8	40.0	n/a	40	40	1	1						
	02/26	03/04	9						0						
	03/05	03/11	10	39.5	0.71	39	40	2	2						
	03/12	03/18	11						0						
	03/19	03/25	12	40.6	2.07	38	45	48	78						
	03/26	04/01	13	43.3	1.71	41	45	4	4						
	04/02	04/08	14	44.0	1.41	42	46	8	8						
	04/09	04/15	15	45.3	5.46	40	55	11	12						
			Totals	41.7	3.29	38	55	78	106						
Screw Trap	04/16	04/22	16	58.8	11.01	42	73	12	16	125.9	10.49	103	161	77	192
	04/23	04/29	17	64.5	11.46	40	85	27	33	120.8	9.36	102	142	81	451
	04/30	05/06	18	73.5	8.45	47	88	138	328	117.6	8.55	102	142	127	767
	05/07	05/13	19	77.8	7.17	60	94	205	1212	117.9	11.78	92	203	143	923
	05/14	05/20	20	78.7	5.57	66	99	968	1239	111.3	9.51	94	144	73	281
	05/21	05/27	21	80.5	5.29	67	96	832	1047	112.5	11.40	91	140	77	140
	05/28	06/03	22	82.6	5.76	67	107	482	1037	109.6	11.12	90	141	36	43
	06/04	06/10	23	82.2	6.01	67	98	272	245	123.0	n/a	123	123	1	2
	06/11	06/17	24	81.8	6.72	70	100	19	76						2
	06/18	06/24	25	97.0	10.58	82	118	14	57						1
	06/25	07/01	26	84.1	4.14	78	91	9	23						0
	07/02	07/08	27						7						0
	07/09	07/15	28						0						0
			Totals	79.8	6.75	40	118	2,978	5,230	117.3	11.3	90	203	615	2,802

Table 20. Comparison of natural-origin chinook sizes measured over seven years (2001-2007) at the Bear Creek fry and screw traps.

	Fry						Parr					
Date	**Avg**	**s.d.**	**Min**	**Max**	**n**	**Catch**	**Avg**	**s.d.**	**Min**	**Max**	**n**	**Catch**
2001	41.1	1.97	34	47	39	63	73.4	11.60	38	105	622	5,131
2002	38.9	3.80	34	52	70	278	81.5	10.83	42	110	885	6,880
2003	40.9	3.20	34	54	78	86	75.9	11.20	35	106	709	8,182
2004	41.6	4.99	38	60	70	102	73.6	11.52	40	107	874	10,613
2005	40.6	2.29	38	47	46	102	78.7	7.06	40	102	1,766	4,612
2006	41.4	4.10	37	64	117	264	76.0	8.82	44	100	907	8,180
2007	41.7	3.30	38	55	75	106	79.8	6.80	40	118	2978	5,320

Coho

Catch

During the first week of screw trap operation, 192 coho were captured, suggesting the coho migration had already begun. During the first six weeks of trapping, catches averaged over 450 smolts per week. Catches steadily increased until May 11, when it peaked at 187 smolts. Following the last week in May through the end of the season, catches declined and averaged only 7 smolts per week during the final seven weeks of trapping. Over the entire 86-day trapping season, ending on the morning of July 10, a total of 2,802 coho smolts were caught. Due to a trap outage, catches on May 19 (14 coho) were not included in the final analysis. A total of 2,788 coho were used to estimate production.

Production Estimate

Coho mark groups were released nearly daily and fin marks were rotated weekly. Ten different weekly strata were released over the season. Due to low recapture rates in some strata, DARR 2.0 aggregated weekly strata into seven final strata. Final strata capture rates ranged from 8.1% to 27.4%. Coho production was estimated at 25,143 smolts with a coefficient of variation of 9.9% and a 95% confidence interval of 20,220 to 30,066 smolts (Figure 15, Appendix C 4).

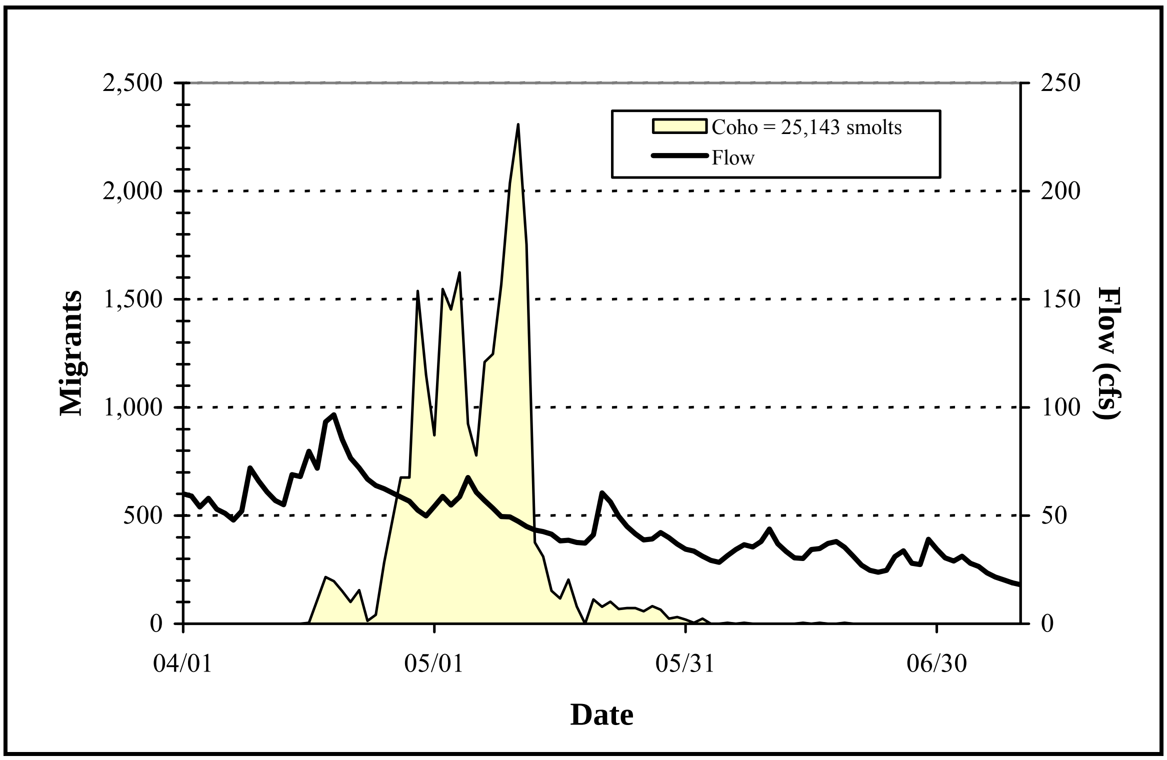

Figure 15. Estimated daily coho smolt migration, Bear Creek screw trap 2007.

Size

Over the trapping period, fork lengths ranged from 90 mm to 203 mm and averaged 117.3 mm (Figure 16). Weekly mean size ranged from 109.6 mm to 125.9 mm over the season (Table 19).

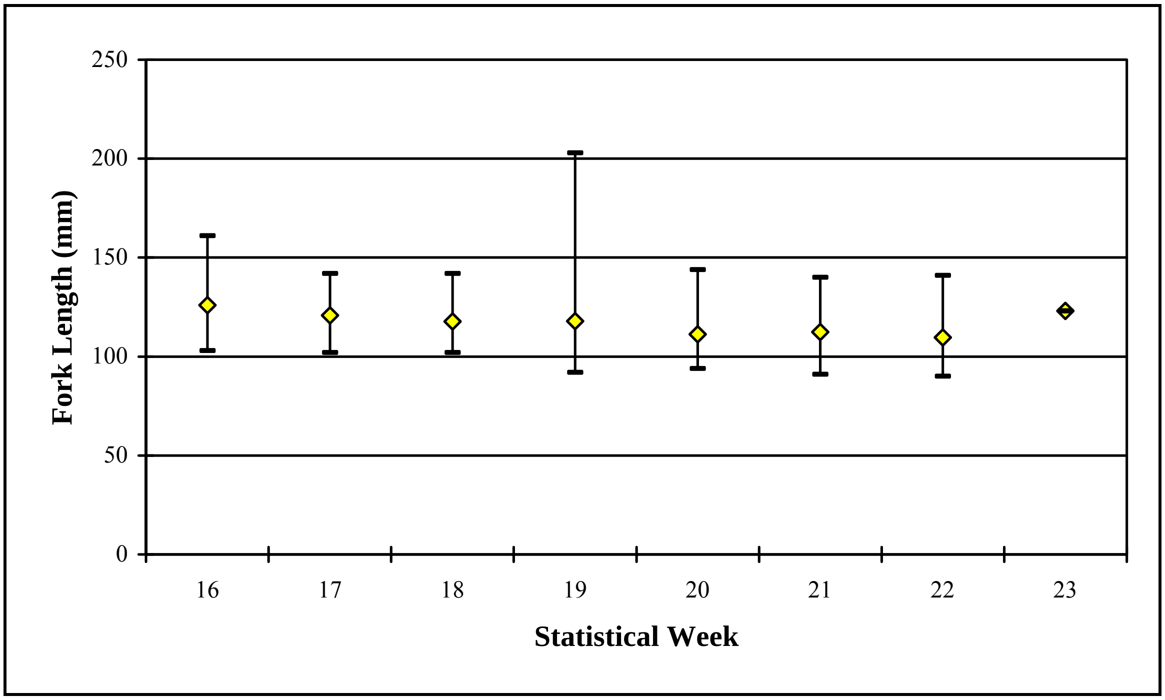

Figure 16. Average and range of fork lengths from coho smolts sampled from Bear Creek, 2007.

Trout

The identification of trout in Bear Creek poses the same difficulties as was discussed earlier in the Cedar River section. For these reasons, trout are referred to as cutthroat trout or steelhead out migrants, based on visual identification.

Catch and Production Estimate

There was one steelhead captured throughout the 2007 trapping season in Bear Creek.

A total of 507 cutthroat trout were captured in the screw trap. During the first week of screw trapping, 137 cutthroat were captured, nearly 27% of the total catch, providing a strong indication that migration was well underway. Catch decline slightly during the following week. It increased again during mid-May before sharply declining thereafter. Daily catches peaked on April 19, when 43 cutthroat were captured. Cutthroat mark groups were released almost daily, and fin marks rotated weekly. Seven different weekly strata were released over the season, ranging from 24 to 113 cutthroat per mark group; these mark groups were large enough to preclude aggregation. DARR output capture rates ranged from 8.3% to 18.6% and estimated production at 3,869 cutthroat, with a coefficient of variation of 15.1% and a 95% confidence interval of 2,705 to 5,033 smolts (Figure 17, Appendix C 5). This estimate applies only to the interval trapped (April 16 through July 10). During the 2000 season, when the screw trap operated from January through June, 35% of the cutthroat migration occurred prior to April 5. Applying this timing to the cutthroat estimated during the 2007 trapping season estimates that a total of 5,952 cutthroat migrated from Bear Creek. Some of these cutthroat may actually be rainbow/cutthroat hybrids if results from limited sampling by Marshal *et al* (2006) in the Cedar River are indicative of the population structure in Bear Creek.

Cutthroat trout fork lengths averaged 168.2 mm, and individuals varied from 102 mm to 287 mm throughout the trapping season (Table 21). Average fork lengths showed little variation across weeks.

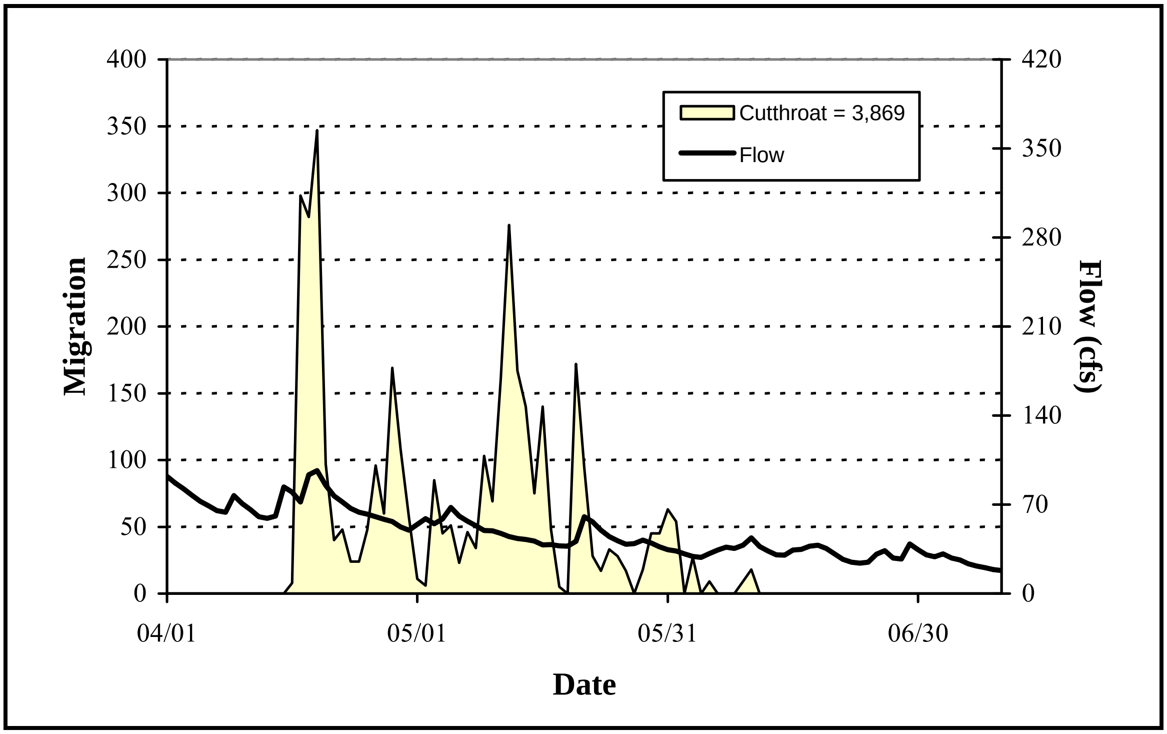

Figure 17. Daily estimated migration of cutthroat trout and flow, Bear Creek screw trap 2007.

Table 21. Mean cutthroat fork length (mm), standard deviation, range, sample size, and catch by statistical week, Bear Creek screw trap 2007.

Statistical Week			Avg.	s.d.	Range		n	Catch
Begin	End	No.			Min	Max		
04/16	04/22	16	170.6	23.98	121	257	60	137
04/23	04/29	17	171.3	19.82	135	230	42	54
04/30	05/06	18	168.9	22.85	134	257	35	47
05/07	05/13	19	172.2	20.10	131	225	67	91
05/14	05/20	20	162.5	16.93	112	193	55	107
05/21	05/27	21	168.4	26.72	124	287	39	39
05/28	06/03	22	157.8	25.50	102	224	24	28
06/04	06/10	23-28						4
		Season Totals	168.2	22.21	102	287	322	507

PIT Tagging

As part of an ongoing multi-agency monitoring of Chinook migrating from the Lake Washington system, PIT tagging also occurred in Bear Creek in 2007. Tagging began on May 7, and occurred three times a week through June 11. Fish were often held overnight to increase the number tagged per day. A total of 2,725 natural-origin Chinook were PIT tagged in Bear Creek throughout the season (Table 22).

Table 22. Natural-origin Chinook parr PIT tagged and released from the Bear Creek screw trap, 2007.

Stat Week			Wild	Length			Portion of
#	Start	End	Chinook	Avg	Min	Max	Migration Tagged
19	07-May	13-May	231	78.47	65	94	15.29%
20	14-May	20-May	958	78.71	66	99	36.96%
21	21-May	27-May	832	80.47	67	96	26.15%
22	28-May	03-Jun	472	82.69	67	107	14.81%
23	04-Jun	10-Jun	232	82.34	67	98	28.19%
Season Totals			2,725	80.23	65	107	21.26%

Mortality

There were no Chinook or coho mortalities during fry trapping. In the screw trap, eighteen Chinook, and 3 yearling coho mortalities were found over the trapping season. Three Chinook mortalities were due to PIT tagging while the remaining occurred during trap operation.

Incidental Species

In addition to sockeye and Chinook fry caught in the fry trap, 8 coho fry, 10 cutthroat smolts, and 31 pink fry were also caught. Other species included lamprey, sculpin, three-spine sticklebacks, pumpkinseed, large mouth bass, dace, and Northern pikeminnow. In addition to target species, the screw trap captured sockeye fry, one sockeye smolt, 9 coho fry, 2 chum fry, 17 resident rainbow trout, and 2 cutthroat adults. Other species caught included lamprey, large-scale suckers, three-spine stickleback, sculpin, pumpkinseed, small and large mouth bass, whitefish, warmouth, peamouth, dace, catfish, and Northern pikeminnow.

Appendix A

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

Kristen Ryding
WDFW Biometrician

Appendix A. Variance of total unmarked smolt numbers, $\hat{U}_i$, when the number of unmarked juvenile out-migrants, $\hat{u}_i$ is estimated. Kristen Ryding, WDFW Biometrician.

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,

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

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

$E\left(\hat{u}_i\right)$ = 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 Stratum for Cedar River Sockeye,
Chinook, and Coho Salmon, 2007.

Appendix B 1. Estimated catch and migration by stratum for Cedar River natural-origin sockeye fry, 2007.

Stratum	Date Begin	Date End	Total Estimated Catch	Capture Rate	Estimated Migration	Variance
1	01/18/07	01/25/07	1,976	3.60%	54,669	1.31E+08
2	01/26/07	01/26/07	880	7.30%	12,100	8.44E+06
3	01/27/07	01/28/07	5,394	6.50%	82,708	3.92E+08
4	01/29/07	01/30/07	3,443	3.70%	92,272	8.21E+08
5	01/31/07	01/31/07	903	11.50%	7,851	6.73E+05
6	02/01/07	02/01/07	969	6.60%	14,739	5.02E+06
7	02/02/07	02/02/07	1,238	8.10%	15,207	3.49E+06
8	02/03/07	02/04/07	3,190	3.40%	93,573	7.83E+08
9	02/05/07	02/05/07	1,791	6.50%	27,436	1.00E+07
10	02/06/07	02/06/07	2,685	9.30%	28,889	9.42E+06
11	02/07/07	02/09/07	22,458	4.40%	512,303	3.45E+09
12	02/10/07	02/11/07	23,216	6.30%	369,934	1.98E+09
13	02/12/07	02/12/07	12,151	8.80%	137,808	1.35E+08
14	02/13/07	02/14/07	8,079	7.40%	109,831	1.45E+08
15	02/15/07	02/16/07	5,165	8.30%	62,051	4.66E+07
16	02/17/07	02/21/07	7,342	1.20%	589,196	2.09E+10
17	02/22/07	02/23/07	1,339	2.60%	51,886	2.09E+08
18	02/24/07	02/26/07	1,130	1.20%	92,509	4.52E+08
19	02/27/07	03/04/07	12,290	6.10%	200,792	4.89E+08
20	03/05/07	03/05/07	9,196	6.70%	136,308	2.65E+08
21	03/06/07	03/06/07	6,538	4.80%	135,179	1.20E+08
22	03/07/07	03/07/07	10,457	8.90%	117,420	1.05E+08
23	03/08/07	04/09/07	51,605	1.60%	3,326,141	8.19E+10
24	04/10/07	04/17/07	38,708	3.40%	1,137,693	1.01E+10
25	04/18/07	04/19/07	14,896	5.30%	280,411	6.39E+08
26	04/20/07	04/20/07	8,548	6.60%	130,143	1.92E+08
27	04/21/07	04/25/07	39,865	4.90%	818,498	4.93E+09
28	04/26/07	06/07/07	31,321	5.40%	579,880	2.19E+09
		Total	**326,773**		**9,217,426**	**1.30E+11**

Appendix B 2. Estimated catch and migration by stratum for Cedar River natural-origin Chinook fry, 2007.

Stratum	Date Begin	Date End	Total Estimated Catch	Capture Rate	Estimated Migration	Variance
1	01/18/07	01/25/07	96	3.60%	2,656	5.76E+05
2	01/26/07	01/26/07	50	7.30%	688	3.50E+04
3	01/27/07	01/28/07	111	6.50%	1,702	1.87E+05
4	01/29/07	01/30/07	117	3.70%	3,136	1.01E+06
5	01/31/07	01/31/07	58	11.50%	504	6.28E+03
6	02/01/07	02/01/07	113	6.60%	1,719	8.83E+04
7	02/02/07	02/02/07	80	8.10%	983	2.44E+04
8	02/03/07	02/04/07	48	3.40%	1,408	1.20E+06
9	02/05/07	02/05/07	5	6.50%	77	1.13E+03
10	02/06/07	02/06/07	4	9.30%	43	4.25E+02
11	02/07/07	02/09/07	38	4.40%	867	9.53E+04
12	02/10/07	02/11/07	27	6.30%	430	2.14E+04
13	02/12/07	02/12/07	29	8.80%	329	4.25E+03
14	02/13/07	02/14/07	187	7.40%	2,542	1.08E+05
15	02/15/07	02/16/07	132	8.30%	1,586	1.53E+05
16	02/17/07	02/21/07	176	1.20%	14,124	1.70E+07
17	02/22/07	02/23/07	38	2.60%	1,473	3.20E+05
18	02/24/07	02/26/07	29	1.20%	2,374	5.67E+05
19	02/27/07	03/04/07	83	6.10%	1,356	4.44E+04
20	03/05/07	03/05/07	68	6.70%	1,008	2.76E+04
21	03/06/07	03/06/07	25	4.80%	517	1.17E+04
22	03/07/07	03/07/07	25	8.90%	281	3.39E+03
23	03/08/07	04/09/07	1,026	1.60%	66,130	4.51E+07
24	04/10/07	04/17/07	105	3.40%	3,086	1.87E+05
		Total	**2,670**		**109,016**	**6.67E+07**

Appendix B 3. Total catch and migration by stratum for Cedar River natural-origin Chinook parr, 2007.

Stratum	Date Begin	Date End	Total Catch	Capture Rate	Estimated Migration	Variance
1	04/18/07	06/02/07	177	3.00%	5,841	6.61E+06
2	06/03/07	06/09/07	350	8.60%	4,065	5.77E+05
3	06/10/07	06/16/07	140	12.30%	1,136	6.18E+04
4	06/17/07	07/20/07	211	6.60%	3,183	7.85E+05
		Total	**878**		**14,225**	**8.04E+06**

Appendix B 4. Total catch and migration by stratum for Cedar River natural-origin coho smolts, 2007.

Stratum	Date Begin	Date End	Total Catch	Capture Rate	Estimated Migration	Variance
1	04/18/07	05/12/07	227	1.30%	17,176	9.70E+07
2	05/13/07	05/19/07	82	2.90%	2,843	2.61E+06
3	05/20/07	07/20/07	169	1.40%	12,084	7.20E+07
		Total	**478**		**32,103**	**1.72E+08**

Appendix C

Catch and Migration Estimates by Stratum for Bear Creek Sockeye, Chinook, Coho Salmon, and Cutthroat Trout, 2007.

Appendix C 1. Estimated catch and migration by stratum for Bear Creek sockeye, 2007.

Stratum	Date Begin	Date End	Total Estimated Catch	Capture Rate	Estimated Migration	Variance
1	02/02/07	02/08/07	776	7.90%	9,797	7.44E+06
2	02/09/07	02/11/07	672	9.30%	7,200	2.71E+06
3	02/12/07	02/12/07	405	8.00%	5,063	1.68E+06
4	02/13/07	02/13/07	244	8.00%	3,050	7.08E+05
5	02/14/07	02/15/07	1,019	12.00%	8,476	4.56E+06
6	02/16/07	02/18/07	1,887	13.30%	14,153	7.34E+06
7	02/19/07	02/19/07	3,931	8.00%	49,138	1.10E+08
8	02/20/07	02/20/07	2,665	9.00%	29,611	3.62E+07
9	02/21/07	02/23/07	5,936	10.20%	58,123	1.09E+08
10	02/24/07	02/25/07	1,416	8.70%	16,338	6.14E+07
11	02/26/07	02/26/07	1,724	11.50%	14,991	7.45E+06
12	02/27/07	02/27/07	404	9.30%	4,329	9.66E+05
13	02/28/07	03/04/07	6,840	7.00%	97,714	5.62E+08
14	03/05/07	03/05/07	1,761	7.50%	23,480	2.67E+07
15	03/06/07	03/06/07	3,707	9.50%	39,021	5.98E+07
16	03/07/07	03/08/07	19,432	7.00%	277,600	6.97E+09
17	03/09/07	03/11/07	41,208	7.00%	588,686	1.85E+10
18	03/12/07	03/12/07	8,469	7.50%	112,920	6.14E+08
19	03/13/07	03/13/07	16,879	7.50%	225,053	2.44E+09
20	03/14/07	03/15/07	24,829	11.50%	215,904	2.17E+09
21	03/16/07	03/18/07	39,558	10.50%	376,743	5.56E+09
22	03/19/07	03/19/07	33,291	7.00%	475,586	1.15E+10
23	03/20/07	03/20/07	26,152	6.00%	435,867	1.09E+10
24	03/21/07	03/22/07	31,567	5.00%	631,340	4.34E+10
25	03/23/07	03/25/07	20,565	1.50%	1,371,000	3.14E+11
26	03/26/07	03/26/07	3,708	4.50%	82,400	4.81E+08
27	03/27/07	03/27/07	5,874	8.00%	73,425	2.46E+08
28	03/28/07	03/29/07	6,196	9.00%	68,844	4.67E+08
29	03/30/07	04/01/07	16,554	9.00%	183,933	2.47E+09
30	04/02/07	04/02/07	5,198	10.50%	49,505	8.77E+07
31	04/03/07	04/03/07	1,918	10.50%	18,267	1.20E+07
32	04/04/07	04/05/07	13,532	11.00%	123,018	1.34E+09
33	04/06/07	04/08/07	21,985	11.50%	191,174	1.29E+09
34	04/09/07	04/09/07	2,657	11.00%	24,155	2.01E+07
35	04/10/07	04/10/07	2,185	10.50%	20,810	1.56E+07
36	04/11/07	04/15/07	2,170	10.70%	20,253	9.75E+07
		Total	**377,314**		**5,946,966**	**4.24E+11**

Appendix C 2. Estimated catch and migration by stratum for Bear Creek Chinook fry, 2007.

Stratum	Date Begin	Date End	Total Estimated Catch	Capture Rate	Estimated Migration	Variance
1	02/02/07	02/08/07	2	7.90%	25	3.63E+02
2	02/09/07	02/11/07	0	9.30%	0	0.00E+00
3	02/12/07	02/12/07	0	8.00%	0	0.00E+00
4	02/13/07	02/13/07	0	8.00%	0	0.00E+00
5	02/14/07	02/15/07	0	12.00%	0	0.00E+00
6	02/16/07	02/18/07	0	13.30%	0	0.00E+00
7	02/19/07	02/19/07	0	8.00%	0	0.00E+00
8	02/20/07	02/20/07	0	9.00%	0	0.00E+00
9	02/21/07	02/23/07	0	10.20%	0	0.00E+00
10	02/24/07	02/25/07	0	8.70%	0	0.00E+00
11	02/26/07	02/26/07	0	11.50%	0	0.00E+00
12	02/27/07	02/27/07	0	9.30%	0	0.00E+00
13	02/28/07	03/04/07	0	7.00%	0	0.00E+00
14	03/05/07	03/05/07	0	7.50%	0	0.00E+00
15	03/06/07	03/06/07	0	9.50%	0	0.00E+00
16	03/07/07	03/08/07	2	7.00%	29	4.96E+02
17	03/09/07	03/11/07	3	7.00%	43	5.61E+02
18	03/12/07	03/12/07	0	7.50%	0	0.00E+00
19	03/13/07	03/13/07	0	7.50%	0	0.00E+00
20	03/14/07	03/15/07	0	11.50%	0	0.00E+00
21	03/16/07	03/18/07	0	10.50%	0	0.00E+00
22	03/19/07	03/19/07	44	7.00%	629	2.70E+04
23	03/20/07	03/20/07	17	6.00%	283	8.15E+03
24	03/21/07	03/22/07	12	5.00%	240	3.09E+04
25	03/23/07	03/25/07	33	1.50%	2,200	6.04E+05
26	03/26/07	03/26/07	2	4.50%	44	8.38E+02
27	03/27/07	03/27/07	0	8.00%	0	0.00E+00
28	03/28/07	03/29/07	4	9.00%	44	4.66E+02
29	03/30/07	04/01/07	4	9.00%	44	4.66E+02
30	04/02/07	04/02/07	1	10.50%	10	7.43E+01
31	04/03/07	04/03/07	0	10.50%	0	0.00E+00
32	04/04/07	04/05/07	5	11.00%	45	6.91E+02
33	04/06/07	04/08/07	9	11.50%	78	7.34E+02
34	04/09/07	04/09/07	1	11.00%	9	6.76E+01
35	04/10/07	04/10/07	0	10.50%	0	0.00E+00
36	04/11/07	04/15/07	27	10.70%	252	5.99E+03
		Total	**166**		**3,976**	**6.81E+05**

Appendix C 3. Total catch and migration by stratum for Bear Creek Chinook parr, 2007.

Stratum	Date Begin	Date End	Total Catch	Capture Rate	Estimated Migration	Variance
1	04/16/07	04/28/07	38	28.60%	133	3.06E+03
2	04/29/07	05/05/07	325	33.70%	963	1.05E+04
3	05/06/07	05/12/07	790	52.30%	1,511	8.76E+03
4	05/13/07	05/18/07	1,200	46.30%	2,593	4.32E+04
5	05/19/07	05/26/07	1,209	38.00%	3,182	1.63E+05
6	05/27/07	06/02/07	1,262	39.60%	3,187	1.02E+05
7	06/03/07	06/09/07	274	33.30%	822	2.09E+04
8	06/10/07	06/16/07	81	40.00%	203	9.97E+02
9	06/17/07	06/23/07	59	44.80%	132	2.47E+02
10	06/24/07	07/10/07	38	41.90%	91	3.14E+02
		Total	**5,276**		**12,816**	**3.53E+05**

Appendix C 4. Total catch and migration by stratum for Bear Creek coho smolts, 2007.

Stratum	Begin	End	Catch	Rate	Migration	Variance
1	04/16/07	04/21/07	170	21.80%	779	1.47E+04
2	04/22/07	04/28/07	330	14.20%	2,330	2.46E+05
3	04/29/07	05/05/07	847	9.30%	9,075	2.13E+06
4	05/06/07	05/12/07	883	8.10%	10,891	3.89E+06
5	05/13/07	05/18/07	340	27.40%	1,241	1.87E+04
6	05/19/07	05/26/07	149	26.50%	562	8.50E+03
7	05/27/07	07/10/07	69	26.00%	266	2.42E+03
		Total	**2,788**		**25,143**	**6.31E+06**

Appendix C 5. Total catch and migration by stratum for Bear Creek cutthroat migrants, 2007.

Stratum	Date Begin	Date End	Total Catch	Capture Rate	Estimated Migration	Variance
1	04/16/07	04/21/07	133	12.40%	1,074	7.12E+04
2	04/22/07	04/28/07	39	8.30%	468	1.00E+05
3	04/29/07	05/05/07	64	17.60%	363	1.05E+04
4	05/06/07	05/12/07	62	8.70%	713	1.15E+05
5	05/13/07	05/19/07	107	18.60%	575	2.07E+04
6	05/20/07	05/26/07	70	18.00%	388	1.09E+04
7	05/27/07	07/10/07	32	11.10%	288	2.43E+04
		Total	**507**		**3,869**	**3.53E+05**

Citations

Literature Cited

Bjorkstedt, E. 2000. DARR (Darroch Analysis with Rank Reduction): A method for analysis of stratified mark-recaptured data from small populations with application to estimating abundance of smolts from outmigrant trap data. NOAA-NMFS Southwest Fisheries Science Center. Administrative Report SC-00-02. 28pp. http://santacruz.nmfs.gov/files/pubs/00116.pdf.............. 12

Bjorkstedt, E. 2005. DARR 2.0: Updated software for estimating abundance from stratified mark-recaptured data. NOAA-TM-NMFS-SWFSC 68. 21pp. http://santacruz.nmfs.noaa.gov/files/pubs/00439.pdf.. 12, 14

Chapman, D.G. 1951. Some properties of the hypergeometric distribution with applications to zoological sample censuses. Univ. CA Publ Stat. 1:131-160. 11

Cramer, S.P., J. Norris, P.R. Mundy, G. Grette, K.P. O'Neal, J.S. Hogle, C. Steward and P. Bahls. 1999. Status of Chinook salmon and their habitat in Puget Sound. Vol 2, Final Report. Prepared for Coalition of Puget Sound Businesses. S.P. Craemer & Assoc, Inc. Gresham OR............................ 5

Darroch , J.N. 1961. The two-sample capture-recapture census when tagging and sampling are stratified. Biometrika 48:241-260. 12

Goodman, L.A. 1960. On the exact variance of products. Journ Am Stat Assoc. 55:708-713........... 17

Marshall, A., M. Small and S. Foley. 2006. Genetic relationships among anadromous and non-anadromous *Oncorhynchus mykiss* in Cedar River and Lake Washington - implications for steelhead recovery planning. WDFW. Olympia and Mill Creek WA. 54pp.................................. 44

Seber, G.A.F. 1982. The estimation of animal abundance and related parameters, 2d ed. Charles Griffin & Co. London.. 11, 12

Seiler, D. and L. Kishimoto. 1996. Annual Report: 1995 Cedar River sockeye salmon fry production evaluation program. WA Dept Fish & Wildl. Olympia WA. 28pp.. 6, 16

Seiler, D., G. Volkhardt and L. Kishimoto. 2003. Evaluation of downstream migrant salmon production in 1999 and 2000 from three Lake Washington tributaries: Cedar River, Bear Creek and Issaquah Creek. WA Dept Fish & Wildl. Olympia WA. 199pp. 5, 6, 9

Seiler, D., S. Neuhauser and M. Ackley. 1981. Upstream/downstream salmonid project 1977-1980. WA Dept Fish Prog Rep No. 144. 195pp.. 5, 9

U.S. Army Corps of Engineers, Seattle District. 1997. Cedar River Section 205 flood damage reduction study. Final Environmental Impact Statement. 6

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

Personal Communication

Antipa, Brodie. Hatchery Manager: Rainier Complex. WA Dept Fish & Wildl, Puyallup WA. Electronic mail on January 2, 2007 26

Foley, Steve[a]. Fish & Wildlife Biologist- Region 4. WA Dept Fish & Wildl, Mill Creek. Electronic mail on December 12, 2007 .... 26, 37

Foley, Steve[b] Fish & Wildlife Biologist- Region 4. WA Dept Fish & Wildl, Mill Creek. Electronic mail on December 12, 2007. .... 32, 40

Ryding, Kirsten. Fisheries Biometrician. WA Dept Fish & Wildl. Olympia. December 2006. 12