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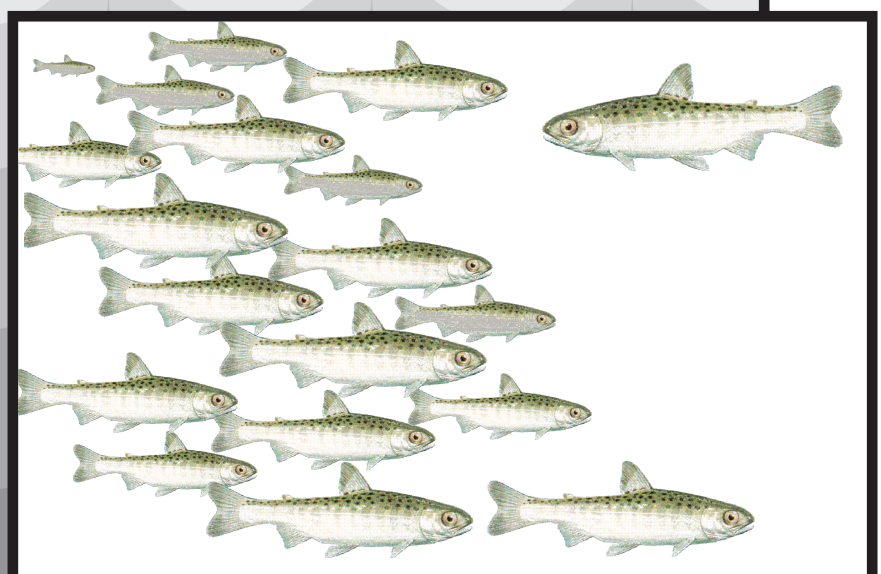
Evaluation of Juvenile Salmon Production in 2009 from the Cedar River and Bear Creek



by Kelly Kiyohara, and Mara Zimmerman

Washington Department of
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Evaluation of Juvenile Salmon Production in 2009 from the Cedar River and Bear Creek

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Success of these projects relied on the hard work of a number of dedicated permanent and temporary Washington Department of Fish and Wildlife (WDFW) personnel. The WDFW Hatcheries Program successfully collected adult sockeye broodstock and incubated eggs, releasing over 2.78 million sockeye fry into the Cedar River. Escapement data were collected and estimates developed by individuals from several agencies: Steve Foley, Larry Lowe, Dan Estell, Lacey Jeroue, and Jared Hoffer from WDFW; Mike Leslie and Brian Footen from the Muckleshoot Tribe; Karl Burton from SPU; and Hans Berge, Mistie Hammer, and Jim Lissa from King County DNRP. WDFW scientific technicians Paul Lorenz, Dan Estell, and Richard Warnick worked long hours, usually at night, in order to operate the traps, mark, identify, and count 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 from King County.

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Cedar River

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

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

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

The United States Geological Survey provided continuous flow monitoring.

Seattle Public Utilities communicated flow changes.

Bear Creek

Blockbuster Video provided electrical power.

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

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

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Executive Summary

This report describes downstream juvenile migrations of five salmonid species emigrating from two heavily spawned tributaries in the Lake Washington watershed: Cedar River and Bear Creek. Cedar River flows into the southern end of Lake Washington, and Bear Creek flows into the Sammamish River, which flows into the north end of Lake Washington. Abundance of juvenile migrants is a measure of salmonid production above the trapping location in each basin.

In 1992, the Washington Department of Fish and Wildlife (WDFW) initiated monitoring of sockeye fry production in the Cedar River to investigate causes of low adult sockeye returns. In 1999, this annual Cedar River trapping program was expanded from three to six months in length and in scope in order to estimate production of juvenile Chinook salmon. Production estimates of coho, steelhead, and cutthroat smolts were also made possible by the expanded trapping program.

In 1997, WDFW initiated an evaluation of juvenile sockeye production in the Sammamish basin. In 1997 and 1998, a juvenile trap was operated during the downstream sockeye migration in the Sammamish River. In 1999, this monitoring study was moved to Bear Creek in order to simultaneously evaluate Chinook and sockeye production. Since 1999, the Bear Creek study has also provided outmigration estimates of coho, steelhead and cutthroat smolts.

Cedar River

This report documents production and survival of 2008 brood year sockeye and Chinook from the Cedar River. These results contribute to an 18-year dataset for the Cedar River. The primary study goal was to estimate the 2009 migration of natural-origin sockeye and Chinook from the Cedar River into Lake Washington in 2009. This estimate was used to calculate survival of the 2008 brood from egg deposition to lake entry. In addition, this estimate provides early life history data useful for calculating survival among other life stages, including juvenile survival within Lake Washington (lake entry to smolt) and marine survival (smolt to returning adults).

A floating inclined-plane screen trap, located at river mile (R.M.) 0.8 in the Cedar River, was operated between February 1 and May 29 and captured a portion of the downstream migrant sockeye fry. Total migration was estimated to be 1.6 million ± 140,649 (95% C.I.) natural-origin sockeye fry. This estimate is based on a total catch of 80,964 and trap efficiencies ranging from 3.36% to 20.0%. Based on an estimated deposition of 25.1 million eggs, survival of natural-origin fry from egg deposition to lake entry was 6.5%. Over the season, 2.78 million hatchery-origin sockeye fry were released into the Cedar River below the inclined-plane trap. If survival of the released hatchery fry is assumed to be 100%, an estimated 4.4 million sockeye fry entered Lake Washington from the Cedar River in 2009.

In 2009, median migration date for natural-origin sockeye fry (March 19) was 2 days earlier than the average median natural-origin outmigration and 13 days later than that of hatchery fry release. Sockeye outmigration timing is correlated with February stream temperatures. Daily average temperatures in 2009 were slightly warmer (6.7°C) than the 18-year average (6.3°C).

Chinook outmigration was evaluated with two different traps. Small, early migrants were captured in an inclined-plane trap, also used to assess sockeye fry production. Large, late migrants were captured in a screw trap, operated April 22 through July 18 at R.M. 1.6. In 2009, the screw trap was operated at a new location from previous years in an effort to improve trap efficiencies. A total of 127,064 ± 38,312 (95% C.I.) natural-origin Chinook were estimated to have passed the inclined-plane trap between January 1 and April 21. This estimate was based on a total catch of 6,565 and trap efficiencies ranging from 3.4% to 20.0%. A total of 12,388 ± 2,621 (95% C.I.) natural-origin Chinook were estimated to have passed the screw trap between April 22 and July 18. This estimate is based on a total catch of 1,168 natural-origin juvenile Chinook in the screw trap and trap efficiencies ranging from 6.9% to 26.6%. Total 2009 production was estimated to be 139,452 ± 38,399 (95% C.I.) natural-origin Chinook.

Weekly average lengths of sub yearling Chinook increased from 39.7 mm fork length (FL) in January to 102.7 mm FL by the end of the season. Migration timing was bi-modal. Fry emigrated between January and mid-April and comprised 90.1% of the total migration. Parr emigrated between mid-April and July, constituting 8.9% of the total migration. Egg-to-migrant survival was estimated to be 5.2%.

A total of 52,691 natural-origin coho were estimated to have migrated passed the screw trap in 2009. This total included 651 coho estimated to have migrated before screw trapping began, 51,804 ± 7,091 (95% CI) coho estimated during the trapped period, and 236 coho following the trapping period. Steelhead and cutthroat production were not estimated for in 2009 due to low catches (1 steelhead and 44 cutthroat smolts).

Bear Creek

An inclined-plane trap was operated 100 yards downstream of the Redmond Way Bridge between February 2 and April 17. A screw trap replaced the inclined-plane trap April 20 and fished until June 30. Downstream migrant production was estimated for natural-origin sockeye fry, natural-origin age 0+ Chinook, coho and cutthroat smolts. Steelhead production was not assessed due to insufficient catch.

Sockeye fry migration in 2009 was estimated to be 327,225 ± 53,877 (95% C.I.). This estimate was based on a total catch of 38,003 sockeye fry and trap efficiencies ranging from 5.9% to 22.3%. Juvenile production, applied to deposition of an estimated 0.9 million eggs from the 2008 adult return, yielded a survival rate of 36.2%, the highest survival since trapping began in 1998.

Chinook production was estimated from catch in both the inclined-plane and screw traps. A total of 15,100 ± 6,167 (95% C.I.) Chinook were estimated to have migrated passed the inclined-plane trap between February 2 and April 17. This estimate is based on a total catch of 2,198 Chinook and efficiencies ranging from 5.9% to 22.3%. A total of 50,102 ± 12,995 (95% C.I.) Chinook were estimated to have migrated passed the screw trap between April 18 and June 30. This estimate is based on a total catch of 9,214 Chinook and screw trap efficiencies ranging from 1.96% to 50.7%. Total 2009 production was estimated to be 65,240 ±14,383 (95% C.I.) natural-origin age-0+Chinook.

Migration timing was bimodal. Fry emigrated between February and April and comprised 23.2% of the total migration. Parr emigrated between May and July. Egg-to-migrant survival was estimated to be 11.0%. Weekly average lengths of sub yearling Chinook migrants averaged 32.0 mm FL in February and increased to an average of 82.9 mm FL near the end of the season.

A total of 33,395 ± 6,555 (95% C.I.) natural-origin coho and 4,401 ± 1,751 (95% C.I.) cutthroat are estimated to have migrated from Bear Creek in 2009. No steelhead were caught in the Bear Creek screw trap during the 2009 trapping season.

Introduction

This report describes downstream juvenile migrations of five salmonid species emigrating from two heavily spawned tributaries in the Lake Washington basin: Cedar River and Bear Creek, also referred to as Big Bear Creek (Figure 1). Juvenile migrant abundances are the measure of salmonid production above the trapping location in each watershed. This long term study focuses on sockeye and Chinook salmon, two species of particular concern in the Lake Washington watershed.

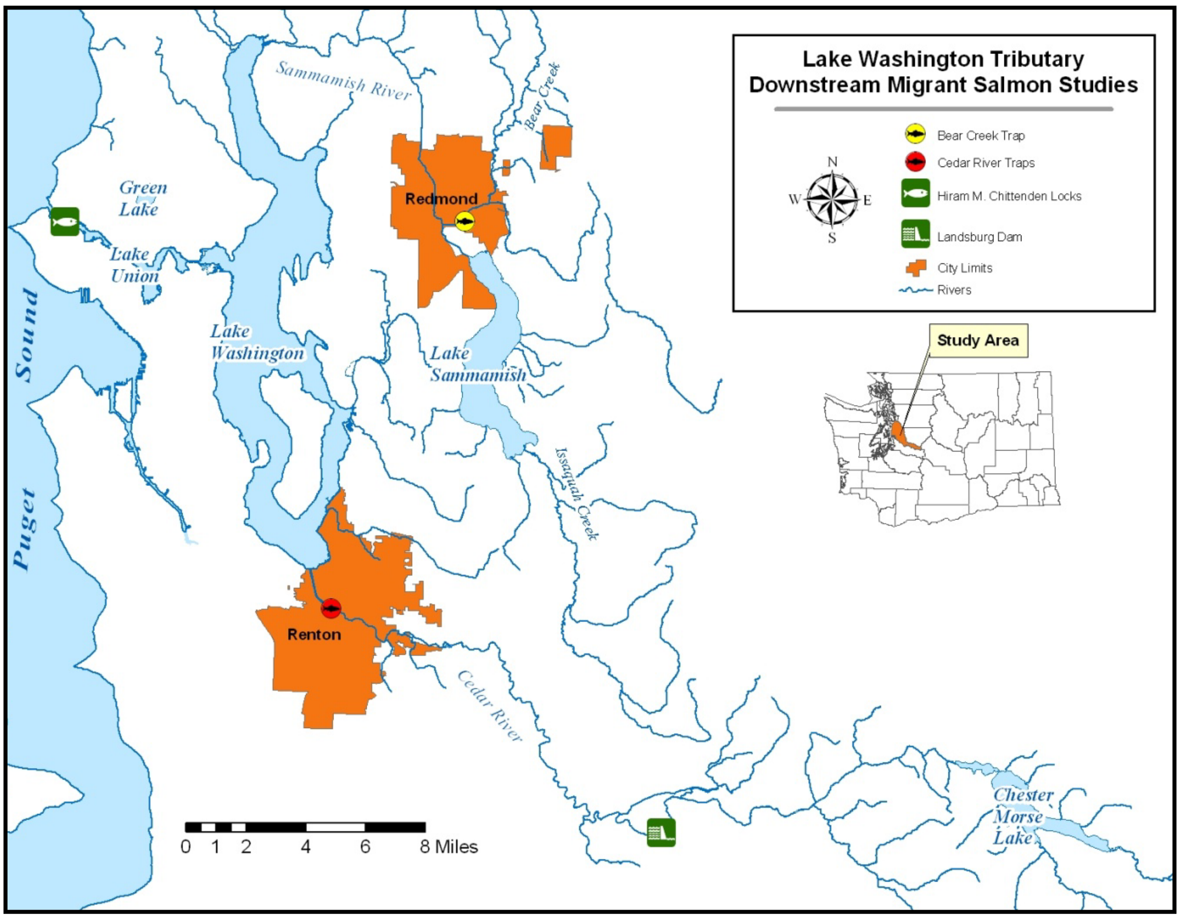


Figure 1. Map of Lake Washington tributary trap sites: Cedar River and Bear Creek, near Renton and Redmond, respectively.

Sockeye salmon have been a management concern in the Lake Washington watershed because of declining returns observed in the mid-1980s to 1991. Although over 500,000 sockeye spawners returned through the Ballard Locks in 1988, by 1991, less than 100,000 sockeye returned. In 1991, a broad-based group was formed to address this decline. Resource managers developed a recovery program that combined population monitoring with artificial production. These efforts continued through 2009 and provide information useful for improving management of Lake Washington sockeye salmon.

Sockeye life history can be partitioned into a freshwater phase and a marine phase. For the 1967 to 1993 broods, marine survival averaged 11% and varied eight-fold (2.6% to 21.4%), with no apparent decline (WDFW unpublished). In contrast, freshwater survival, measured by smolts produced per spawner, declined over this same period. These observations pointed to freshwater survival as an important contributor to the declines of Lake Washington sockeye.

The freshwater phase of sockeye production occurs in two habitats. In the stream habitat, sockeye spawn, eggs incubate, and fry emerge and migrate to the lake. Growth from fry to smolt stages occurs in the lake, where virtually all of the juveniles rear for one year before emigrating to the ocean. Partitioning survival between these habitats will help explain causes of population decline. In the Lake Washington watershed, monitoring of natural and hatchery-origin sockeye was initiated in 1992 in the Cedar River and in 1997 in the Sammamish Slough. Monitoring in the Sammamish has continued in Bear Creek since 1999.

Chinook salmon are a management concern in the Lake Washington watershed due to the "threatened" status of the Puget Sound Chinook ESU under the Endangered Species Act (March 1999). Increased understanding of habitat requirements, early life history, freshwater productivity and survival of Chinook salmon should improve planning of recovery efforts in the Lake Washington watershed. At the time of listing, baseline information included the number of Chinook spawners; however, adult-to-adult survival provides little insight into life stage-specific survival in freshwater or marine habitat. Combining information on adult spawners and juvenile migrants separates survival into freshwater and marine components and provides a more direct accounting of the role that stream habitats play in regulating salmon production (Seiler *et al.* 1981, Cramer *et al.* 1999). As recovery efforts are often associated with particular life stages (e.g., freshwater rearing habitat versus marine harvest), partitioning of survival among life stages will provide valuable information for the recovery planning process.

Downstream migrant evaluations of Chinook were initiated in 1999 in both the Cedar River and Bear Creek (Seiler *et al.* 2003). The Chinook migration spans a period of nearly 6 months and includes an early migration of newly emerged fry and a later migration of larger Chinook (i.e, parr). Two different gear types have been used to sample the entire Chinook migration. An inclined-plane trap gently captures early-timed fry but is ineffective at capturing larger migrants later in the season. A screw trap more effectively catches the late-timed parr migration.

Cedar River

The WDFW has operated a floating inclined-plan trap in the lower Cedar River since 1992. This trap is used to evaluate outmigrant abundances and survival of natural-origin and hatchery sockeye fry. Production of sockeye fry at the Landsburg Hatchery on the Cedar River began with the 1991 brood. All sockeye incubated at the Landsburg Hatchery can be identified with thermally-induced otolith marks (Volk *et al.* 1990). Annual sockeye returns since 1991 range from 15,995 to 230,000 spawners, and average 94,350 spawners. Egg-to-migrant survival of natural-origin spawners have ranged from 1.9% to 31.95%.

Water flow is a key variable influencing survival of hatchery and natural-origin sockeye in the Cedar River. In-river survival of hatchery releases is positively influenced by higher flow during the release period, as demonstrated in a 1995 study conducted by WDFW (Seiler and

Kishimoto 1996). In-river survival of natural-origin sockeye from egg deposition to fry emigration, is negatively correlated with the magnitude of peak flows during egg incubation period, as demonstrated by the eighteen-year data set on Cedar River sockeye obtained and compiled by the WDFW. Based on available information, numbers of natural-origin sockeye fry entering Lake Washington are the product of the number of eggs deposited (i.e., spawner returns) and flow-induced survival rates during incubation and migration.

Bear Creek

Bear Creek is one of the more heavily spawned tributaries in the Sammamish watershed. When the juvenile salmonid study in the Sammamish watershed began in 1997, sockeye were returning to Bear Creek in excess of 50,000 spawners. Over the duration of the juvenile salmonid study, escapement has ranged from 577 to 60,000 spawners, with an average return of 14,896 sockeye.

Location of trapping operations has changed over the 12-year study period. In 1997 and 1998, a downstream migrant trap was operated in the Sammamish Slough at Bothell. Catches in this trap were used to estimate the contribution of the Sammamish portion of the watershed to the sockeye fry migration into Lake Washington. While this operation successfully estimated sockeye fry production, velocities in the Sammamish Slough were too low to capture migrants larger than sockeye fry, such as Chinook parr, coho, and cutthroat smolts. In 1999, the migrant trapping operation was moved upstream to Bear Creek, a tributary of the Sammamish River, where velocities were high enough to capture larger migrants. In addition to estimating Chinook and sockeye production, higher velocities also enabled measures of coho, steelhead and cutthroat production.

Goals and Objectives

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

Chinook

1. **Estimate in-river survival.** In-river survival is estimated from total migrant production and estimated egg deposition. Correlation between in-river survival and variables such as spawner abundance, flows, and habitat condition will identify density dependent and independent factors limiting juvenile production.
2. **Determine variables contributing to juvenile production.** Identifying variables that limit production of both life history stages will inform management on the current carrying capacities for each watershed.
3. **Estimate lake/marine survival of natural production.** Survival from river outmigration to returning spawners indicates the relative contribution of early riverine survival to lake/locks/marine survival for Chinook abundance.
4. **Identify variable contributing to life history diversity.** Chinook migrate at two different life stages, fry and parr. Identifying variables that contribute to life history diversity of Chinook will provide understanding of fry and parr migration components and migration timing.

Sockeye

1. **Estimate in-river survival**. Overall success of natural spawning sockeye will be determined from natural-origin fry production and estimated egg deposition. Variation in survival among broods, as a function of spawner abundance and flows will be evaluated to assess stream carrying capacity and the relative importance of environmental variables.
2. **Determine variables contributing to juvenile production**. Rearing survival within the lake can be determined from the combined estimate of natural-origin and hatchery fry entering the lake and smolt production the following spring. This information can be used to evaluate the carrying capacity of Lake Washington.
3. **Estimate incidence of hatchery fry in the population at lake entry (Cedar River).** Relative survival of hatchery and natural-origin sockeye can be determined from comparing the proportion of hatchery and natural-origin sockeye at the fry life history stage with the incidence of hatchery and natural-origin fish in the sockeye population at later life stages (smolts and adults).
4. **Compare migration timing of natural-origin and hatchery fry.** Identification of environmental variables that influence migration timing of natural-origin sockeye will contribute to in-season decisions on hatchery releases and improve in-season estimates of production. A comparison of migration timing and subsequent survival of hatchery versus

natural-origin sockeye fry will contribute to the adaptive management process guiding Cedar River Hatchery sockeye fry production and release.

Coho, Cutthroat and Steelhead

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

Methods

Fish Collection

Trapping Gear and Operation

Cedar River

Two traps were operated in the lower Cedar River during the spring out-migration period. A small floating inclined-plane trap was operated late winter through spring to trap sockeye and Chinook fry emigrating during this period. The design of this trap was chosen to avoid capture of yearling migrants and predation in the trap. A floating rotary screw trap was operated early spring through summer to assess migration of larger sub-yearling Chinook as well as coho, steelhead, and cutthroat smolts. This trap captured larger migrants that were potential predators of sockeye fry; therefore, the live box was designed so as to not retain sockeye fry. Together, these traps provided production estimates for each species while minimizing mortality.

The inclined-plane trap consists of one or two low-angle inclined-plane screen (scoop) traps (3-ft wide by 2-ft deep by 9-ft long) suspended from a 30x13 ft steel pontoon barge. Fish are separated from the water with a perforated aluminum plate (33 - 1/8 in. holes per in^2). The inclined-plane trap resembles larger traps used to capture juvenile salmonids in the Chehalis and Skagit rivers, described in Seiler *et al.* 1981. Each scoop trap screens a cross-sectional area of 4 ft^2 when lowered to a depth of 16 inches. The screw trap consisted of a 5 ft diameter rotary screw trap supported by a 12-ft wide by 30-ft long steel pontoon barge (Seiler *et al.* 2003).

Over the 18-year course of the Cedar River juvenile salmonid study, trapping operations have been modified in response to changes in channel morphology and project objectives. In summer 1998, the lower Cedar River was dredged to reduce flooding potential (USACE 1997). Dredging lowered the streambed, created a wider and deeper channel, and reduced water velocity near the inclined-plane trap location to near zero. In response to the change in channel morphology, the inclined-plane trap location was moved upstream in 1999 in order to operate under suitable current velocities.

In 2009 the inclined-plane trap was positioned at RM 0.8, just downstream of the South Boeing Bridge (Figure 2). This trap fished off the east bank and was repositioned within eight feet of the shoreline in response to changing flows. Two scoop traps were fished in parallel throughout the season except on 3 nights when only one trap was operated due to high flows and debris loads.

Damages accrued by record high flows in the Cedar River in early January 2009 delayed trap installation and operation until early February. The inclined-plane trap was operated 79 nights between February 1 and May 29, 2009. During each night of operation, trapping began before dusk and continued past dawn. Trapping was also conducted during periodic daylight intervals to assess daytime movement. Daytime trapping consisted of eleven daytime periods and was conducted nearly once a week from the beginning of February through the end of April. Inclined-plane trap operations were suspended for a total of three hours over two nights during the season.

During both evenings the screw trap required immediate attention for repairs and debris loads, and the inclined-plane trap could not fish unattended because flows and debris were too high. Captured fish were removed from the trap, identified by species, and counted each hour. All salmonid species, except for sockeye, were randomly sampled for measuring fork length.

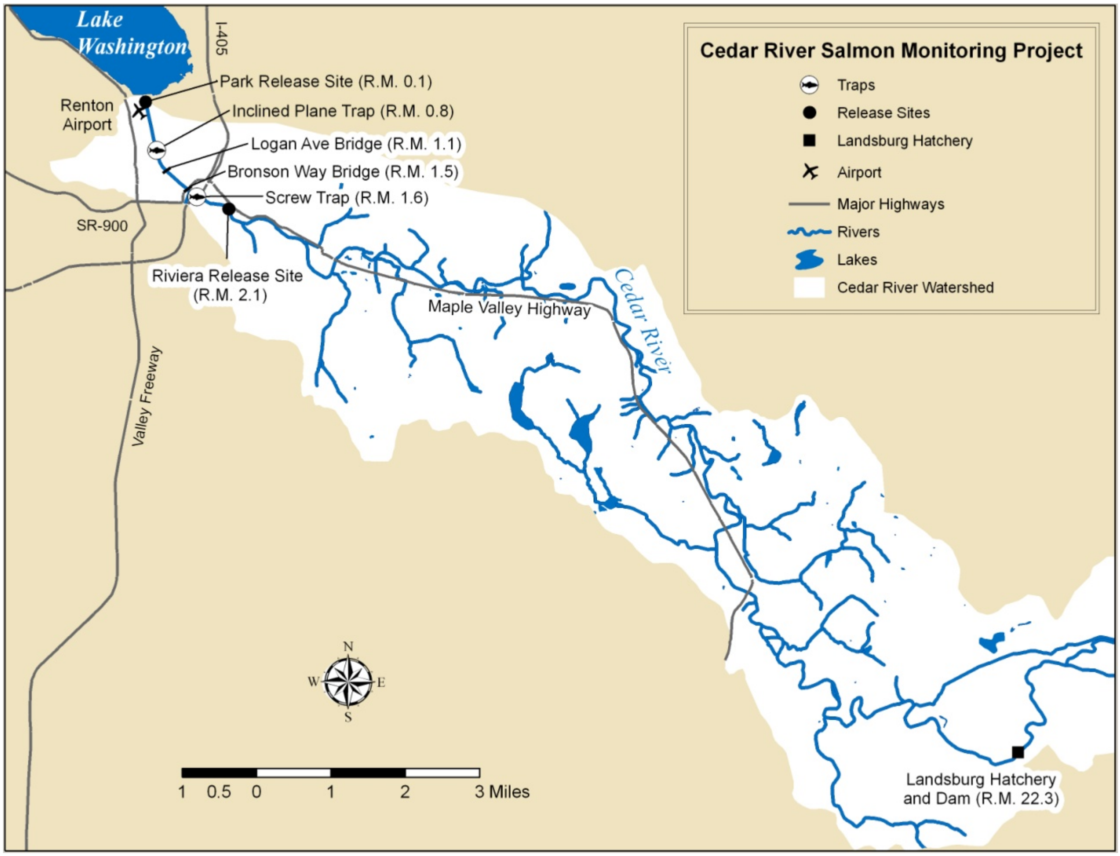


Figure 2. Site map of the lower Cedar River watershed depicting the inclined-plane and screw trap locations and hatchery sockeye release site for the 2009 trapping season.

In 2009, the screw trap operated in a new location (R.M 1.6) just under the I-405 Bridge (Figure 2). Prior to 2009, the screw trap had been positioned roughly 300 yards downstream of the Logan Avenue Bridge (RM 1.1). This site downstream did not provide optimal conditions for trapping in 2006 to 2008 and prompted the search for a better trap location. Although safety and security at the I-405 site were of initial concern, this site proved to be an ideal location throughout the season.

The screw trap was operated between April 22 and July 18, except during 9 nights outage periods (April 26, 27, 28, May 25, June 1, 11, 19, and July 10 and 18) caused by high debris loads and 18 day periods when the trapping was intentionally halted due to public safety concerns. Catches were enumerated at dusk and in the early morning in order to discern diel movements. All Chinook, coho, steelhead, and cutthroat smolts were enumerated by species and randomly sampled for size (fork length, FL).

Bear Creek

As with the Cedar River, outmigrating salmonids were captured using two traps in lower Bear Creek. An inclined-plane trap, identical to that employed in the Cedar River, was used to capture sockeye and Chinook fry early in the trapping season. This trap was replaced with a 5 ft diameter screw trap in mid April to capture Chinook, coho, steelhead, and cutthroat. In response to the discovery of beaver dams that were impeding water flow below the trap during the 2008 season, flexible pipe pond levelers were installed in September 2008. As a result, adequate velocities for trapping were restored at the trap site.

The inclined-plane trap was operated between February 2 and April 17. A single scoop trap was suspended from a 30x12 ft steel pontoon barge positioned in the middle of the channel approximately 100 yards downstream of Redmond Way, below the railroad trestle (Figure 3). When the trap was operated, fishing began before dusk and continued past dawn. During trap operations, captured fish were removed from the trap and enumerated. Depending on catch rates, fish were removed from the trap every hour or every several hours. The inclined-plane trap did not fish during daytime hours. On April 20, 2009 the screw trap was hung in place of the inclined-plane trap and fished for the remainder of the season.

The screw trap was operated between April 22 and June 30, except during four outage periods (May 20, 30, and June 2 and 4) caused by debris. 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 (FL).

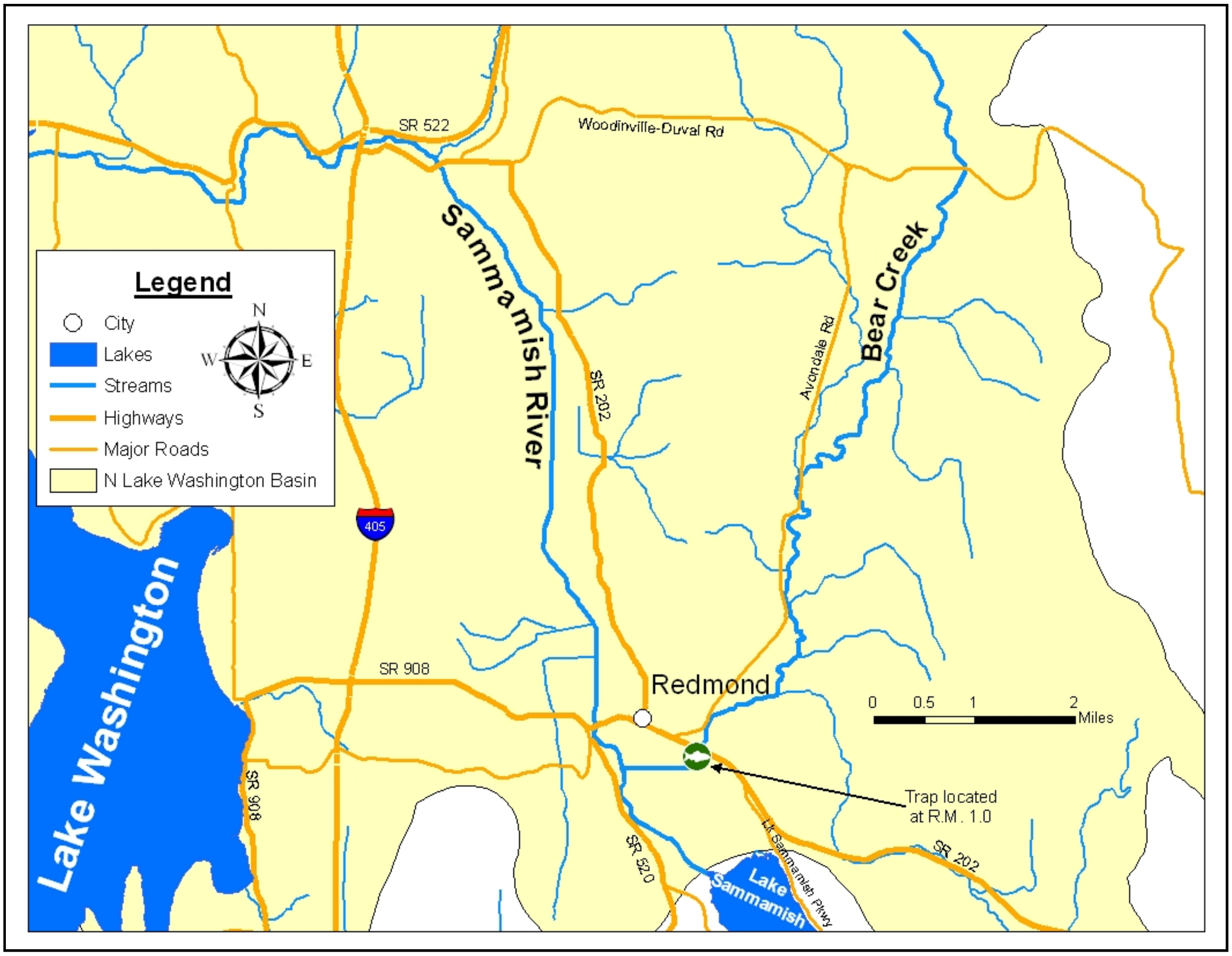


Figure 3. Site map of the Bear Creek watershed in the North Lake Washington Basin depicting trap location for the 2009 trapping season.

Trap Efficiencies

Cedar River

Inclined-Plane Trap

Trap efficiencies of the Cedar River inclined-plane trap were estimated from recaptures of marked fish released above the trap. Mark groups were natural-origin or hatchery sockeye fry. Natural-origin sockeye fry captured in the early hours of the night were used for efficiency trials when possible. Due to low catches, hatchery fry obtained from Landsburg Hatchery were used for eleven separate efficiency trials throughout the season. In nine of those instances, fry were not fed prior to release; the remaining two groups had been fed. Hatchery fry were removed from the hatchery groups within a day of moving fry into ponds to prepare them for feeding and release. All fry used for efficiency trials were marked in a solution of Bismarck brown dye (14 ppm for 1.5 hours). The health of marked fish was assessed prior to release. Deceased or compromised fish were not included in releases. Release groups, ranging from 25 to 878 marked sockeye fry, were released at the Logan Street Bridge (R.M. 1.1) nearly every night the trap operated (79 nights) throughout the season. At the release location, marked fry were distributed across the middle of the channel. Catches were examined for marked fish and recaptures were noted during each trap check.

Screw Trap

Trap efficiencies of the Cedar River screw trap were determined for Chinook, coho, and cutthroat from recaptures of marked fish released above the trap. Trap efficiency trials were conducted for each species. Fish were anesthetized in a solution of MS-222 and marked with alternating upper and lower, vertical and horizontal partial-caudal fin clips. Marks were changed on weekly intervals or more frequently when there was a significant change in water flow. Marked fish were allowed to recover from the anesthetic during the day in perforated buckets suspended in calm river water. In the evening, groups were released approximately 1,200-yds upstream of the trap (Riviera release location). Releases occurred over multiple-, one- or two-day intervals throughout each week, varying from 1 to 100 juveniles of each species per release. Due to low catches, release groups in 2009 were smaller in number than those in previous years. Catches were examined for marks or tags and recaptures were noted during each trap check.

After May 5, Chinook longer than 65 mm FL were tagged with Passive Integrated Transponder tags (PIT tags) while smaller Chinook continued to be fin clipped. Similar to fin marks, PIT tags enabled stratified release and recaptures to be evaluated during data analysis. In addition, individual fish could be identified from the PIT tags, providing information on recapture timing for release groups of Chinook parr.

Bear Creek

Inclined-Plane Trap

Trap efficiencies for the Bear Creek inclined-plane trap were estimated from recaptures of marked sockeye fry released above the trap. Release groups ranged from 43 to 1,260 sockeye and were released approximately 100 yards upstream of the trap at the Redmond Way Bridge. Fry releases occurred on 29 nights throughout the season, as adequate numbers of fish were available. Fry captured in the early hours of the night were marked in a solution of Bismarck brown dye (14 ppm for 1.5 hours). The health of marked fish was assessed prior to release. All deceased or compromised fish were not included in releases. Catches were examined for marks and recaptures were noted during each trap check.

Screw Trap

Trap efficiencies for the Bear Creek screw trap were estimated for Chinook, coho, and cutthroat using the same approach described for the Cedar River screw trap. Efficiency trials, ranging from 1 to 60 individuals of each species, were released from the Redmond Way Bridge.

Analysis

Production was the abundance of juvenile downstream migrants. Abundance was estimated using a single-trap mark-recapture approach stratified by time. The general approach was to (1) calculate total catch, (2) group efficiency trials into strata (3) calculate abundance for each strata, (4) extrapolate migration prior to and post trapping, and (5) calculate total production.

Cedar River

Inclined-Plane Trap

Sockeye

Calculate Total Catch

Total catch ($\hat{n}_2$) was the actual catch (u) summed with estimated missed catch ($\hat{u}$) during periods of trap outages. Missed catch was estimated using three different approaches depending on what type of trap outage occurred: 1) entire night periods when trap operations were suspended, 2) partial night periods when trap operations were suspended, and 3) day periods when trap operations were suspended. Three approaches were used because previous work has demonstrated that catch rates of sockeye differ between the day and night time hours.

Estimated Catch for Entirely Missed Night Samples

When trapping was suspended for entire night periods, missed catch was estimated using a straight-line interpolation between catches on adjacent nights. When catch was estimated for a single night, variance of the estimated catch was the variances of the mean catch on adjacent nights (Equation 1). If one or both adjacent night catches were estimates, then Equation 2 was used.

Equation 1

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

Equation 2

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

where:

n = number of sample nights used in the interpolation

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

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

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

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

Equation 3

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

Estimated Catch for Partially Missed Nighttime Sampling

Sockeye catch was also estimated for night periods when trap operations were partially suspended. Where the trap was operated intermittently through the night, catch during the un-fished interval(s) ($\hat{u}_z$) was estimated by:

$$\hat{u}_z = T_z * \overline{R} \qquad \text{Equation 4}$$

where:

T_z = Hours during non-fishing period z

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

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

$$Var(\hat{u}_z) = T_z^{\,2} * Var(\overline{R}) \qquad \text{Equation 5}$$

Total catch of unmarked fish on night i ($\hat{u}_i$) was the sum of actual catches from the fished periods, and estimated catches from the un-fished periods. Variance of the total night catch [$Var(\hat{u}_i)$] was the sum of all variances for the un-fished period during night i.

Estimated Catch for Missed Daytime Samples

Daytime sockeye catches were estimated by multiplying the previous night catch by the proportion of the 24-hour catch caught during the day. This proportion (F_d) was estimated as:

$$F_d = \frac{T_d}{\overline{Q}^{-1} T_n + T_d} \qquad \text{Equation 6}$$

Variance in the day:night catch ratio was:

$$Var(F_d) = \frac{Var(\overline{Q}) T_n^{\,2} T_d^{\,2}}{\overline{Q}^4 \left(\frac{1}{\overline{Q}} T_n + T_d \right)^4} \qquad \text{Equation 7}$$

where:

T_n = hours of night during 24 hour period,

T_d = hours of day during 24 hour period, and

$\overline{Q}_d$ = season average day:night catch ratio.

Group Efficiency Trials into Strata

When using a mark-recapture approach to estimate abundance, precision of the estimate increases with the number of recaptures. A manufactured drawback of too many stratifications is high variance associated with the estimate. Therefore, a G-test was used to determine whether to pool or hold separate adjacent efficiency trials (Sokal and Rohlf 1981) .

Of the marked fish (M) released in each efficiency trial, a portion are recaptured (R) and a portion are not seen (M-R). If the seen:unseen [R:(M-R)] ratio differs between trials, the trial periods were considered as separate strata. However, if the ratio did not differ between trials, the two trials were pooled into a single stratum. A G-test determined whether adjacent efficiency trials were statistically different at an α-level of 0.05. Trials that did not differ were pooled and the pooled group compared to the next adjacent efficiency trial. Trials that did differ were held separately. Pooling of time-adjacent efficiency trials continued iteratively until the seen:unseen ratio differed between time-adjacent trials. Once a significant difference was identified, the pooled trials are assigned to one strata and the significantly different trial is the beginning of the next strata.

Calculate Abundance for Each Strata

Abundance for a given strata hj was calculated from total catch ($\hat{n}_2$), marked fish released in that strata ($\hat{n}_1$), and marked fish recaptured in that strata ($\widehat{m}_2$). Abundance was estimated using a Peterson estimator with a Chapman correction (Seber 1973).

Equation 8

$$\hat{N}_h = \frac{(\hat{n}_{2h}+1)(n_{1h}+1)}{(m_{2h}+1)}$$

Variance associated with the Peterson-Chapman estimator was modified to account for variance of the estimated catch during trap outages (derivation in Appendix A):

Equation 9

$$V(\hat{N}_h) = Var(\hat{n}_{2h})\left(\frac{(n_{1h}+1)(n_{1h}*m_{2h}+3n_{1h}+2)}{(m_{2h}+1)^2(m_{2h}+2)}\right)+\left(\frac{(n_{1h}+1)(n_{1h}-m_{2h})*\hat{n}_{1h}*(\hat{n}_{1h}+m_{2h}+1)}{(m_{2h}+1)^2*(m_{2h}+2)}\right)$$

Extrapolate Migration Prior to and Post Trapping

A portion of the outmigration occurred outside the period of trap operation. Modality of the trap catches suggested that this migration was minimal. Pre and post trapping migrations were estimated using linear extrapolation.

Equation 10

$$\hat{N}_e = \frac{\sum_{d=1}^{d=k}\hat{N}_d}{k}*\frac{t}{2}$$

Variance of the extrapolation was estimated as:

Equation 11

$$V(\hat{N}_e) = \frac{\sum_{d=1}^{d=k}(\hat{N}_d - \overline{N})^2}{k(k-1)} * \left(\frac{t}{2}\right)^2$$

where:

$\hat{N}_d$ =Daily migration estimates,

k = Number of daily migration estimates used in calculation, and

t = Number of days between assumed start/end of migration and the first/last day of trapping.

Pre and post season migration was based on the first and last two days of measured migration. The beginning and end of the assumed migration for sockeye in the Cedar River was January 1 through June 30. Chinook migration was assumed to occur between January 1 and July 13. Coho migration was assumed to occur between April 1 and July 13. Migration end dates may change if catches indicate that the migration is still occurring. Assumed migration for Bear Creek sockeye was January 1 through April 30. Chinook migration was assumed to be January 1 through June 30 and coho migration was assumed to be April 1 and continue through June 30. If there are multiple consecutive days at the beginning or end of the trapping period when catch is zero, migration is assumed to have not begun or already concluded, and pre or post trapping was not estimated.

Calculate Total Production

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

Equation 12

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

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

Chinook

Chinook fry migration during the inclined-plane trapping period was estimated using the same methods described for estimating sockeye. Sockeye fry efficiency trials were used as a surrogate for calculating Chinook migrations from Chinook catches. Procedures used to estimate variance associated with missed Chinook catch in the inclined-plane trap were identical to those described for sockeye fry. One difference from the sockeye calculations was that daytime migrations of Chinook were estimated by applying weekly (rather than seasonal) day:night catch ratios. This approach was used because day:night ratios were more variable for Chinook than sockeye throughout the trapping season.

Screw Trap

Chinook, Coho, and Trout

Calculate Total Catch

All missed catch for a given period *i* in the screw trap was estimated as:

Equation 13

$$\hat{u}_i = \overline{R} * T_i$$

where:

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

T_i= time (hours) during missed fishing period *i*.

Variance of total catch was estimated as:

Equation 14

$$Var(\hat{n}_2) = Var(\hat{u}_i) = T_i^2 * Var(\overline{R})$$

Group Efficiency Trials into Strata

For Chinook, coho and trout caught in the Cedar River screw trap, efficiency trials were stratified by temporal flow changes. This approach was used because flows oscillated dramatically on the Cedar River during most of screw trap operations. Three strata were formed; 0-500 cfs, 500-900 cfs, and flows over 900 cfs. The G-test was not used for stratification.

Steps 3, 4, and 5 in estimating total downstream migrant production were similar to that described for the inclined-plane trap.

Bear Creek

Downstream migrant production calculated from inclined-plane and screw trap on Bear Creek were estimated using a similar approach to that used with Cedar River data. One difference between the analyses was the estimation of daytime catch during inclined-plane trapping. Whereas day catches in the Cedar River were estimated using day:night catch ratios (*Q*), missed day catches were not estimated in Bear Creek. Previous years' sampling has indicated that day migrations are minimal in Bear Creek. Variances of missed night catches in the Bear Creek inclined-plane trap were estimated using Equation 1 or Equation 2. A second difference between the analyses for Cedar River and Bear Creek was the stratification of efficiency trials in the screw trap. Whereas efficiency trails were stratified by flow for the Cedar River screw trap, the G-test approach was applied to Bear Creek efficiency trails.

Egg-to-Migrant Survival

Cedar River

Egg-to-migrant survival for Cedar River sockeye was the natural-origin fry migration divided by the potential egg deposition (PED) for the Cedar River. PED was based on an Area Under the Curve (AUC) escapement estimate of 15,995 spawners (S. Foley, Washington Department of

Fish and Wildlife, personal communication), an assumed even sex ratio, and an average fecundity of 3,135 eggs per female (Cuthbertson 2009) Spawner abundance was calculated and agreed upon in a multi-agency effort to survey adult returns each year. Fecundity was derived from the average number of eggs per female during 2008 sockeye brood stock collection for the Landsburg Hatchery on the Cedar River.

Egg-to-migrant survival for Cedar River Chinook was based on 2009 juvenile migrant abundance, 599 Chinook redds in 2008, and an assumed fecundity of 4,500 eggs per female (Burton et al. 2009). The number of females was based on annual redd counts conducted by state, local and tribal agencies and assumed one female per redd. The assumed Chinook fecundity was derived from the Chinook fecundity as measured at the Soos Creek Hatchery (M. Wilson, Washington Department of Fish and Wildlife, personal communication).

Bear Creek

Egg-to-migrant survival for Bear Creek sockeye and Chinook were similar to methods described in the Cedar River section above.

Sockeye egg deposition was based on an estimated 577 adult sockeye spawners returning to Bear Creek in 2008 (S. Foley, Washington Department of Fish and Wildlife, personal communication), an assumed even sex ratio, and the assumption that Bear Creek sockeye have the same fecundity as Cedar River sockeye (3,135 eggs per female).

Chinook egg deposition was based on 132 redds in Bear Creek and an assumed fecundity of 4,500 eggs per female (Burton et al. 2009). Chinook fecundity was based on the Chinook fecundity measured at Soos Creek Hatchery (M. Wilson, Washington Department of Fish and Wildlife, personal communication).

Cedar River Results

Sockeye

Catch and Estimated Missed Catch

A seasonal total of 55,507 natural-origin sockeye fry were caught in the inclined-plane trap during trap operations. An estimated 2,208 fry should have been captured had the trap fished during daytime periods, representing 2.7% of the season's total catch. Eleven day intervals were trapped to evaluate daytime migration: February 3, 10, 17, 24, March 3, 11, 18, 24, 30, and April 7 and 14. Flows ranged from 486 cfs to 1,089 cfs and are believed to have accurately captured the range of flows experienced during night operations throughout the season. Day:night catch ratios ranged from 0% to 85.7%.

An additional 23,250 sockeye fry should have been caught had the inclined-plane trap fished continuously, without high water or debris outages, every night between February 1 and May 29, 2009. Based on actual and estimated missed catches, total seasonal catch in the inclined-plane trap was 80,965 sockeye.

Production Estimate

A total of 58 efficiency trials, ranging in size from 25 to 878 sockeye, were released. Original efficiency trials were aggregated into eight final strata. Recapture rates for the final strata ranged from 3.36% to 20.00%. Capture rates of hatchery fry, as surrogates for natural-origin sockeye, were included in strata used to estimate total production.

Migration was low at the beginning of the season, slowly increasing to its first peak of 58,000 sockeye on March 2. Migration decreased but stayed above 10,000 sockeye per day then peaked again at 64,800 sockeye on March 24. Thereafter, daily migration declined with pulses of fish ranging from a few hundred to 30,000 from March 25 through the end of the May.

An estimated 4.42 million sockeye fry entered Lake Washington from the Cedar River in 2009 (Table 1, Figure 4, Appendix B1). This migration included 1.64 million ± 140,649 (95% C.I.) natural-origin fry and 2.78 million hatchery fry. Pre-season migration, January 1 through January 30, was estimated to be 8,927 fry, and the post-season migration, May 30 through June 30, was estimated to be 1,193 fry. Both pre- and post-season tails each represent less than 1% of the total natural production. Coefficient of variation (*CV*) associated with the natural-origin migration was 4.4%.

Table 1. Cedar River natural-origin and hatchery sockeye fry migrations entering Lake Washington with 95% confidence intervals, 2009.

Component	Period	Dates	Estimated Migration	CI 95% Low	CI 95% High	CV	Proportion of Total
Natural Origin	Before Trapping	January 1 - 31	8,927	7,411	10,443	8.7%	0.5%
	During Trapping	February 1- May 29	1,630,081	1,489,440	1,770,722	4.4%	99.4%
	After Trapping	May 30- June 30	1,193	1,013	1,373	7.7%	0.1%
		Subtotal	**1,640,201**	**1,499,552**	**1,780,850**	**4.4%**	
Hatchery	Below Trap	February 17 - April 2	2,783,000				
		Subtotal	**2,783,000**				
		Total	**4,423,201**				

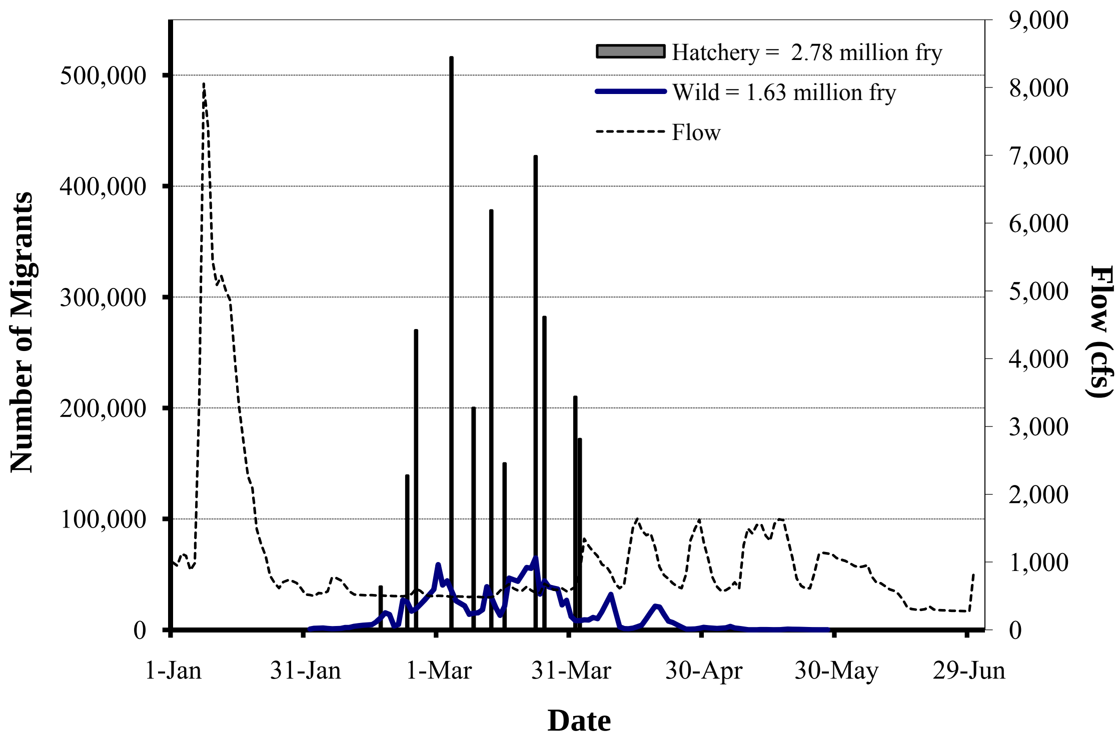


Figure 4. Daily migration of natural-origin and hatchery Cedar River sockeye fry into Lake Washington from February 1to May 28, 2009 and daily average flow (USGS Renton gage Station #12119000) in 2009.

Natural-Origin and Hatchery Timing

In 2009, hatchery sockeye were released downstream of the trap at the mouth of the Cedar River. Releases of hatchery fry began on February 17 and continued through April 2 (Table 2). Median migration date for hatchery fry released downstream of the inclined-plane trap was March 6 (Table 3).

Natural-origin fry migration was under way when trapping began on February 1. Natural-origin migration escalated to two major peaks on March 1 and March 23 (Figure 4). After the peak, migration declined more rapidly than they increased to the peak. The median migration date for natural-origin fry occurred on March 19, thirteen days later than the hatchery median migration date (Table 3). Migration was 25%, 50% and 75% completed by March 4, March 19, and March 28, respectively (Figure 5).

Stream temperatures were correlated with median migration date. After evaluating temperature data throughout the period of fry incubation and migration, total thermal units in the Cedar River for the month of February best explained observed variation in migration timing ($R^2 = 0.52$, Figure 6). Temperature data was acquired from the USGS Renton gage Station # 12119000. February stream temperatures averaged 6.7° C in 2009, slightly warmer than the 18-year average of 6.3°C. Median migration date was close to the 18-year average median migration date (Table 3). The 2001 fry migration was not included in this analysis. This point was treated as an outlier due to extreme low flows that may have increased predation and an earthquake (February 28), which triggered a landslide that temporarily blocked flow and may have caused a significant mortality in the later-timed portion of the fry production.

Table 2. Hatchery sockeye fry released into the Cedar River in 2009 (Cuthbertson 2009)

Release Date	**Number Released Below Trap (RM 0.1)**
2/17/2009	39,000
2/23/2009	139,000
2/25/2009	270,000
3/4/2009	516,000
3/9/2009	200,000
3/13/2009	378,000
3/16/2009	150,000
3/23/2009	427,000
3/25/2009	282,000
4/1/2009	210,000
4/2/2009	172,000
Total	**2,783,000**

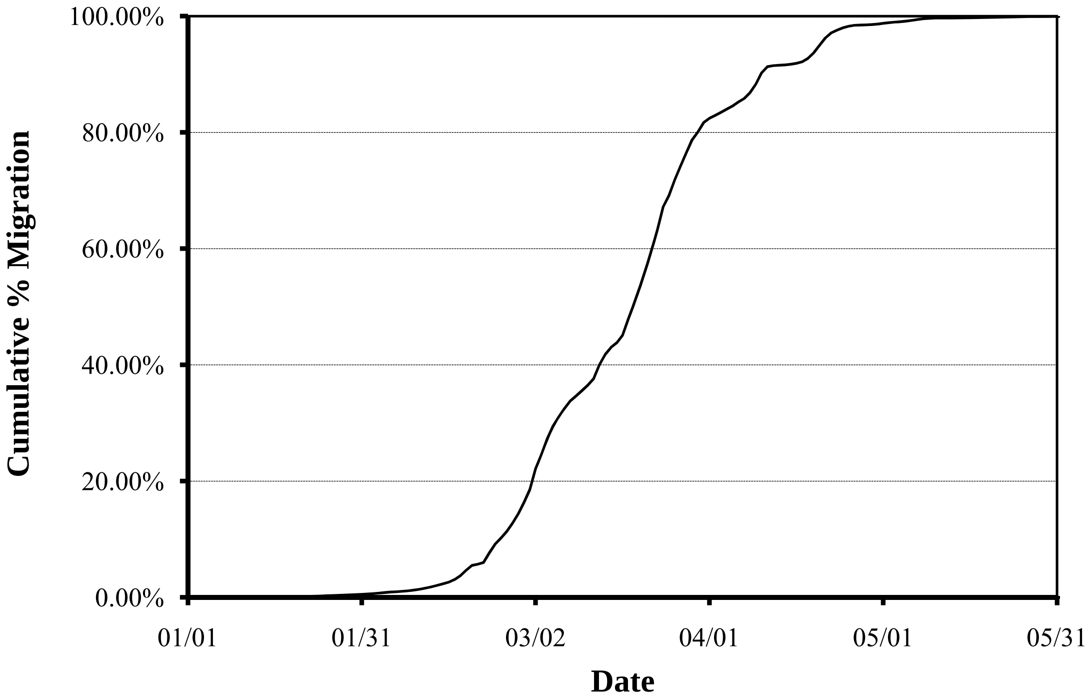


Figure 5. Cumulative migration of natural-origin sockeye fry from the Cedar River into Lake Washington in 2009.

Table 3. Median migration dates of natural-origin, hatchery, and total (combined) sockeye fry populations in the Cedar River for brood years 1991 to 2008, and total thermal units for February. Temperature was measured in degrees Celsius, USGS Renton gage Station #12119000. Temperature was not available for the 1991 brood year. Brood year 2000 was treated as an outlier and not included in this analysis.

Brood Year	Trap Year	February	Median Migration Date			Difference
i	i+1	Thermal Units	Wild	Hatchery	Combined	(days) W-H
1991	1992		03/18	02/28	03/12	19
1992	1993	156	03/27	03/07	03/25	20
1993	1994	162	03/29	03/21	03/26	8
1994	1995	170	04/05	03/17	03/29	19
1995	1996	153	04/07	02/26	02/28	41
1996	1997	147	04/07	02/20	03/16	46
1997	1998	206	03/11	02/23	03/06	16
1998	1999	187	03/30	03/03	03/15	27
1999	2000	161	03/27	02/23	03/20	32
2000	2001	158	03/10	02/23	03/08	15
2001	2002	186	03/25	03/04	03/19	21
2002	2003	185	03/08	02/24	03/03	12
2003	2004	186	03/21	02/23	03/15	26
2004	2005	193	03/02	02/01	02/28	29
2005	2006	184	03/20	02/23	03/14	25
2006	2007	193	03/23	02/16	03/12	35
2007	2008	170	03/16	03/06	03/15	10
2008	2009	187	03/19	03/06	03/13	13
	Average		03/22	02/27	03/14	23

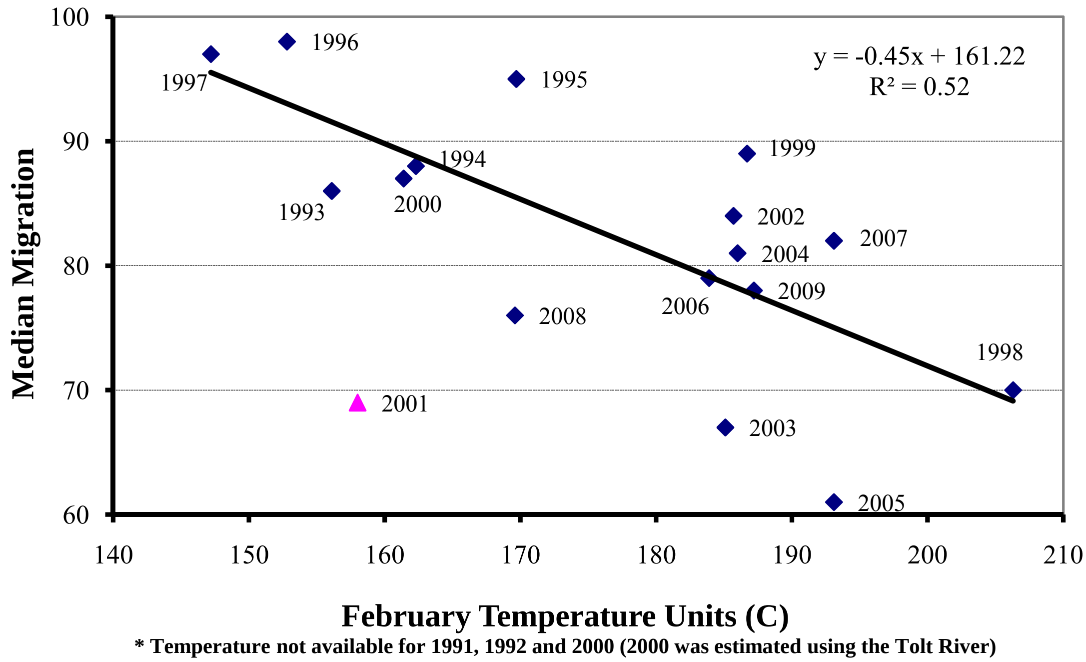


Figure 6. Linear regression of median migration date (Julian Calendar day) for natural-origin Cedar River sockeye fry as a function of total February thermal units, migration years1993-2009, as measured at the USGS Renton gage Station #12119000. Migration year 2001 treated as an outlier and not included in analysis.

Egg-to-Migrant Survival of Natural-Origin Fry

Egg-to-migrant survival of the 2008 brood sockeye was estimated to be 6.5 % (Table 4). Survival was calculated from 1.6 million natural-origin fry surviving from a potential 25.1 million eggs deposited by 7,998 females.

Across brood years, egg-to-migrant survival was negatively correlated with peak flow during the incubation period (R^2 = 0.40, Figure 7). The best fit model for this data series was a decreasing exponential equation ($y = be^{-ax}$). 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, this model and others will continue to be assessed to increase our understanding of the factors affecting natural-origin sockeye fry production from the Cedar River.

Table 4. Egg-to-migrant survival of natural-origin sockeye fry in the Cedar River and peak mean daily flows during egg incubation period for brood years 1991 - 2008. Sockeye spawners were estimated using the area-under-the-curve method. Flow was measured as cubic feet per second (cfs), USGS Renton gage Station #12119000.

Brood Year	Spawners	Females (@50%)	Fecundity	Potential Egg Deposition	Fry Production	Survival Rate	Peak Incubation Flow (cfs)	Date
1991	77,000	38,500	3,282	126,357,000	9,800,000	7.76%	2,060	1/28/1992
1992	100,000	50,000	3,470	173,500,000	27,100,000	15.62%	1,570	1/26/1993
1993	76,000	38,000	3,094	117,572,000	18,100,000	15.39%	927	1/14/1994
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	1/2/1997
1997	104,000	52,000	3,292	171,184,000	25,350,000	14.81%	1,790	1/23/1998
1998	49,588	24,794	3,176	78,745,744	9,500,000	12.06%	2,720	1/1/1999
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	1/5/2001
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	2/4/2003
2003	110,404	55,202	3,412	188,349,224	38,686,899	20.54%	2,039	1/30/2004
2004	116,978	58,489	3,276	191,609,964	37,027,961	19.32%	1,900	1/18/2005
2005	50,887	25,444	3,065	77,984,328	10,861,369	13.90%	3,860	1/11/2006
2006	106,961	53,481	2,910	155,628,255	9,246,243	5.90%	5,411	11/9/2006
2007	45,489	22,745	3,450	78,468,525	25,072,141	31.95%	1,820	12/3/2007
2008	15,995	7,998	3,135	25,072,163	1,630,081	6.50%	9,390	1/8/2009

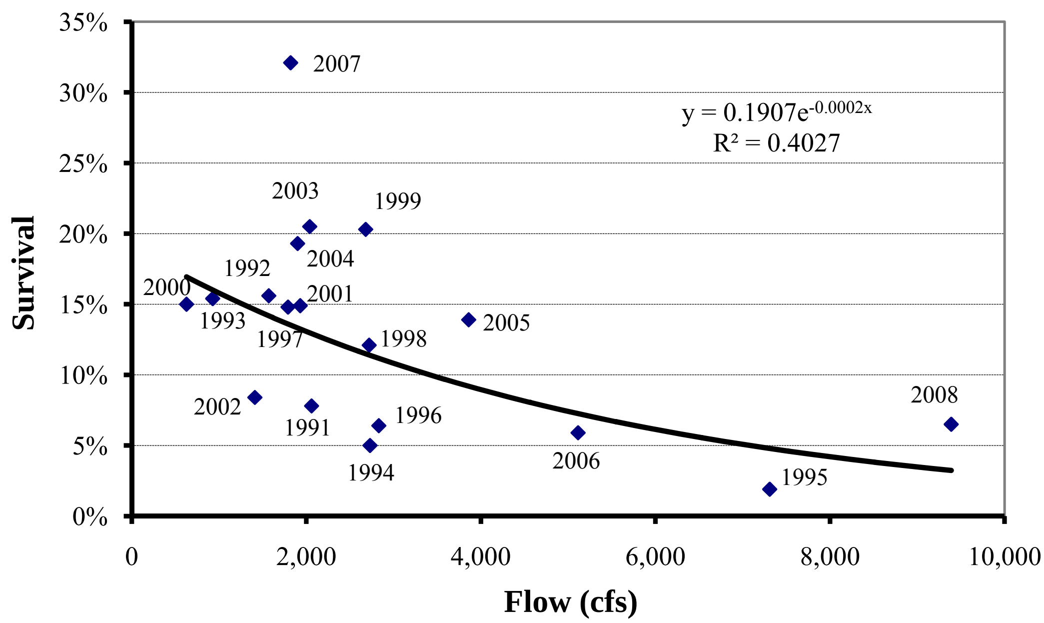


Figure 7. Egg-to-migrant survival of natural-origin sockeye in the Cedar River as a function of peak flow during the winter egg incubation period. Survival for brood years 1991 to 2008 is fit with a decreasing exponential curve.

Chinook

Catch and Estimated Missed Catch

Inclined-Plane Trap

A total of 4,561 Chinook were captured in the inclined-plane trap. If the inclined-plane trap fished continuously (day and night) between February 1 and April 21, an estimated 2,209 additional fry should have been caught. Day:night catch ratios used to calculate missed day catch ranged from 2.6% to 218.2%. Catch was partially missed on four nights due to large amounts of debris. Combining expanded and actual catches, total catch was estimated to be 6,565 Chinook in the inclined-plane trap.

Screw Trap

A total of 1,114 natural-origin (unmarked) and 11 hatchery (adipose fin clipped or ad-marked) Chinook were caught in the screw trap. Production estimate was based on natural-origin Chinook catches only.

Catch was estimated for eleven periods when the trap was stopped by debris (5 night periods and 6 day periods). Catch was also estimated for eighteen day periods that the trap was intentionally not operated due to either high flows or public safety precautions. Estimated catch for these outage periods was 82 Chinook and accounted for only 7.0% of the total estimated catch. Had the trap fished continuously, from April 22 to July 18, a total of 1,168 Chinook would have been caught.

Production Estimate

Inclined-Plane Trap

A total of 52 sockeye efficiency trials, ranging in size from 25 to 878 sockeye, were used to estimate migration. Original efficiency trials were aggregated into seven final strata. Recapture rates for the final strata ranged from 3.36% to 20.00%.

Chinook migration was estimated to be 124,096 fry between February 1 and April 21, 2009 (Appendix B 2). A migration of 2,968 Chinook fry were estimated to have migrated prior to inclined-plane trap operation based on a linear extrapolation between January 1 and 30. This extrapolation combined with the migration estimate during trap operation yields a total migration of 127,064 ± 38,312 (95% C.I.) Chinook fry through April 21 (Table 5).

The Chinook estimate between February 1 and April 21 used inclined-plane trap catches and efficiency data. During weeks 17 (beginning April 22) through 22 (ending May 29), both the inclined-plane and screw traps operated simultaneously. During the overlapping period, catches in the inclined-plane trap began to decrease while catches increased in the screw trap. Catches in the screw trap were consistently significantly larger than those in the inclined-plane trap (Z-test, $\alpha=0.05$) and were used to estimate migration from April 22 forward.

Table 5. Natural-origin Cedar River juvenile Chinook production estimate and confidence intervals, 2009.

Gear	Period	Estimated		95% CI		CV
		Catch	Migration	Low	High	
Pre-Trapping	January 1 - 31		2,968	1,475	4,462	25.7%
Inclined-Plane Trap	February 1-April 21	6,565	124,096	85,813	162,378	15.7%
Total Fry		**6,565**	**127,064**			
Screw Trap	April 22-July 18	1,168	12,388	9,767	15,010	10.8%
Total Parr			**12,388**			
	Season Total	**7,733**	**139,452**	**101,051**	**177,853**	**14.05%**

Screw Trap

A total of 49 efficiency trials were released, ranging in size from 1 to 72 Chinook. Due to unusual flow regimes during the trapping period, efficiency trials were stratified based on temporal flow periods. Original efficiency trails were aggregated into 8 final strata. Recapture rates ranged from 6.9% to 26.6% (Appendix B3).

Migration during screw trap operation between April 22 and July 18 was estimated to be 12,388 ± 2,621 (95% C.I.) Chinook parr (Table 5). In total, 139,452 age 0+ Chinook are estimated to have migrated from the Cedar River into Lake Washington in 2009. This estimate is the combination of the Chinook production estimated from the interpolated pre-trapping period, the inclined-plane trap from February 1 through April 21, and the estimate from the screw trap for April 22 to July 18 (Table 5). Since no Chinook had been caught since July 12, migration was assumed to be completed by July 18 and no post season migration was estimated.

As in previous seasons, timing of Chinook migration was bi-modal (Figure 8). Migration was 25%, 50%, and 75% complete by roughly February 21, March 6, and March 25, respectively (Figure 9). Chinook fry migration quickly climbed above 1,000 fish per night at the beginning of the season. Fry migration peaked on February 24 at 8,758 fry. Two additional prominent peaks occurred on March 16 and 25, both over 5,000 fish. Migration then declined, with daily migrations being significantly lower in the screw trap than the inclined-plane trap. Parr peak migration occurred June 22 when 796 Chinook were estimated to have migrated. Juvenile Chinook emigrated mostly as fry, contributing 91.1% of the total migration. This represented the greatest proportion of fry since trapping began in 1998 (Table 6).

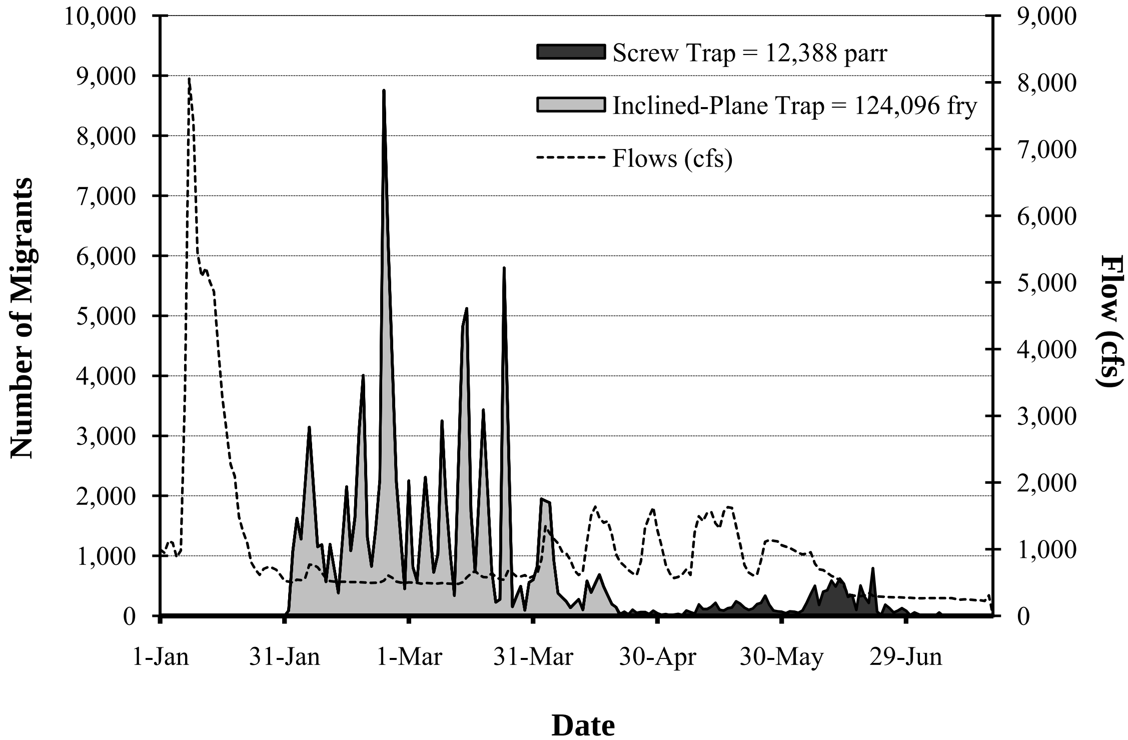


Figure 8. Estimated daily Cedar River Chinook migration from inclined-plane (February 1toApril 20) and screw trap estimates (April 21 to July 18) and mean daily flow (USGS Renton gage, Station #12119000) in 2009.

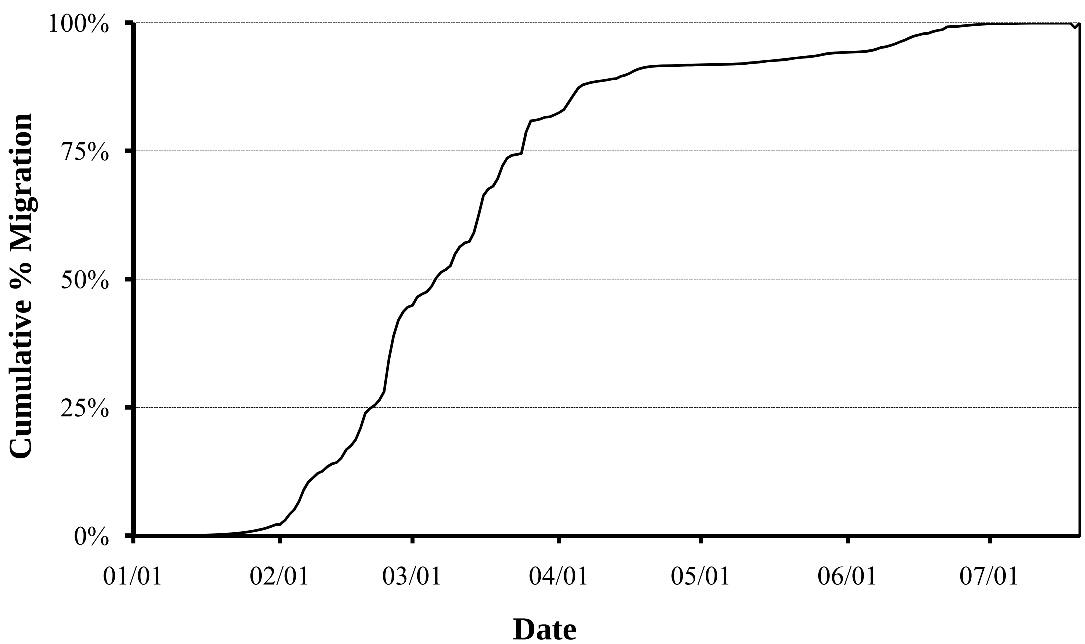


Figure 9. Cumulative percent migration of age 0+ Chinook from the Cedar River in 2009.

Table 6. Production, productivity (production per female), and survival of Chinook fry and parr among brood years. Fry migration was assumed to be January 1 to April 15. Parr migration was assumed to be April 16 through July 13. Productivity was calculated from potential egg deposition (PED) for returning spawners. Data are Cedar River broods 1998 to 2008.

Brood	Estimated Migration			Percent Migration		Est.	PED	Production/Female			Survival Rates		
Year	Fry	Parr	Total	Fry	Parr	Fem.		Fry	Parr	Total	Fry	Parr	Total
1998	67,293	12,811	80,104	84%	16%	173	778,500	389	74	463	8.6%	1.6%	10.3%
1999	45,906	18,817	64,723	71%	29%	180	810,000	255	105	360	5.7%	2.3%	8.0%
2000	10,994	21,157	32,151	34%	66%	53	238,500	207	399	607	4.6%	8.9%	13.5%
2001	79,813	39,326	119,139	67%	33%	398	1,791,000	201	99	299	4.5%	2.2%	6.7%
2002	194,135	41,262	235,397	82%	18%	281	1,264,500	691	147	838	15.4%	3.3%	18.6%
2003	65,875	54,929	120,804	55%	45%	337	1,516,500	195	163	358	4.3%	3.6%	8.0%
2004	74,292	60,006	134,298	55%	45%	511	2,299,500	145	117	263	3.2%	2.6%	5.8%
2005	98,085	19,474	117,559	83%	17%	339	1,525,500	289	57	347	6.4%	1.3%	7.7%
2006	107,796	14,613	122,409	88%	12%	587	2,641,500	184	25	209	4.1%	0.6%	4.7%
2007	691,216	75,746-81,404	766,962-772,620	89.5-90.1%	9.9-10.5%	899	4,045,500	769	84-90	856-862	17.2%	1.9-2.0%	19.1-19.2%
2008	124,655	14,883	139,538	89%	11%	599	2,695,500	208	25	233	4.6%	0.6%	5.2%

Egg-to-Migrant Survival

Natural-origin Chinook egg-to-migrant survival for the 2008 brood was estimated to be 5.2% (Table 6). Fall 2008 had the second largest Chinook return to the Cedar River on record (Burton et. al 2009). Despite record high flows and a low egg-to-migrant survival rate, this large adult return still produced the third largest migration of Chinook in the Cedar River since trapping began in 1999.

Size

From January through mid-April, fork lengths (FL) of Chinook fry caught in the inclined-plane trap averaged less than 50 mm each week with the average weekly size increasing less than 8 mm (Table 7, Figure 10). Not until statistical week 17 (April 19-25), did the weekly average length increased to more than 50 mm; however, the smallest Chinook fry continued to be less than 40 mm. Weekly average size did not increase to be over 60 mm until statistical week 20 (May 11-17).

Chinook caught in the screw trap increased in size from a weekly average fork length of 60.9 mm in mid-April to 102.7 mm in July (Table 7). Chinook averaged more than 70 mm FL by mid-May. During screw-trap operation, sizes ranged from 41 mm to 116 mm FL and averaged 84.9 mm FL. Fork lengths of fry caught in 2009 were larger than the 9-year average and parr lengths were near the median of the 9-year data set (Table 8).

Table 7. Natural-origin Chinook fork length (mm) in Cedar River inclined-plane and screw traps in 2009. Data are mean, standard deviation (s.d.), range, sample size (n), and catch for each statistical week.

Statistical Week			Inclined-Plane Trap						Screw Trap					
Begin	End	No.	Avg.	s.d.	Range Min	Range Max	n	Catch	Avg.	s.d.	Range Min	Range Max	n	Catch
02/01	02/07	6	39.7	2.33	35	45	94	397						
02/08	02/14	7	40.3	2.35	33	50	110	234						
02/15	02/21	8	41.0	2.14	35	48	87	645						
02/22	02/28	9	40.7	1.74	36	45	125	1,008						
03/01	03/07	10	41.1	1.96	35	47	73	310						
03/08	03/14	11	41.5	2.40	37	52	87	539						
03/15	03/21	12	41.6	2.61	36	55	112	640						
03/22	03/28	13	42.2	3.78	37	60	62	266						
03/29	04/04	14	42.8	3.69	36	55	98	152						
04/05	04/11	15	47.0	6.69	37	60	30	108						
04/12	04/18	16	47.6	9.05	37	74	24	53						
04/19	04/25	17	53.3	11.90	34	72	19	19	60.9	8.12	45	81	35	36
04/26	05/02	18	47.1	12.22	35	68	16	16	62.1	9.75	41	81	18	28
05/03	05/09	19	57.8	13.73	32	75	34	34	66.5	8.10	51	84	39	60
05/10	05/16	20	71.0	8.94	56	90	26	27	73.1	7.67	51	88	45	71
05/17	05/23	21	59.2	15.82	35	89	52	56	74.4	9.54	49	94	65	108
05/24	05/30	22	59.6	19.61	32	89	53	57	76.8	7.56	56	98	70	155
05/31	06/06	23							83.9	9.89	69	114	52	98
06/07	06/13	24							91.7	8.76	72	114	157	206
06/14	06/20	25							92.2	5.77	76	106	180	190
06/21	06/27	26							93.9	7.13	60	109	81	102
06/28	07/04	27							102.7	7.04	91	116	33	33
07/05	07/11	28							97.7	9.29	85	107	6	6
07/13	07/19	29												0
Season Totals			44.7	10.20	32	90	1,102	4,561	84.9	13.6	41	116	781	1,093

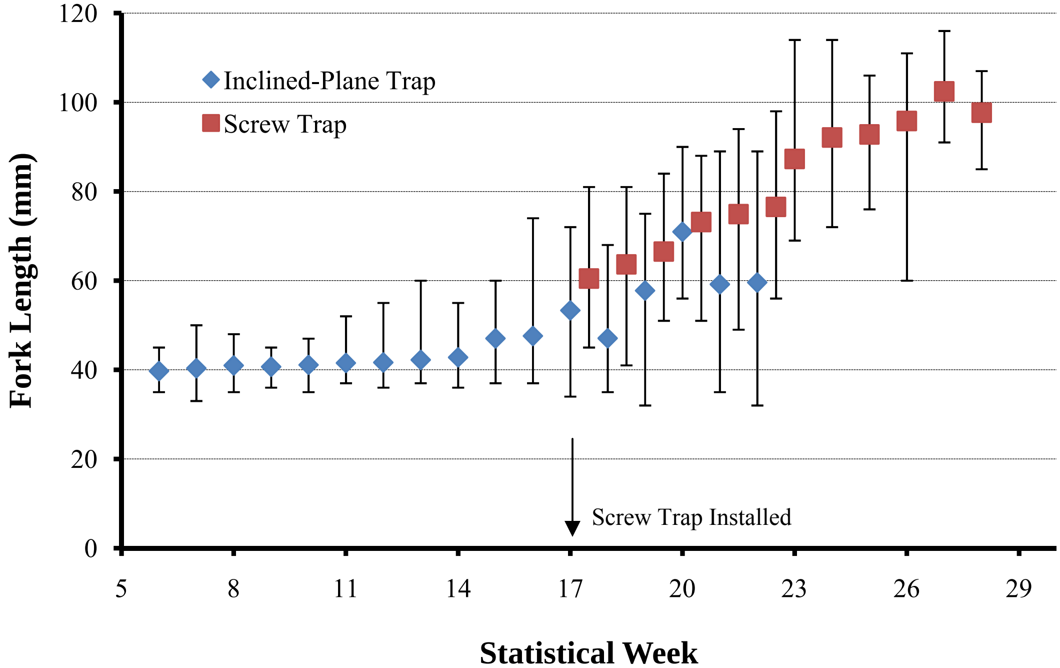


Figure 10. Average and range of fork lengths of Chinook sampled from the Cedar River, 2009.

Table 8. Comparison of natural-origin Chinook sizes measured over eight years (brood years 2000-2008) at the Cedar River inclined-plane and screw traps.

Brood	Inclined-Plane Trap						Screw Trap					
Year	Avg	s.d.	Min	Max	n	Catch	Avg	s.d.	Min	Max	n	Catch
2000	40.3	4.18	34	75	287	687	81.3	14.91	40	121	379	2,872
2001	41.3	7.47	32	92	634	3,781	78.1	21.19	32	131	997	2,592
2002	44.3	10.79	34	90	563	7,186	91.0	13.69	42	128	1,782	3,675
2003	41.9	7.09	34	91	629	2,918	87.4	13.82	42	126	812	6,156
2004	44.7	9.00	36	110	416	4,640	95.7	10.80	42	138	2,260	4,524
2005	45.0	10.70	34	82	496	1,975	82.8	10.92	38	116	701	879
2006	41.8	6.20	34	85	568	2,714	91.7	10.10	45	125	803	878
2007	42.1	5.79	34	95	1,585	21,000	73.6	12.26	37	121	1,153	1,651
2008	44.7	10.20	32	90	1,102	4,561	84.9	13.6	41	116	781	1,093

Coho

Catch and Estimated Missed Catch

A total of 5,549 natural-origin coho smolts were caught during screw trap operations between April 22 and July 18. An additional 256 coho would have been caught had the trap fished continuously. Based on actual and expanded catch, a total seasonal catch in the screw trap is estimated to be 5,805 coho.

Production Estimate

A total of 52 efficiency trials, ranging in size from 1 to 100 coho, were released. Original efficiency trials were aggregated into eight strata reflecting temporal changes in flow. Recapture rates for the final strata ranged from 9.2% to 13.7% (Appendix B 4).

Total coho production was estimated to be 52,691 smolts. Coho production during trap operation was estimated to be 51,804 ± 7,091 (95% C.I.) smolts (Appendix B 4). Pre-trapping migration was estimated to be 651 and post-trapping migration was estimated to be 236 coho.

Migration was already under way when trapping began. Migration came to an abrupt peak of an estimated 1,399 coho passing by the trap on April 26 (Figure 11). Migration dipped to below 500 coho for a few days before quickly increasing to two major peaks of over 4,000 fish migrating by the trap on May 9 and 16. Nearly 84% of the season's migration occurred during the month of May. Daily migrations quickly dropped to below 50 per day through the remainder of the season.

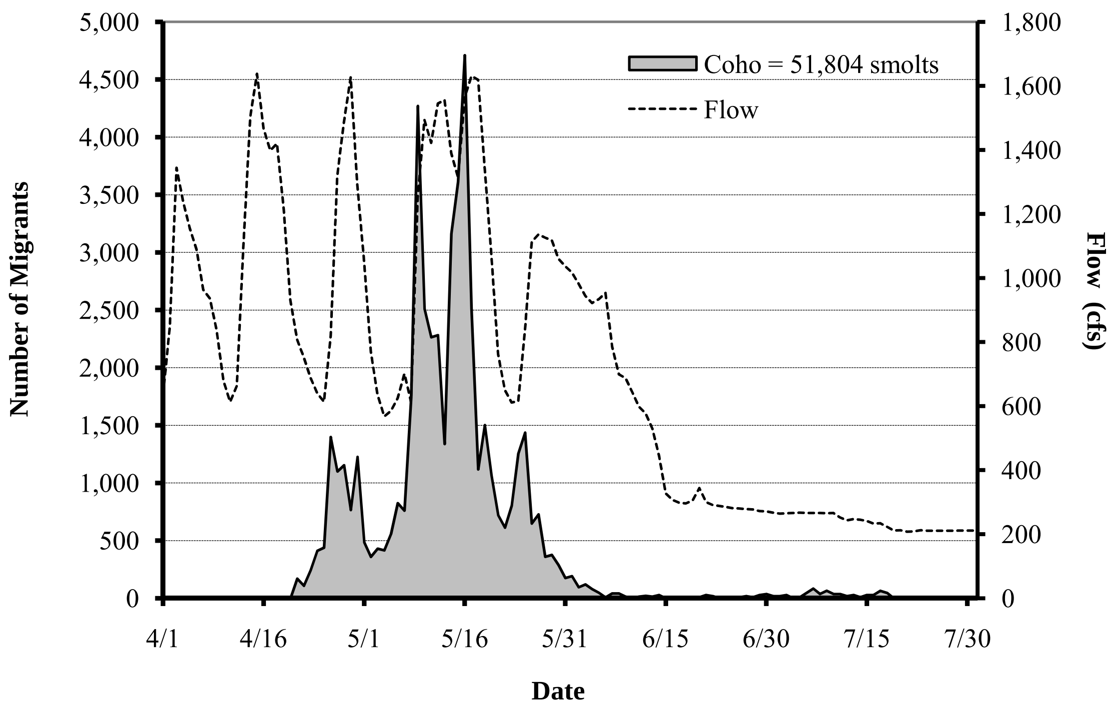


Figure 11. Daily coho smolt migration and daily average flow (USGS Renton gage Station #12119000), Cedar River screw trap, 2009.

Size

Average of all measured coho smolts was 105.9 mm; weekly averages ranged from 97.8 mm to 107.6 mm FL. Individuals ranged from 75 mm to 148 mm FL (Table 9, Figure 12). Coho lengths were comparable to previous years (Table 10).

Table 9. Fork length (mm) of coho smolts from the Cedar River screw trap in 2009. Data are mean, standard deviation (s.d.), range, sample size (n), and catch for each statistical week.

Statistical Week			Avg.	s.d.	Range		n	Catch
Begin	End	No.			Min	Max		
04/19	04/25	17	107.6	10.57	85	133	55	153
04/26	05/02	18	107.2	11.21	91	148	140	481
05/03	05/09	19	107.5	8.71	89	129	120	1,122
05/10	05/16	20	104.1	10.42	82	147	147	2,167
05/17	05/23	21	106.8	10.14	85	136	149	878
05/24	05/30	22	104.1	10.71	75	134	90	555
05/31	06/06	23	106.3	12.53	80	133	48	90
06/07	06/13	24	106.0	12.38	75	128	21	21
06/14	06/20	25	108.5	27.58	89	128	2	6
06/21	06/27	26	97.8	9.62	86	110	6	8
06/28	07/04	27	102.0	7.50	91	112	12	15
07/05	07/11	28	101.4	7.36	89	126	30	34
07/12	07/18	29	107.2	7.77	92	116	13	19
		Season Totals	105.9	10.50	75	148	833	5,549

Table 10. Comparison of natural-origin Cedar River coho sizes over eleven years (broods 1997-2007). Trap location was not optimal during years marked with * and may have been size biased.

Brood	Screw Trap					
Year	Avg	s.d.	Min	Max	n	Catch
1997	105.9	11.46	82	242	839	5,105
1998	107	13.15	76	175	212	2,446
1999	112	11.20	60	172	621	5,927
2000	107.7	10.11	84	142	459	3,406
2001	111.6	10.94	62	175	1,406	3,763
2002	109.8	10.01	86	145	466	2,668
2003	110.0	9.90	84	158	1,430	2,899
2004*	107.7	9.19	84	141	388	796
2005*	109	10.00	86	148	403	482
2006*	105.3	12.35	81	168	232	315
2007	105.9	10.50	75	148	833	5,549

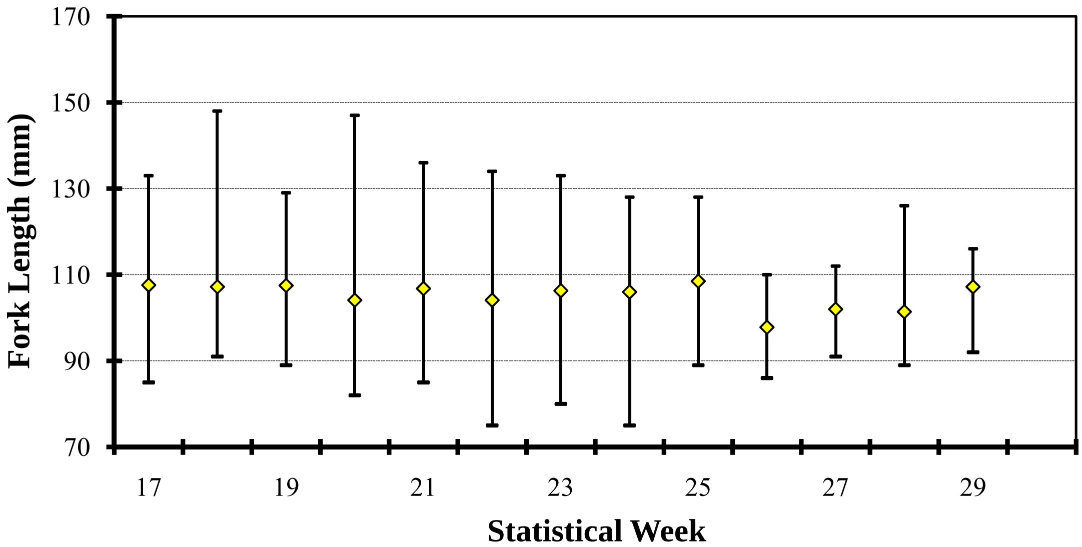


Figure 12. Fork lengths for coho smolts captured in the Cedar River screw trap in 2009. Data are mean, minimum, and maximum lengths.

Trout

Life history strategies used by trout in the Cedar River may include anadromous, ad-fluvial, and resident forms. For simplicity, catches and estimates reported herein are for trout that were visually identified as either cutthroat or steelhead. We acknowledge that cutthroat-rainbow hybrids are included in the reported cutthroat numbers. Furthermore, it is difficult to determine whether juvenile steelhead have adopted the anadromous life form. The juvenile anadromous life history strategy, or “smolt,” was assigned to steelhead trout that had a silver coloration upon capture. In this report, steelhead and rainbow trout are described separately. Steelhead are reported in the Trout section and rainbow trout in the Incidental Catch section. Further smoltification may occur downstream of the trap contributing to a steelhead estimate that is biased low. Life history strategies for cutthroat trout are not differentiated in the migration estimate.

Throughout the season, 1 steelhead migrant and 44 cutthroat trout were captured. Catches were too small to develop migration estimates. Cutthroat fork lengths ranged from 102 to 204 mm, and averaged 140.9 mm.

PIT Tagging

To support the ongoing, multi-agency evaluation of salmonid survival within the Lake Washington basin, natural-origin Chinook were tagged with passive integrated transponder (PIT) tags. Tagging occurred two to three times a week from May 5 through July 1, 2009. Due to low catches of Chinook parr, fish were held from the previous day in order to increase the number tagged per day. Over the season, a total of 604 natural-origin Chinook parr were tagged (Table

11). This tag group comprised 4.8% of the estimated Chinook parr production from the Cedar River in 2009, the largest percentage of the parr migration PIT tagged to date.

Table 11. Natural-origin Chinook parr PIT tagged and released from the Cedar River screw trap in 2009.

Stat Week			#	Length			Portion of Parr Migration
#	Start	End	Tagged	Avg	Min	Max	Tagged
19	05/05	05/10	7	73.1	65	83	2.5%
20	05/11	05/17	21	72.9	66	84	0.7%
21	05/18	05/24	25	76.8	66	91	0.6%
22	05/25	05/31	67	79.4	65	99	0.6%
23	06/01	06/07	52	83.9	69	114	0.8%
24	06/08	06/14	148	91.7	71	114	0.2%
25	06/15	06/21	157	92.1	76	106	0.3%
26	06/22	06/28	103	94.1	76	109	0.5%
27	06/29	07/05	24	100.7	91	111	1.9%
Season Totals			604	89.0	65	114	4.8%

Mortality

No Chinook mortalities occurred while operating the inclined-plane trap.

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

Incidental Catch

Incidental catches in the inclined-plane trap included 213 coho fry, 485 coho smolts, 1 chum fry, 1 sockeye smolt, and 6 cutthroat smolts. Other species caught included three-spine stickleback (*Gasterosteus aculeatus*), unspecified sculpin species (*Cottus spp*.), lamprey (*Lampetra spp.*), largescale sucker fry (*Catostomus macrocheilus*), long-fin smelt (*Spirinchus thaleichthys*), speckled dace (*Rhinichthys osculus*), small mouth bass (*Micropterus dolomieui*) and yellow perch (*Perca flavescens*).

Other salmonids caught in the screw trap include 11 ad-marked hatchery Chinook parr, 1 sockeye smolt, 68 coho parr, 1 yearling Chinook and 1 trout fry. Other species caught included three-spine stickleback, unspecified sculpin species, lamprey, large-scale suckers fry, peamouth (*Mylocheilus caurinus*), speckled dace, small mouth bass, and whitefish (*Prosopium spp.).*

Bear Creek Results

Sockeye

Catch and Estimated Missed Catch

During inclined-plane trap operations from February 2 to April 17, sockeye catches total 21,511 fry. A total of 38,003 sockeye fry should have been caught had the trap fished the entire period between February 2 and April 17. This expanded catch includes 16,492 fry estimated for the 30 nights not fished.

Production Estimate

Twenty-nine efficiency trials were conducted during the season and aggregated into nine final strata. Recapture rates ranged from 5.9% to 22.3% (Appendix C 1). At the beginning of the season, catches were so low that there were not enough fish to form an efficiency trial until February 23. Thereafter, efficiency trials were released nearly every night the trap fished.

During the period of inclined-plane trap operation (February 2 through April 17), 322,038 sockeye fry are estimated to have migrated passed the trap (Table 12). Migration of sockeye fry appeared to be underway when trapping began. Linear extrapolation was used to estimate what may have passed the trap from January 1 to February 3, contributing 338 fry to the total estimated migration (Table 12). The sockeye fry migration was still underway when the screw trap replaced the inclined-plane trap on April 17. Rather than attempting to calibrate the screw trap for sockeye fry, the end of the sockeye migration was estimated using linear extrapolation. Migration from April 17 to April 30 was estimated to be 4,849 fry.

A total of 327,225 ± 53,877 (95% C.I.) sockeye fry were estimated to have migrated from Bear Creek in 2009, with an associated 8.4% coefficient of variation (Table 12). The estimate includes migration prior to, during, and following inclined-plane trap operation.

The sockeye migration was low at the beginning of the season with one small peak of 6,000 sockeye passing the trap on March 6. Daily migrations then increased to over 2,000 sockeye per day beginning March 18 and continuing to be high through the April 17 when trapping concluded. Daily migration peaked on March 25 with over 30,000 sockeye estimated to have passed the trap (Figure 13).

Egg-to-migrant survival of the 2008 brood was estimated to be 36.2% (Table 13). Survival was 327,225 fry divided by 904,448 eggs potentially deposited by 289 females. This is the highest survival measured since trapping began in 1999 (see Discussion Section).

Table 12. Bear Creek juvenile sockeye fry production estimate and confidence intervals, 2009.

Period	Dates	Est. Migration	CV	95% CI Low	95% CI High
Pre-Trapping	Jan 1-Feb 1	338	2.9%	319	357
Inclined-Plane Trap	Feb 2-April 17	322,038	8.5%	268,181	375,895
Post-Trapping	April 18-April 30	4,849	15.4%	3,389	6,310
	Season Totals	327,225	8.4%	273,348	381,102

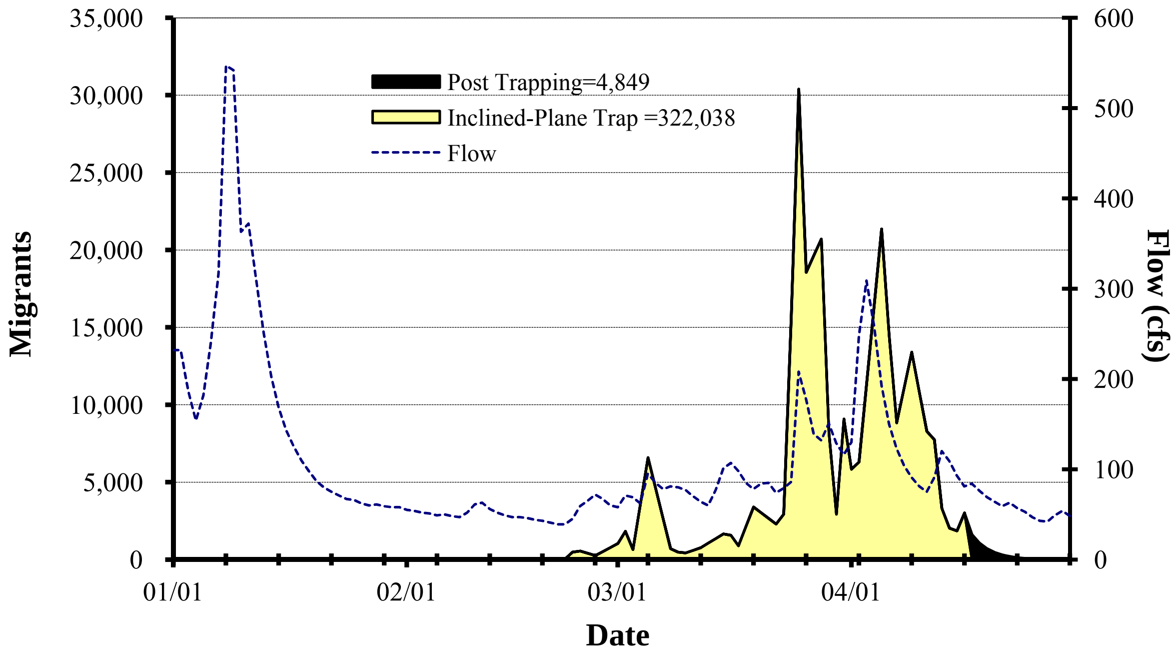


Figure 13. Estimated daily migration of sockeye fry from Bear Creek and daily average flow measured by the King County gaging station at Union Hill Road in 2009.

Table 13. 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)	Peak Incubation Flow Date
1998	8,340	4,170	3,176	13,243,920	1,526,208	11.5%	515	11/26/1998
1999	1,629	815	3,591	2,924,870	189,571	6.5%	458	11/13/1999
2000	43,298	21,649	3,451	74,710,699	2,235,514	3.0%	188	11/27/2000
2001	8,378	4,189	3,568	14,946,352	2,659,782	17.8%	626	11/23/2001
2002	34,700	17,350	3,395	58,903,250	1,995,294	3.4%	222	01/23/2003
2003	1,765	883	3,412	3,011,090	177,801	5.9%	660	01/30/2004
2004	1,449	725	3,276	2,373,462	202,815	8.5%	495	12/12/2004
2005	3,261	1,631	3,065	4,999,015	548,604	11.0%	636	01/31/2005
2006	21,172	10,586	2,910	30,805,260	5,983,651	19.4%	581	12/15/2006
2007	1,080	540	3,450	1,863,000	251,285	13.5%	1,055	12/04/2007
2008	577	289	3,135	904,448	327,225	36.2%	546	01/08/2009

Chinook

Catch and Estimated Missed Catch

Inclined-Plane Trap

In total, 1,014 Chinook fry were captured in the inclined-plane trap by the time inclined-plane trap operations concluded on the morning of April 17. A total of 2,198 Chinook fry should have been caught had the inclined-plane trap operated continuously. Total catch includes actual catch plus catch expansion for the 30 nights not fished.

Screw Trap

A total of 8,613 Chinook were caught over the 71 days the screw trap operated. The trap did not operated during four occasions (May 20, May 30, June 2 and June 4) when debris stopped the trap. Had the trap fished continuously, a total of 9,214 Chinooks should have been caught. Total catches include actual catch plus catch expansion for the four missed periods.

Production Estimate

Inclined-Plane Trap

A total of 29 efficiency trials were conducted, ranging in size from 43 to 1,260 sockeye, as surrogates for estimating Chinook efficiency. Chinook migration was estimated to be 15,100 ± 6,167 (95% C.I.) between February 2 and April 17 (Table 14, Appendix C 2). As the first Chinook was not captured until two weeks into trapping and catches thereafter were scarce, migration prior to trapping is assumed to be zero.

Screw Trap

Forty Chinook efficiency trials were aggregated into eleven strata; capture rates of the final strata ranged from 1.96% and 50.7%. Chinook migration during screw trap operation was estimated to be 51,102 ±12,571 (95% C.I.) (Table 14, Appendix C3).

Combining information from inclined-plane and screw trap estimates yields a total production of 65,240 ± 14,002 (95% C.I.) Chinook with a coefficient of variation of 10.95%. Total production includes fry estimates from the inclined-plane trap, parr estimates from the screw trap and a post trapping estimate.

Fry migration was estimated using inclined-plane trap data and parr migration was estimated using the screw trap data. The Chinook fry migration came to one abrupt peak 3,500 Chinook on March 5. Remaining daily fry migrations were low. Chinook parr daily migrations were larger than fry migrations with 65% of the Chinook migration occurring in the month of May. Migration peaked with an estimated 9,400 Chinook pass the trap on June 2. Migration was bi-modal with 23.1% of the migration emigrating as fry and 76.9% emigrating as parr (Figure 14).

Table 14. Bear Creek juvenile Chinook production estimate and confidence intervals, 2009.

Gear	Period	Estimated Catch	Estimated Migration	95% CI Low	95% CI High	CV
Inclined-Plane Trap	February 2 - April 16	2,198	15,100	8,933	21,266	20.84%
Screw Trap	April 17 - June 30	9,214	50,102	37,106	63,098	13.23%
Post-Trapping	July 1- July 15		38	16	60	30.01%
	Season Totals	11,412	65,240	51,238	79,242	10.95%

Table 15. Production, productivity (production per female), and survival of natural-origin Chinook in Bear Creek. Fry are assumed to have migrated between February 1 and April 8. Parr are assumed to have migrated between April 9 and June 30. Data are 2000 to 2008 brood years.

Brood	Estimated Migration			% Migration		Est.	PED	Production/Female			Survival Rates		
Year	Fry	Parr	Total	Fry	Parr	Females		Fry	Parr	Total	Fry	Parr	Total
2000	419	10,087	10,506	4.0%	96.0%	133	598,500	3	76	79	0.1%	1.7%	1.8%
2001	5,427	15,891	21,318	25.5%	74.5%	138	621,000	39	115	154	0.9%	2.6%	3.4%
2002	645	16,636	17,281	3.7%	96.3%	127	571,500	5	131	136	0.1%	2.9%	3.0%
2003	2,089	21,558	23,647	8.8%	91.2%	147	661,500	14	147	161	0.3%	3.3%	3.6%
2004	1,178	8,092	9,270	12.7%	87.3%	121	544,500	10	67	77	0.2%	1.5%	1.7%
2005	5,764	16,598	22,362	25.8%	74.2%	122	549,000	47	136	183	1.0%	3.0%	4.1%
2006	3,452	13,077	16,529	20.9%	79.1%	131	589,500	26	100	126	0.6%	2.2%	2.8%
2007	1,163	11,543	12,706	9.2%	90.8%	276	1,242,000	4	46	50	0.1%	0.9%	1.0%
2008	14,243	50,959	65,202	21.8%	78.2%	132	594,000	108	386	494	2.4%	8.6%	11.0%

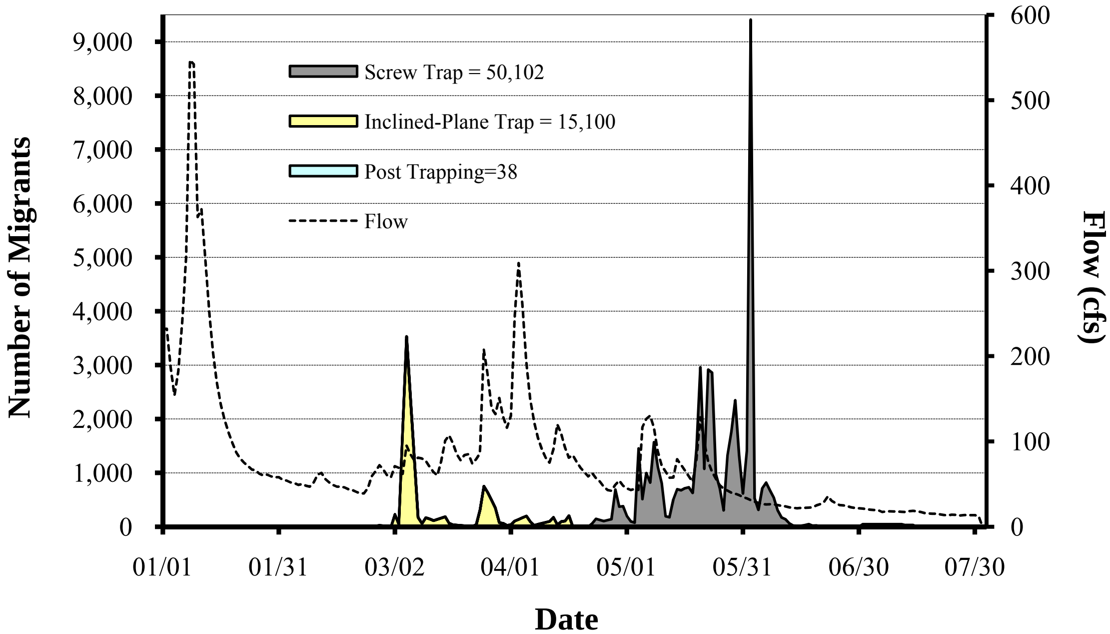


Figure 14. Daily Chinook 0+ migration and daily average flow from Bear Creek, 2009. Daily mean flows were measured at the King County flow gauging station at Union Hill Road.

Egg-to-Migrant Survival

Egg-to-migrant survival of the 2008 brood was estimated to be 11.0% (Table 15). Survival was estimated by dividing 65,239 Chinook by 594,000 eggs deposited by 132 females.

Size

From early February through mid- April, sizes of Chinook fry captured in the inclined-plane trap averaged 43.4 mm FL, and ranged from 32 mm to 61 mm FL (Table 16).

Fork lengths of Chinook caught in the screw trap ranged from 38 mm to 99 mm, averaged 67.3 mm and increased over the season. In early April, the Chinook weekly average was 50.5 mm FL, with the weekly average remaining below 70 mm FL until mid-May. By the end of the trapping season, weekly average lengths reached 80 mm FL (Table 16, Figure 15). The average parr length in 2009 was much shorter than those observed in the previous eight years (Table 17).

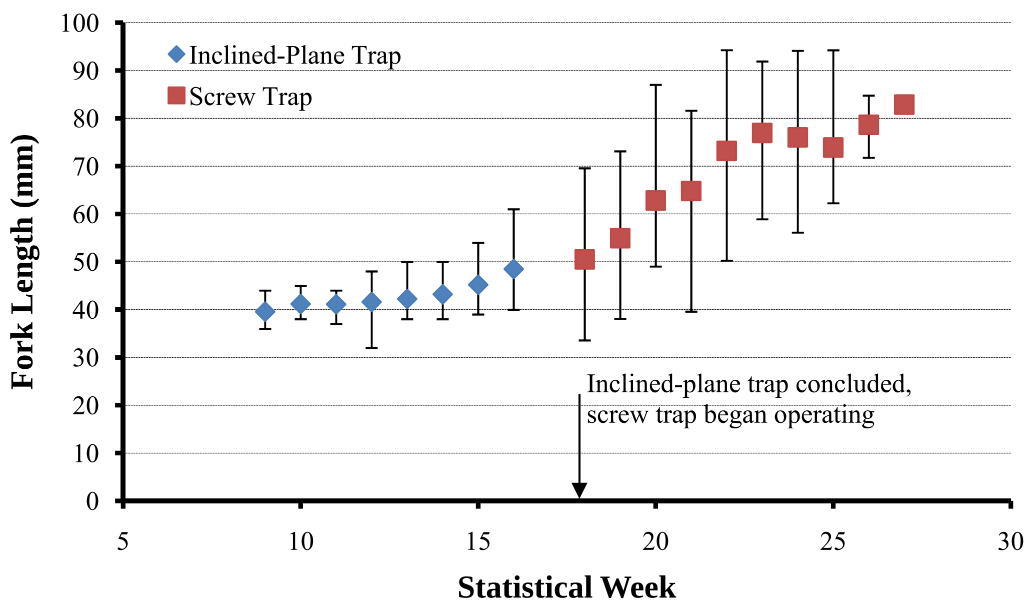


Figure 15. Fork lengths of Chinook 0+ sampled from Bear Creek in 2009. Data are mean, minimum, and maximum lengths each statistical week.

Table 16. Fork lengths of juvenile Chinook and coho in the Bear Creek inclined-plane and screw traps in 2009. Data are mean fork lengths (mm), standard deviation (s.d.), ranges, sample sizes (n), and catch.

Gear	Statistical Week			Chinook						Coho					
	Begin	End	No.	Avg.	s.d.	Range Min	Range Max	n	Catch	Avg.	s.d.	Range Min	Range Max	n	Catch
Inclined-Plane Trap	02/22	02/28	9	39.6	2.35	36	44	9	9						
	03/01	03/07	10	41.2	1.75	38	45	29	634						
	03/08	03/14	11	41.1	1.59	37	44	41	85						
	03/15	03/21	12	41.6	3.69	32	48	17	52						
	03/22	03/28	13	42.2	2.62	38	50	44	98						
	03/29	04/04	14	43.2	3.62	38	50	16	33						
	04/05	04/11	15	45.2	4.78	39	54	27	42						
	04/12	04/18	16	48.5	5.62	40	61	44	61						
			Totals	43.4	4.57	32	61	227	1,014						
Screw Trap	04/19	04/25	17	50.5	5.48	40	63	83	285	123.4	8.05	104	140	30	60
	04/26	05/02	18	54.9	7.65	38	74	147	993	111.8	13.85	92	162	89	355
	05/03	05/09	19	62.8	7.36	46	81	100	1,414	108.9	11.61	89	143	114	1,383
	05/10	05/16	20	64.8	7.52	51	89	80	1,196	108.6	11.34	89	160	120	1,275
	05/17	05/23	21	73.2	7.02	48	90	278	1,715	109.4	9.83	92	148	90	565
	05/24	05/30	22	76.9	9.43	54	98	90	1,569	107.1	8.99	87	142	56	164
	05/31	06/06	23	76.0	8.14	58	91	40	1,105	110.0	n/a	110	110	1	10
	06/07	06/13	24	73.9	7.86	54	92	49	258	101.9	33.65	70	162	7	9
	06/14	06/20	25	78.6	6.03	67	99	45	58						
	06/21	06/27	26	82.9	4.67	76	89	8	18						
	06/28	07/04	27	82.0	n/a	82	82	1	2						1
			Totals	67.3	11.85	38	99	921	8,613	110.0	12.27	70	162	507	3,822

Table 17. Comparison of natural-origin Chinook sizes measured over nine years (brood years 2000-2008) at the Bear Creek inclined-plane and screw traps.

Brood	Inclined-Plane Trap						Screw Trap					
Year	Avg	s.d.	Min	Max	n	Catch	Avg	s.d.	Min	Max	n	Catch
2000	41.1	1.97	34	47	39	63	73.4	11.60	38	105	622	5,131
2001	38.9	3.80	34	52	70	278	81.5	10.83	42	110	885	6,880
2002	40.9	3.20	34	54	78	86	75.9	11.20	35	106	709	8,182
2003	41.6	4.99	38	60	70	102	73.6	11.52	40	107	874	10,613
2004	40.6	2.29	38	47	46	102	78.7	7.06	40	102	1,766	4,612
2005	41.4	4.10	37	64	117	264	76.0	8.82	44	100	907	8,180
2006	41.7	3.30	38	55	75	106	79.8	6.80	40	118	2,978	5,320
2007	41.0	2.01	36	46	52	57	71.1	8.95	37	116	1,748	2,774
2008	43.4	4.57	32	61	227	1,014	67.3	11.85	38	99	921	8,613

Coho

Catch

A total of 3,822 coho smolts were caught in the screw trap over the 71-day trapping season. If the trap had fished without interruptions, a total of 3,926 coho would have been caught from April 22 to June 30.

Production Estimate

Production was based on recapture rates of 37 different efficiency trials, which were aggregated into five strata. Final efficiency strata ranged from 8.2% to 21.7%. Coho production was estimated to be 33,395 ± 6,555 (95% C.I.) smolts with a coefficient of variation of 10.5% (Figure 16, Appendix C 4). Total production includes a pre-trapping period from April 1 to April 21 and the period the trap was operating. Catches declined to zero near the end of the season and it was assumed the coho migration had ended. No post-trapping migration was estimated.

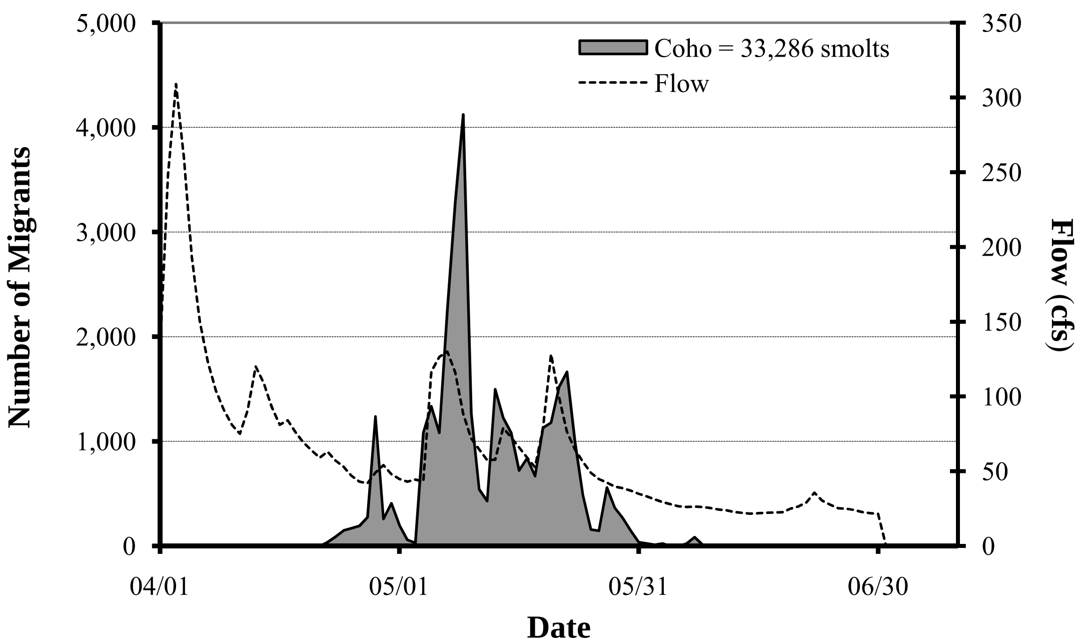


Figure 16. Daily coho smolt migration in Bear Creek from April 22 to June 30, and mean daily flows in 2009. Flow data were measured at the King County gaging station at Union Hill Road.

Size

Over the trapping period, fork lengths ranged from 70 mm to 162 mm and averaged 110.0 mm (Figure 17). Weekly mean lengths ranged from 101.9 mm to 123.4 mm FL during screw trap operation (Table 16). Coho were slightly smaller than previous years (Table 18).

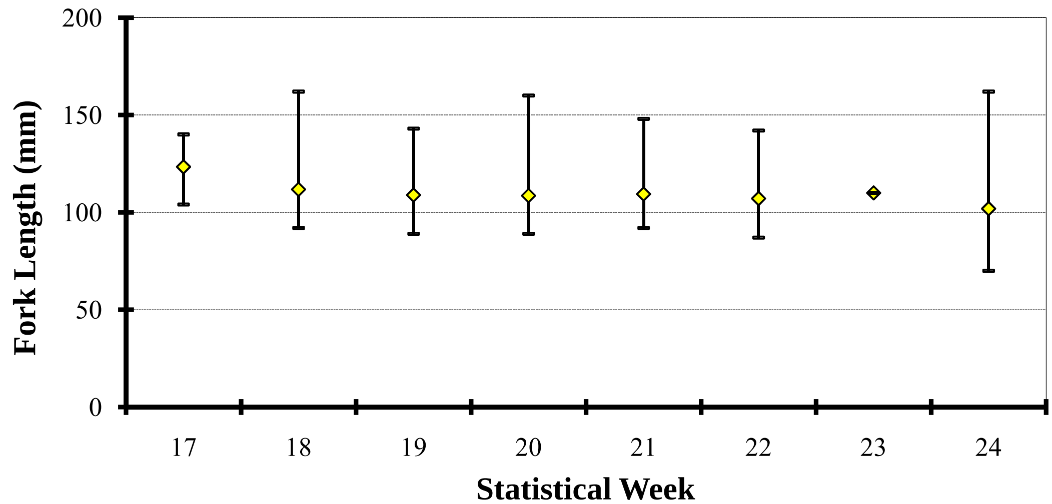


Figure 17. Fork lengths of migrating coho smolts sampled from the Bear Creek screw trap in 2009. Data are mean, minimum, and maximum lengths.

Table 18. Comparison of natural-origin Bear Creek coho sizes over nine years (brood years 2000-2007).

Brood	Screw Trap					
Year	Avg	s.d.	Min	Max	n	Catch
2000	119.9	13.80	75	209	461	17,366
2001	116.3	12.40	86	191	2,425	15,048
2002	111.9	14.40	80	198	610	9,111
2003	110.9	12.10	81	220	1,752	16,191
2004	113.8	13.98	80	184	857	11,439
2005	117.3	11.30	90	203	615	2,802
2006	114.3	13.03	89	168	582	1,573
2007	110.0	12.67	70	162	507	3,822

Trout

The identification of trout in Bear Creek poses the same difficulties discussed earlier in the Cedar River section. Based on available visual identification, trout are referred to as cutthroat trout or steelhead outmigrants. The cutthroat estimate does not differentiate migration for different life history strategies and is a measure of the number of cutthroat moving past the trap, not cutthroat production.

Catch and Production Estimate

No steelhead were captured during the entire 2009 trapping season in Bear Creek.

A total of 408 cutthroat trout were captured in the screw trap. Some of the cutthroat catch may actually be hybrids of rainbow and cutthroat trout if Cedar River results from Marshall *et al* (2006) are indicative of population structure in Bear Creek. From April 27 to May 1 catches totaled one-third of the entire season's catch. Thereafter, catches were intermittent with 24 cutthroat being the largest daily catch.

Twenty-seven different efficiency trials of cutthroat were released over the season, ranging from 1 to 30 cutthroat per efficiency trial. Efficiency trials were aggregated into two strata with capture rates of 6.5 % and 12.4%. Season migration of cutthroat was estimated to be 4,401 ± 1,751 cutthroat, with a coefficient of variation of 20.3% (Figure 18, Appendix C 5) for the trapping period (April 22 through June 30). During the 2000 season, when the screw trap operated from January through June on Bear Creek, 35% of the cutthroat migration occurred prior to April 5. If this time allocation for the migration is applied to cutthroat estimates from the 2009 trapping season, a total of 6,770 cutthroat are estimated to have migrated from Bear Creek.

Cutthroat trout fork lengths averaged 153.3 mm, and ranged from 112 mm to 228 mm throughout the trapping season (Table 19). Average fork lengths showed no consistent trend across weeks.

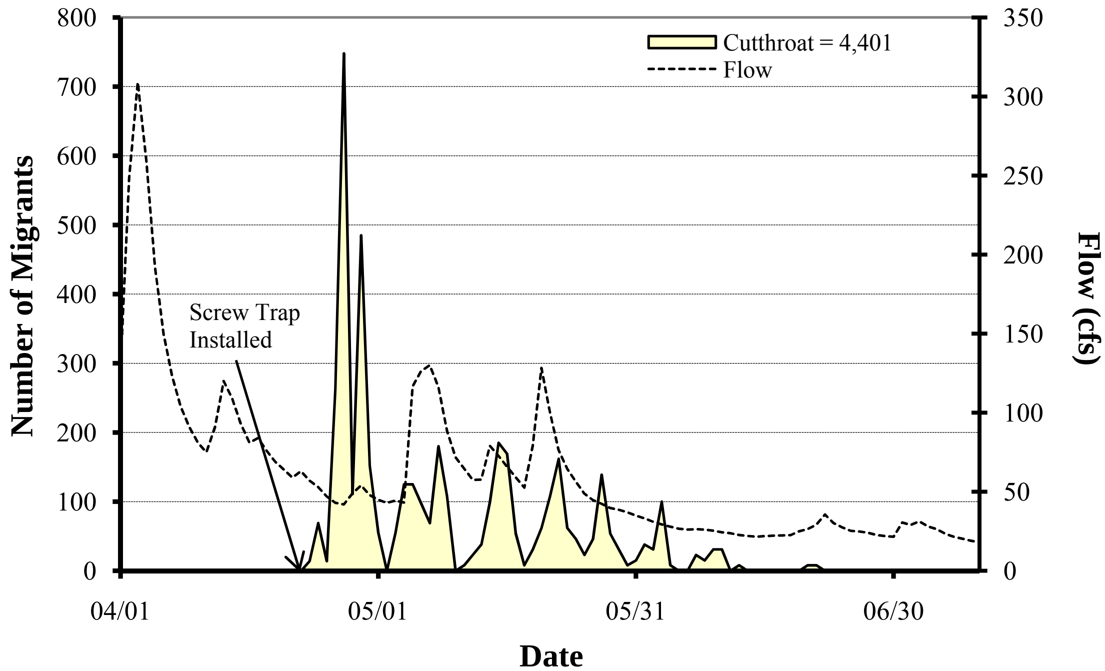


Figure 18. Daily estimated migration of cutthroat trout passing the Bear Creek screw trap in 2009. Flow data were measured at the King County gaging station at Union Hill Road.

Table 19. Cutthroat fork length (mm), standard deviation (s.d.), range, sample size (n), and catch by statistical week in the Bear Creek screw trap, 2009.

Statistical Week			Avg.	s.d.	Range		n	Catch
Begin	End	No.			Min	Max		
04/19	04/25	17	161.2	16.92	140	190	6	7
04/26	05/02	18	165.5	25.47	120	228	38	131
05/03	05/09	19	153.8	17.93	112	196	30	61
05/10	05/16	20	149.4	15.11	120	197	46	68
05/17	05/23	21	157.9	23.36	132	225	22	59
05/24	05/30	22	147.1	14.41	125	174	20	41
05/31	06/06	23	137.5	10.91	121	154	15	25
06/07	06/13	24	145.0	25.71	112	192	11	14
06/14	06/20	25						1
06/14	06/20	26	158.0	n/a	158	158	1	1
06/23	07/09	27-28						
Season Totals			**153.3**	**20.78**	**112**	**228**	**189**	**408**

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 2009. Tagging began on May 5 and occurred three times a week through June 19. Fish were often held overnight to increase the number tagged per day. A total of 1,826 natural-origin Chinook were PIT tagged in Bear Creek throughout the season (Table 20).

Table 20. Natural-origin Chinook parr PIT tagged and released from the Bear Creek screw trap in 2009.

Stat Week			#	Length			Portion of Parr
#	Start	End	Tagged	Avg	Min	Max	Migration Tagged
19	05/06	05/10	83	70.1	65	80	1.14%
20	05/11	05/17	121	74.3	66	92	3.27%
21	05/18	05/24	344	75.0	65	91	2.67%
22	05/25	05/31	574	79.3	65	104	6.83%
23	06/01	06/07	426	77.2	65	98	3.07%
24	06/08	06/14	249	75.9	65	97	20.00%
25	06/15	06/21	29	76.8	69	99	17.88%
Season Totals			**1,826**	**74.7**	**65**	**104**	**3.64%**

Mortality

One Chinook mortality occurred during inclined-plane trapping. One hundred and fifty-two Chinook mortalities occurred in the screw trap; eight of these were due to PIT tagging while the remaining were a result of heavy debris in the live box and a combination of high temperatures and debris contributing to poor water circulation.

Incidental Species

In addition to sockeye and Chinook fry, 10 coho fry were also caught in the inclined-plane trap. Other species included lamprey (*Lampetra spp.*), sculpin (*Cottus spp.*), bluegill (*Lepomis macrochirus*), brown and/or yellow bullhead catfish (*Ameiurus spp.*), yellow perch fry (*Perca flavescens),* pumpkinseed (*Lepomis gibbosus),* green sunfish (*Lepomis cyanellus*), and three-spine stickleback (*Gasterosterus aculeatus*).

In addition to target species, the screw trap captured sockeye fry, 14 coho fry, 10 trout fry, 2 sockeye smolts, 8 hatchery trout plants from Cottage Lake and 2 cutthroat adults. Other species caught included lamprey, large-scale suckers (*Catostomus macrocheilus*), three-spine stickleback, sculpin, pumpkinseed, largemouth bass (*Micropterus salmoides*), whitefish (*Prosopium spp.*), peamouth (*Mylocheilus caurinus*), speckled dace (*Rhinichthys osculus*), brown and/or yellow bullhead catfish, bluegill, yellow perch, and a green sunfish.

Discussion

The 2009 downstream migrant study resulted in precise estimates of sockeye and Chinook production (*CV* < 15%). Production was also estimated for coho and cutthroat trout. A number of changes and improvements occurred in the 2009 trap season; a new approach to analyzing efficiency stratification was applied to the 2009 season's data, preliminary evaluation of the capture rates of hatchery and natural-origin sockeye was conducted through the use of hatchery sockeye for some efficiency trials, the Cedar River screw trap was moved to a new location, and a pond leveler was installed in a beaver dam in Bear Creek to restore flow at the trap site. These improvements and the overall goals of this study are evaluated and discussed below.

Analysis

G-test Approach to Stratification

In the past, multiple methods have been used to stratify and apply efficiency trial data to catches for the purpose of estimating production. These methods include applying the seasonal average trap efficiency, stratifying release groups by mark type over a period (usually by statistical week), or stratifying over different flow regimes. In 2009, a different approach was taken. A G-test was applied to determine whether or not the recapture rate from one efficiency trial was statistically different from the next and whether or not the two should be aggregated or held separate. The G-test-is a statistical method used to aggregate efficiency trials. In applying a new method for analysis, it was prudent to compare production estimated with the G-test method to previous methods used for estimating production. Bear Creek Chinook parr mark data were chosen to compare stratification methods because Bear Creek provided large efficiency trials and subsequent recaptures.

For this comparison, Chinook production was estimated from the Bear Creek screw trap data using three stratification approaches: 1) stratification by G-tests of efficiency trials, 2) weekly stratification by efficiency trails, and 3) single seasonal stratification of all efficiency trials (Table 21). The production estimate from the G-test stratification was 55,819 ± 11,872 (*CV* = 10.85%). Production estimate from the weekly stratification of efficiency trails was 59,433 ± 12,389 (*CV* = 10.63%). Production estimate using the seasonal average efficiency was 31,919 (*CV* = 5.36%).

Production estimates calculated with each of the three stratification methods were compared using pair-wise *Z*-tests (α=0.05). Production estimates did not differ between the G-test and weekly efficiency trial stratifications (Z = -0.41, p = 0.68). However, production estimates using the seasonal efficiency stratification were lower than the G-test stratification (Z = 3.79, p = 0.0001) and stratification based on weekly efficiency trials (Z = 4.2, p = 0.000026).

Table 21. Comparison of Bear Creek Chinook production using various methods for stratifying efficiency trial data.

Stratification Method	Migration	Variance	CV
G-test	55,819	3.67E+07	10.85%
Weekly Efficiency Trials	59,433	3.99E+07	10.63%
Seasonal Average	31,919	2.93E+06	5.36%

Cedar River

Sockeye

Hatchery and Natural-Origin Release Groups

During January 2009, the Cedar River experienced record high flows. In anticipation of smaller sockeye catches during the season, sockeye from Landsburg Hatchery were arranged to be used as surrogates for some release groups (ten separate groups), as smaller and fewer release groups can result in less accurate estimates. As the season proceeded, natural-origin sockeye catches were higher than anticipated and were used in conjunction with hatchery sockeye for release groups (46 natural-origin release groups throughout the season). Using both natural-origin and hatchery sockeye for mark release groups provided a comparison of hatchery and natural-origin sockeye capture rates.

Differences in capture rates based on sockeye origin were evaluated using the G-test approach described in the methods section (α=0.05). The ratio of seen:unseen marked sockeye was compared between natural-origin and hatchery-origin efficiency trials. Efficiency trials were compared using two approaches; average seasonal capture rates and individual hatchery efficiency trials paired with surrounding nights' efficiency trials of natural-origin sockeye. The seasonal average capture rate did not differ between hatchery-origin (efficiency = 6.2%) and natural-origin sockeye (efficiency = 5.2%) (p = 0.09).

For the second approach, each hatchery efficiency trial was paired with a natural-origin sockeye efficiency trail that was released on a night preceding or following the hatchery release group. Flow was taken into consideration when deciding which natural-origin releases to choose for comparison. When pairing hatchery efficiency trials with surrounding nights' natural-origin sockeye efficiency trials, the findings were similar to that of the seasonal average efficiency. Each hatchery release group did not prove to be significantly different from its paired natural-origin release group ($p \geq 0.59$). Both approaches suggest that hatchery sockeye behave similarly enough to natural-origin sockeye to be used a surrogates should natural-origin sockeye fry be scarce in the future.

Median Migration Date

One of the goals identified for this study is to identify environmental variables that influence sockeye migration timing. Previous reports have demonstrated that total thermal units during the month of February are a good predictor of the sockeye median migration date (Figure 19, R^2=0.52). However, upon further exploration of the data, average temperatures from November through January are a better predictor of median migration date than February thermal units (Figure 19, R^2= 0.73). Because these months occur earlier in the season, they should be useful for making management decisions such as the release timing of hatchery sockeye. The period between November and January represents the incubation period when most sockeye spawning has been completed and majority of the eggs have been deposited in the gravel. If temperatures are warmer during the incubation period, the median migration date may occur earlier. Further analysis will evaluate the influence temperature at different stages of egg development have on sockeye and Chinook migration timing in the Cedar River and Bear Creek. Broods 1999 and 2005 were not included in analysis as November and December temperatures were not available. Brood 2000 was not included in analysis due to extreme low flows and a landslide that impeded migration for a portion of the season.

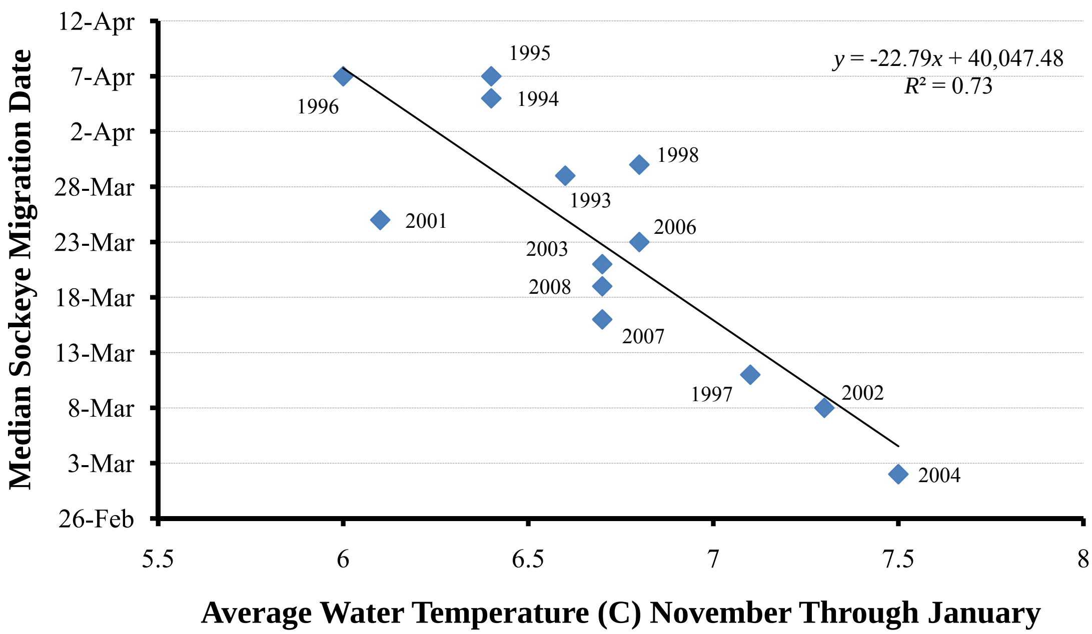


Figure 19. Median migration date for brood years 1993-2008 sockeye as a function of average November through January water temperatures in the Cedar River as measured at the USGS Renton Gage #12119000. Brood years 1999, 2000, and 2005 were not included. Temperature data was not available for brood years 1999 and 2005. Brood year 2000 was treated as an outlier.

Screw Trap Location

Between 2006 and 2008, the Cedar River screw trap operated in a location that provided small catches and low recapture rates, contributing to wide confidence intervals and less accurate estimates of all species. In 2009, the Cedar River screw trap was moved upstream to a new location. The trap operated at river mile1.6 just downstream of the where I-405 crosses the river. This new site provided larger catches which allowed larger and more frequent efficiency trial releases. As a result, there is greater confidence in the 2009 migration estimates of both Chinook and coho. Higher capture rates also resulted in PIT tagging a larger proportion of the Chinook parr migration (4.8% in 2009 compared to 1.2% in 2008, 0.2% in 2007, and 3.2% in 2006).

Egg-to-Migrant Survival

One goal of this study was to estimate in-river survival and identify variables that cause variation in survival. During January 2009, the Cedar River saw the highest flows since trapping began in 1992. Flows peaked at 9,390 cfs in Renton, as measure at the USGS Renton gage. This flood event provided a chance to further examine the resiliency of juvenile salmon to extreme environmental variation. Although the flow event was extreme in intensity and duration (flows above 2,000 cfs for 13 days), both Chinook and sockeye survived at higher rates than years when flood events were less intense (brood 1994, 1995, 1996, and 2006).

Egg-to-migrant survival of the 2008 brood sockeye was estimated to be 6.5%, considerably higher than the all four of the broods mentioned above. In 1994, flows only peaked at 2,730 cfs during the incubation period, yet survival was recorded at only 5.03%. In 1995, the previous record flow event of 7,310 cfs scoured and buried sockeye redds resulting in a mere 1.9% egg-to-migrant survival for the 1995 brood. The 1996 brood egg-to-migrant survival was estimated to be 6.43%, with peak incubation flows at 2,830 cfs, considerably lower flows than the 2009 flood. During late fall 2006, flows exceeded 5,400 cfs resulting in a 5.9% survival of the 2006 brood. Although peak incubation flows seem to be an important variable influencing survival of sockeye in the Cedar River, this does not explain why the 2008 brood survived better than other years when flows were not nearly as extreme. There may be other factors that, in conjunction with peak flows during incubation, contribute to survival. One possible explanation that warrants further examination is the timing of the high water event during incubation coupled with the developmental stage of the sockeye. Developmental stage will be determined by the total thermal units that redds experience before being affected by flow. With increased thermal units, eggs may be further along in development and better equipped to cope with disruption. Density of spawners and location of redds within the basin may also be a contributing factor.

Cedar River Chinook production was not estimated until the 1999 brood. As a result, survival of 2008 brood cannot be compared to the severe flow events affecting the 1995 brood. However, it can be compared to the 2006 high flow event with flows peaking at 5,114 cfs. Survival for the 2005 brood was estimated to be 4.7%. With the intensity and duration of the 2009 flood, it was expected that Chinook survival would be considerably lower; however, survival was actually estimated to be slightly higher (5.2%). Although this difference in survival is small, the difference in flows was extreme. At this time, no significant correlations have been found contributing to survival rates of Chinook and further evaluation is needed to better understand factors affecting both Chinook and sockeye survival.

Bear Creek

Trap Site

During the 2008 trap season, three beaver dams were located downstream of the Bear Creek trap, impeding water flow and creating little velocity at the trap site. This decrease in velocity was thought to have affected the trap's ability to capture fish. In fall of 2008, a flexible pipe pond leveler (Appendix D) was installed in two of the dams. Some water velocity was restored at the trap site shortly thereafter, and lasted throughout the 2009 trap season. Little to no rebuilding activity was found at the dams and water flow at the trap appeared to be unimpeded. During the last week of trapping (beginning June 21), velocity at the trap slowed. Upon further inspection, the upper-most dam had begun to be rebuilt and was retaining water. In the following months little work was done to deter building activity with hopes the pond leveler could adequately relieve the water pressure over time. After a few small fall storms in 2009, the pond leveler has not kept up with local water inflows and the dam continues to be built on. Although the pond leveler continues to allow flow through the dam, the increased height of the dam allows enough water retention to reduce velocity at the trap site again.

When comparing the average and maximum trap efficiencies for each species from 2003 to 2008, beaver dams were thought to have decreased trap efficiency in 2007 and 2008. However, after knocking down the dams, installing pond levelers and trapping nearly a whole season with little water retention, sockeye trap efficiency appears to be the only species' capture rate to have rebounded. Although the relief the pond levelers' provided was substantial, the change may not have been enough to affect the trap's ability to capture larger more mobile fish. Sockeye mobility is limited in comparison to larger parr size life stages. The return of velocity at the trap site may have been enough to increase capture rates of less mobile fish, but not enough to influence large fish. Trap efficiencies for Chinook parr in 2009 increased slightly compared to 2008. In contrast, coho and cutthroat trap efficiencies continued to decreased in 2009 (Table 22). The reason for lower recapture rates of larger migrants is still unclear.

Table 22. Trap efficiencies for Bear Creek 2003-2009. Only two cutthroat efficiency trials were released in 2003 with no recaptures.

Trap	Sockeye			Chinook Parr			Coho			Cutthroat		
Year	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
2003	6.8%	31.0%	18.8%	31.0%	72.0%	49.1%	14.0%	60.0%	31.0%			
2004	8.7%	20.9%	16.5%	27.0%	85.0%	49.2%	16.0%	70.0%	43.2%	17.0%	33.0%	25.6%
2005	8.7%	28.3%	19.4%	9.8%	96.2%	67.5%	5.4%	72.0%	37.3%	20.0%	30.2%	27.9%
2006	4.0%	20.6%	15.3%	25.7%	64.4%	49.6%	15.0%	46.8%	27.0%	7.5%	21.8%	13.9%
2007	1.5%	13.3%	8.8%	28.6%	52.3%	41.0%	8.1%	27.4%	15.6%	7.3%	18.6%	14.5%
2008	6.2%	12.5%	10.1%	18.0%	42.1%	25.3%	7.8%	28.7%	15.9%	9.0%	18.9%	11.5%
2009	5.9%	22.3%	15.0%	1.9%	50.7%	27.7%	6.7%	21.7%	12.5%	6.5%	12.4%	8.3%

Production and Egg-to-Migrant Survival

Sockeye

Two goals identified for this study are to estimate in-river survival of sockeye fry and determine variable contributing to fry production. These questions are integrally linked as the variables contributing to survival will limit production. The 2008 brood sockeye egg-to-migrant survival (36.18%) was higher than any year measured since trapping began. This higher survival rate occurred for the 2008 adult sockeye return which was the smallest Bear Creek has seen since trapping began (577 adult sockeye). Survival is weakly correlated with the total number of adult sockeye that seed Bear Creek. As the number of sockeye returning increases, survival decreases (R^2=0.37, Figure 20).

This relationship is also reflected in the spawner recruit plot. Total production of Bear Creek sockeye appears to be limited by the density of spawners contributing to the respective brood year (R^2=0.52, Figure 21). Higher survival at lower spawner densities suggests that spawning habitat is one factor limiting sockeye production in Bear Creek.

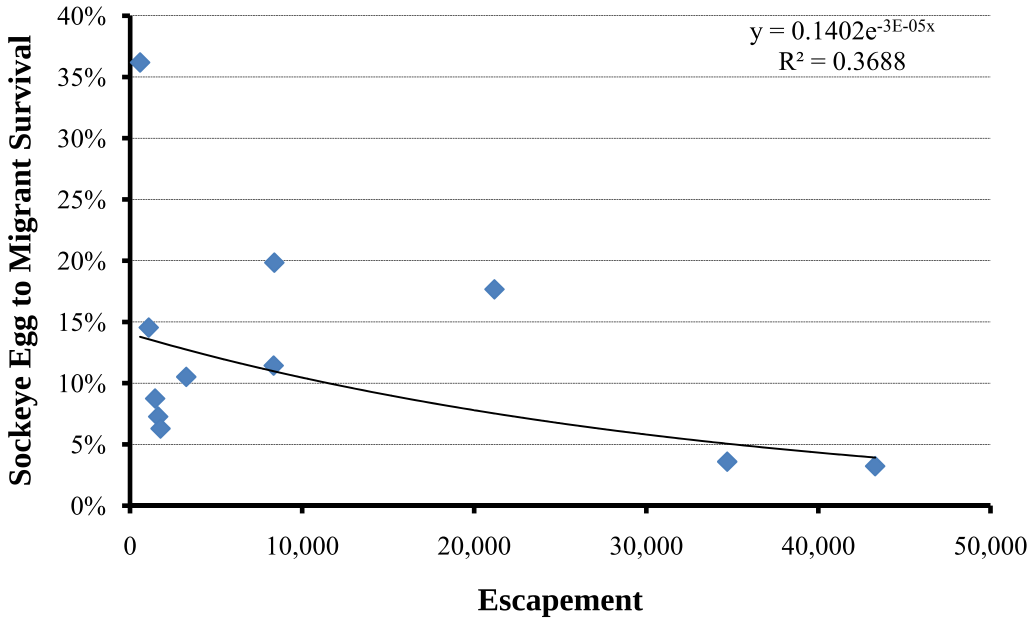


Figure 20. Egg to migration survival as a function of total sockeye escapement in Bear Creek, broods 1998-2008.

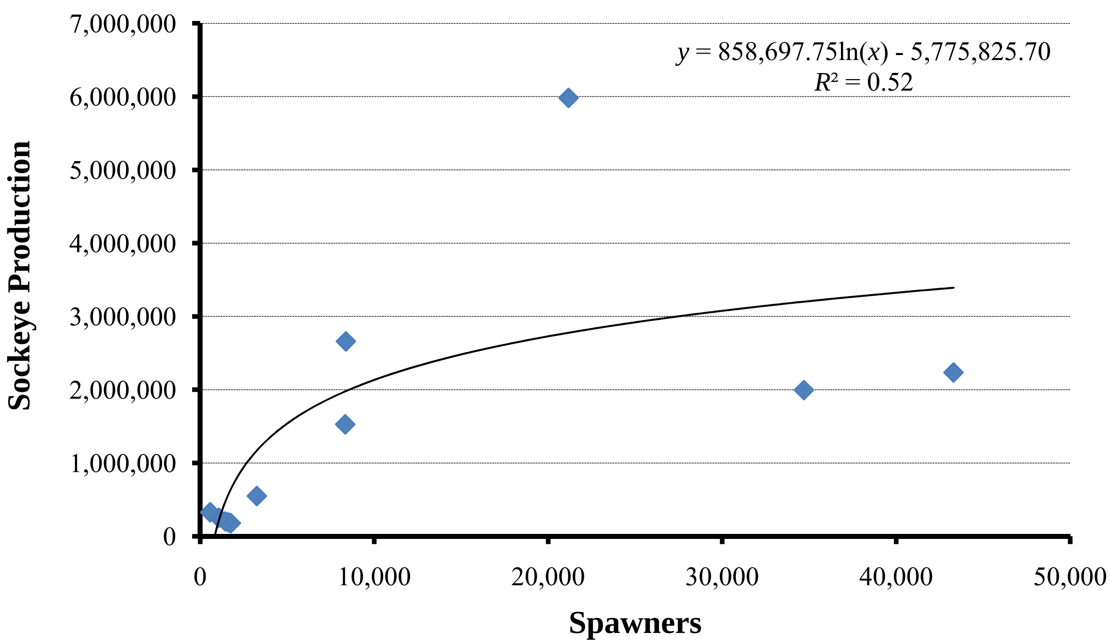


Figure 21. Bear Creek sockeye production as a function of total number of spawners, broods 1998-2008.

Chinook

Although the number of Chinook redds in 2008 was near the median for the last nine years, Chinook production was nearly twice as large as any year measured since trapping began. Production, estimated to be 65,202, resulted from good egg-to-migrant survival of the 2008 brood. Egg-to-migrant survival was estimated to be 10.98%, nearly two-fold any previously measured survival. There was no correlation between spawner abundance and production or spawners and survival for Bear Creek Chinook. The factor or combination of factors that provided optimal survival for both Chinook and sockeye in Bear Creek during the 2008-2009 incubation and migration periods remains to be identified.

Recommendations

The 2009 trapping season in Cedar River and Bear Creek experienced a number of successes. For example, the Cedar River screw trap operated in a new location with very little difficulties. The new location resulted in greater capture and recapture rates for all species as well as a greater percentage of the Chinook migration being PIT tagged. Due to larger catches, releasing larger groups of marked fish enabled more robust and confident migration estimates. Bear Creek also had flow restored to the trap site by placing a pond leveler in two beaver dams downstream.

Furthermore, when evaluating 2009 data for both systems, a number of assumptions associated with the uncertainty of our estimates became apparent and will be addressed in the 2010 trap season. Tests of these assumptions will improve the accuracy of migration estimates each trap season and more confidently identify contributing factors that affect survival and productivity of salmon in each basin.

Recommendation 1: Test assumption that there is very little, or no, sockeye and Chinook fry movement occurring during daylight hours in Bear Creek. This was a recommendation for the 2009 trap season, however an extreme flood on the Cedar River precluded efforts of measuring day movement on Bear Creek. Efforts were directed to producing a more accurate estimate of production and survival after a record flood event. Although daylight movement in Bear Creek was tested in the 1990s, it seems appropriate to periodically retest assumptions to confirm that salmonids are still behaving as expected. The consequence of missing day time catch of juvenile salmonids is an underestimate of the juvenile migration. In 2010, the Bear Creek inclined-plane trap will operate periodically throughout the season during daylight hours to assess daylight fry migrations, develop day:night ratios, and to reassess daytime migration.

Recommendation 2: Test the assumption that sockeye are adequate surrogates for estimating Chinook fry capture rates of the Cedar River inclined-plane trap. This assumption has been made based on similar physical states of fry for each species. Mobility as a fry is somewhat reduced in increased flows. As a result, it is assumed that Chinook fry move and behave similar enough to sockeye fry that applying sockeye capture rates to Chinook catches provides an adequate estimate of Chinook production while incurring the least amount of harm to natural-origin Chinook fry. During the 2010 trapping season, this assumption will be tested when Chinook fry abundance is large enough to form adequate size release groups. Ideally multiple releases throughout the season and in a wide range of flows would occur to better understand similarities and differences in movement over time, as well as produce more accurate production estimates. In an effort to formulate a statistically sound comparison, the first year will be focused on data gathering, deciphering whether or not there is an initial difference between efficiencies, and determining an associated variance. Subsequent years will continue to focus on data gathering, determining whether or not a difference can be detected based on the number of trials conducted, and at what statistical level of confidence a difference could be detected.

Recommendation 3: Test assumption that yearling fish of all sizes have equal probability of recapture in screw trap on both watersheds. One assumption of a mark-recapture study is that all fish have an equal probability of be captured and recaptured. Testing the assumption that fish of all sizes have an equal probability of being caught will reveal any size bias by the screw trap.

Size selectivity may skew population estimates. This assumption is particularly important to test in Bear Creek as trap efficiencies of larger migrants have consistently decreased over time. A subsample of fork lengths of fish marked for release will be measured. All recaptured fish will be measured. Size of recaptures will be compared to the size of those marked and released. No difference should be found if there is no size bias of the traps ability to catch fish.

Appendix A

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

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

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

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

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

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

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

where

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

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

Derivation:

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

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

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

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

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

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

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

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

Note that,

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

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

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

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

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

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

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

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

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

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

Appendix B

Catch and Migration Estimates by Stratum for Cedar River
Sockeye, Chinook, and Coho Salmon, 2009.

Appendix B 1. Catch and migration by stratum for Cedar River natural-origin sockeye fry, 2009.

Stratum	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	02/01/09	02/19/09	4,803	5.86%	81,314	5.39E+07
2	02/20/09	02/21/09	1,749	20.00%	8,337	5.17E+06
3	02/22/09	03/08/09	22,508	4.91%	456,326	1.09E+09
4	03/09/09	03/12/09	5,015	7.94%	62,256	6.46E+07
5	03/13/09	03/26/09	24,435	4.33%	561,096	2.20E+09
6	03/27/09	04/02/09	11,550	6.30%	182,255	2.32E+08
7	04/03/09	04/22/09	7,968	3.36%	232,332	1.45E+09
8	04/23/09	05/22/09	2,937	6.30%	46,165	5.05E+07
		Total	**80,965**		**1,630,081**	**5.15E+09**

Appendix B 2. Catch and migration by stratum for Cedar River natural-origin Chinook fry, 2009.

Stratum	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	02/01/09	02/19/09	1,690	5.86%	30,148	9.82E+06
2	02/20/09	02/21/09	448	20.00%	2,141	4.07E+05
3	02/22/09	03/08/09	1,810	4.91%	36,713	1.30E+07
4	03/09/09	03/12/09	582	7.94%	7,240	3.35E+08
5	03/13/09	03/26/09	1,437	4.33%	33,029	2.03E+07
6	03/27/09	04/02/09	194	6.30%	3,078	1.65E+05
7	04/03/09	04/22/09	402	3.36%	11,747	3.29E+06
		Total	**6,565**		**124,096**	**3.81E+08**

Appendix B 3. Catch and migration by stratum for Cedar River natural-origin Chinook parr, 2009.

Stratum	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/21/09	04/26/09	44	15.38%	286	8.85E+03
2	04/27/09	05/01/09	27	9.09%	297	8.56E+03
3	05/02/09	05/08/09	60	26.67%	225	3.49E+03
4	05/09/09	05/20/09	125	7.78%	1,607	2.18E+05
5	05/21/09	05/25/09	105	13.79%	761	4.80E+04
6	05/26/09	06/06/09	241	15.67%	1,538	9.50E+04
7	06/07/09	06/13/09	242	8.15%	2,969	4.59E+05
8	06/14/09	07/18/09	331	6.91%	4,791	9.77E+05
		Total	**1,175**		**12,474**	**1.82E+06**

Appendix B 4. Catch and migration by stratum for Cedar River natural-origin coho smolts, 2009.

Stratum	Date		Total Catch	Recapture Rate	Estimated Migration	Variance
	Begin	End				
1	04/21/09	04/26/09	309	10.60%	2,771	3.97E+05
2	04/27/09	05/01/09	525	10.45%	4,733	1.58E+06
3	05/02/09	05/08/09	710	13.71%	5,092	4.76E+05
4	05/09/09	05/20/09	3311	10.80%	30,346	9.67E+06
5	05/21/09	05/25/09	457	9.20%	4,830	7.02E+05
6	05/26/09	06/06/09	390	12.31%	3,119	1.91E+05
7	06/07/09	06/13/09	21	10.53%	146	4.76E+03
8	06/14/09	07/18/09	82	9.59%	767	6.26E+04
Total			**5,805**		**51,804**	**1.31E+07**

Appendix C

Catch and Migration Estimates by Stratum for Bear Creek
Sockeye, Chinook, Coho Salmon, and Cutthroat Trout, 2009.

Appendix C 1. Catch and migration by stratum for Bear Creek sockeye, 2009.

Stratum	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	02/02/09	03/01/09	1,024	22.31%	4,549	5.48E+05
2	03/02/09	03/24/09	10,290	16.63%	61,745	3.93E+07
3	03/25/09	03/28/09	5,510	5.93%	89,323	4.51E+08
4	03/29/09	04/01/09	4,262	16.26%	26,094	1.40E+07
5	04/02/09	04/05/09	3,718	6.54%	55,359	2.00E+08
6	04/06/09	04/11/09	10,854	16.17%	66,982	4.70E+07
7	04/12/09	04/13/09	1,323	11.79%	11,069	1.82E+06
8	04/14/09	04/14/09	714	17.83%	3,895	4.61E+05
9	04/16/09	04/16/09	308	9.56%	3,023	5.68E+05
		Total	**38,003**		**322,038**	**7.55E+08**

Appendix C 2. Catch and migration by stratum for Bear Creek natural-origin Chinook fry, 2009.

Stratum	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	02/02/09	03/01/09	18	22.31%	83	8.08E+02
2	03/02/09	03/24/09	1,827	16.63%	10,967	9.53E+06
3	03/25/09	03/28/09	136	5.93%	2,220	3.29E+05
4	03/29/09	04/01/09	32	16.26%	201	1.27E+03
5	04/02/09	04/05/09	40	6.54%	609	2.14E+04
6	04/06/09	04/11/09	65	16.17%	406	4.62E+03
7	04/12/09	04/13/09	24	11.79%	208	2.02E+03
8	04/14/09	04/14/09	36	17.83%	201	1.96E+03
9	04/16/09	04/16/09	20	9.56%	205	3.90E+03
		Total	**2,198**		**15,100**	**9.90E+06**

Appendix C 3. Catch and migration by stratum for Bear Creek natural-origin Chinook parr, 2009.

Stratum	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/22/09	05/03/09	1,278	50.73%	2,513	2.00E+04
2	05/04/09	05/06/09	779	25.66%	2,963	2.16E+05
3	05/07/09	05/10/09	635	14.36%	4,297	5.47E+05
4	05/11/09	05/19/09	1,869	32.00%	5,782	3.54E+05
5	05/20/09	05/23/09	1,105	10.67%	9,823	7.89E+06
6	05/24/09	05/28/09	1,219	23.62%	5,082	4.16E+05
7	05/29/09	06/01/09	1,017	17.00%	5,711	1.78E+06
8	06/02/09	06/02/09	361	1.96%	9,411	2.90E+07
9	06/03/09	06/04/09	321	36.73%	846	3.50E+04
10	06/05/09	06/09/09	405	11.86%	3,044	9.06E+05
11	06/10/09	06/30/09	225	35.16%	629	8.51E+03
		Total	**9,214**		**50,102**	**4.11E+07**

Appendix C 4. Catch and migration by stratum for Bear Creek natural-origin coho smolts, 2009.

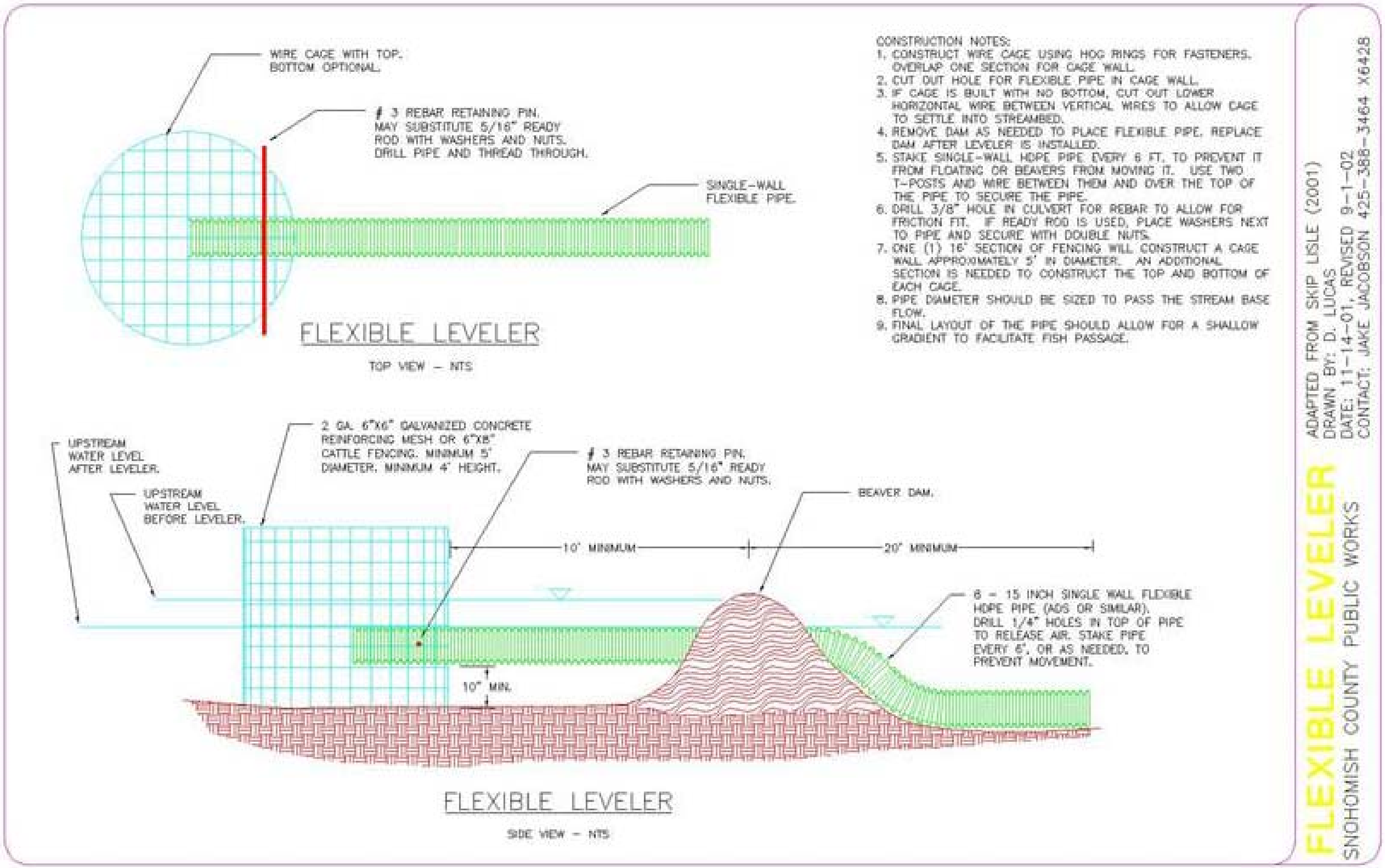
Stratum	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/22/09	05/04/09	565	13.22%	4,187	3.95E+05
2	05/05/09	05/06/09	531	21.67%	2,317	2.82E+05
3	05/07/09	05/09/09	702	6.67%	9,649	7.29E+06
4	05/10/09	05/16/09	1275	18.61%	6,773	5.68E+05
5	05/17/09	06/30/09	853	8.04%	10,359	2.66E+06
		Total	**3,926**		**33,286**	**1.12E+07**

Appendix C 5. Catch and migration by stratum for Bear Creek cutthroat migrants, 2009.

Stratum	Date Begin	Date End	Total Catch	Recapture Rate	Estimated Migration	Variance
1	04/22/09	05/09/09	185	6.50%	2,562	6.32E+05
2	05/10/09	06/30/09	239	12.41%	1,839	1.66E+05
		Total	**424**		**4,401**	**7.98E+05**

Appendix D

Snohomish County Public Utility District's schematics of a flexible pipe pond leveler used to alleviate retained water due to beaver dams in Bear Creek, 2009.


WIRE CAGE WITH TOP. BOTTOM OPTIONAL.
3 REBAR RETAINING PIN. MAY SUBSTITUTE 5/16" READY ROD WITH WASHERS AND NUTS. DRILL PIPE AND THREAD THROUGH.
SINGLE-WALL FLEXIBLE PIPE.
FLEXIBLE LEVELER
TOP VIEW – NTS
CONSTRUCTION NOTES:
1. CONSTRUCT WIRE CAGE USING HOG RINGS FOR FASTENERS. OVERLAP ONE SECTION FOR CAGE WALL.
2. CUT OUT HOLE FOR FLEXIBLE PIPE IN CAGE WALL.
3. IF CAGE IS BUILT WITH NO BOTTOM, CUT OUT LOWER HORIZONTAL WIRE BETWEEN VERTICAL WIRES TO ALLOW CAGE TO SETTLE INTO STREAMBED.
4. REMOVE DAM AS NEEDED TO PLACE FLEXIBLE PIPE. REPLACE DAM AFTER LEVELER IS INSTALLED.
5. STAKE SINGLE-WALL HDPE PIPE EVERY 6 FT. TO PREVENT IT FROM FLOATING OR BEAVERS FROM MOVING IT. USE TWO T-POSTS AND WIRE BETWEEN THEM AND OVER THE TOP OF THE PIPE TO SECURE THE PIPE.
6. DRILL 3/8" HOLE IN CULVERT FOR REBAR TO ALLOW FOR FRICTION FIT. IF READY ROD IS USED, PLACE WASHERS NEXT TO PIPE AND SECURE WITH DOUBLE NUTS.
7. ONE (1) 16' SECTION OF FENCING WILL CONSTRUCT A CAGE WALL APPROXIMATELY 5' IN DIAMETER. AN ADDITIONAL SECTION IS NEEDED TO CONSTRUCT THE TOP AND BOTTOM OF EACH CAGE.
8. PIPE DIAMETER SHOULD BE SIZED TO PASS THE STREAM BASE FLOW.
9. FINAL LAYOUT OF THE PIPE SHOULD ALLOW FOR A SHALLOW GRADIENT TO FACILITATE FISH PASSAGE.
UPSTREAM WATER LEVEL AFTER LEVELER.
UPSTREAM WATER LEVEL BEFORE LEVELER.
2 GA. 6"X6" GALVANIZED CONCRETE REINFORCING MESH OR 6"X8" CATTLE FENCING. MINIMUM 5' DIAMETER, MINIMUM 4' HEIGHT.
3 REBAR RETAINING PIN. MAY SUBSTITUTE 5/16" READY ROD WITH WASHERS AND NUTS.
BEAVER DAM.
10' MINIMUM
20' MINIMUM
8 – 15 INCH SINGLE WALL FLEXIBLE HDPE PIPE (ADS OR SIMILAR). DRILL 1/4" HOLES IN TOP OF PIPE TO RELEASE AIR. STAKE PIPE EVERY 6', OR AS NEEDED, TO PREVENT MOVEMENT.
10" MIN.
FLEXIBLE LEVELER
SIDE VIEW – NTS
FLEXIBLE LEVELER
SNOHOMISH COUNTY PUBLIC WORKS
ADAPTED FROM SKIP LISLE (2001)
DRAWN BY: D. LUCAS
DATE: 11-14-01, REVISED 9-1-02
CONTACT: JAKE JACOBSON 425-388-3464 X6428

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