# 1999 Cedar River Sockeye Salmon Fry Production Evaluation

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The success of this project relies on the hard work of a number of dedicated permanent and temporary WDFW personnel. The Hatcheries Program successfully collected adult broodstock and incubated eggs, releasing over 9.6 million sockeye fry. Eric Volk and Gene Sanborn designed and implemented the otolith-marking program at Landsburg Hatchery. Volk and his staff at the Otolith Lab extracted and analyzed otoliths from the fry sampled at the trap. Scientific Technicians Paul Lorenz, Chuck Ridley and Tim Eichler worked long hours at night operating and maintaining the trap, marking and releasing fry, and enumerating catches. WDFW Wild Salmon Production & Survival Evaluation Unit biologists Mike Ackley and Pete Topping provided valuable logistical support.

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# Executive Summary

Declining adult sockeye salmon returns in the late 1980's and early 1990's prompted the creation of a multi-agency broad-based program to investigate causes for these declines. To determine which portion of the freshwater habitat was having the greatest impact on sockeye survival, a sockeye fry production study was undertaken in the Cedar River beginning in 1992. Assessing the sockeye population at this location and life-stage separates freshwater production into river and lake components. This report documents our investigations during 1999, the eighth year of this project. Study objectives in 1999 included estimating the season total migration of wild and hatchery sockeye fry into Lake Washington, estimating the survival rate from egg deposition to lake entry, estimating survival of hatchery fry by release group, and estimating the incidence of hatchery fry in the population at lake entry.

As in previous years, a floating inclined-plane screen trap was operated nightly in the lower 1/2-mile of the Cedar River. A portion of the sockeye fry migrating into Lake Washington were captured in this trap. To estimate the capture efficiency, over the season 54 groups of 1,266 to 3,175 dye-marked fry were released upstream of the trap. The recapture rates were correlated with flow to develop a relationship that would predict nightly capture efficiency. Dredging in the lower Cedar River in 1998 substantially changed the channel morphology which reduced both the capture efficiency and the strength of the flow-based capture efficiency relationship. A number of trap position adjustments were made to improve capture efficiency. Nightly migration was estimated by dividing the nightly catch by either the flow-based estimates of capture efficiency or the mean capture efficiency rate depending on the position of the trap.

Over the season, 9.6-million hatchery sockeye fry were released into the Cedar River from three locations. To enable separation of hatchery and wild fry in the catch, thermal marks were intentionally placed on the otoliths (bony structures in the inner ear of fish) of hatchery fry by manipulating water temperatures in the hatchery. On the nights of and following hatchery releases, fry caught in the trap were sampled for thermal marks to determine the proportion of hatchery fish present.

Over the 126 night trapping period, nearly 757,000 sockeye fry were captured in the traps. From this catch and the estimated capture efficiencies, we estimated a total of 18.5-million wild and hatchery sockeye fry entered Lake Washington in 1999. This estimate was based on two assumptions; 1) it assumed that daytime migration (when the trap was not operated) accounted for 10% of the total daily migration (estimated from daytime trapping in 1998), and 2) that an estimated 73,000 sockeye fry migrated between an assumed January 1 migration starting date and the date that trapping began (January 23).

Out of the total estimate of 18.5-million sockeye fry that entered Lake Washington, we estimated that 9.5-million were wild fry. Of the 9.6-million hatchery fry released upstream of the trap, we estimated that 9.0-million (94%) survived to enter the lake.

Migration timing for wild sockeye fry was about average compared to the other seven years studied. In 1998, we determined that median migration timing for wild sockeye fry was found to be correlated with February stream temperatures. The median stream temperature in 1999 was 6.7C, also about average for the eight years evaluated so far.

The survival rate from egg deposition to lake entry for wild sockeye fry was estimated by dividing the wild fry migration estimate by the potential egg deposition (PED). PED was estimated from the 1998 sockeye escapement estimate by assuming and even sex ratio and an average fecundity of 3,176 eggs per female (estimated from hatchery spawners). The escapement estimate of 50,000 adults yielded a PED of 79.4-million eggs. The resulting egg-to-migrant survival rate was estimated to be 11.96%, the fourth highest found over the eight years studied. Over this period, egg-to-migrant survival has been negatively correlated with the highest daily average winter streamflow occurring during egg incubation. Survivals were found to be lowest (1.91%) for the 1995 brood which experienced a peak flow of 7,310-cfs, and highest for the 1992 brood (15.62%) where peak flows only reached 1,570-cfs. Peak flows affecting the 1998 brood were estimated at 2,720-cfs.

# Introduction

Adult sockeye salmon returns to the Lake Washington system have declined from peak runs in excess of 600,000 fish as recently as 1988, to under 100,000 fish in subsequent years. In 1991, a broad-based group comprised of representatives of local governments, the Muckleshoot Indian Tribe, state and federal fisheries agencies, academic institutions, and concerned citizens was formed to address this decline. Resource managers developed a program to investigate the cause(s) of the sockeye decline through research and population monitoring in combination with an artificial production program. Information generated by these efforts will be used to devise a restoration plan for Lake Washington sockeye salmon.

At a gross-scale, sockeye life history can be partitioned into a freshwater incubation and rearing phase and a marine rearing phase. Habitat and environmental conditions during each of these phases affects survival of the brood. Existing management information indicated that marine survival has averaged 11.4%, varying eight-fold (2.6% to 21.4%), for the 1967 to 1993 broods with no apparent decline over the data set (WDFW unpublished data). In contrast, however, survival during the freshwater phase has declined in recent years. For the 1985 through 1993 broods, freshwater survival (as indicated by the estimated numbers of pre-smolts produced/spawner) has averaged only 6.9. This rate is less than half of the average production rate of 14.1 pre-smolts per spawner for the previous 18 broods (1967-1984) (WDFW unpublished data).

During the freshwater phase, the majority of sockeye production involves two freshwater habitats: the stream, where spawning, egg incubation, fry emergence, and migration to the lake occurs; and the lake, where virtually all of the juveniles rear for one year before emigrating to the ocean as smolts. Measuring survival rates in both of these habitats will help in defining possible causes for population declines. Survival rate measurement during stream rearing requires quantifying the numbers of hatchery and naturally-produced sockeye fry entering Lake Washington as well as estimating the population of parent spawners producing these fry. In 1992, we developed the trapping gear and methodology to estimate sockeye fry production from the Cedar River and began monitoring.

Production at the Landsburg Hatchery began with the 1991 brood. This brood, released in 1992, and all subsequent sockeye incubated at this hatchery, have been identified with thermally-induced otolith-marks (Volk *et al.* 1990). During the first three years of this evaluation, we determined that survival of hatchery fry from Landsburg to the trap was very low, often less than 10% (Seiler 1993, Seiler 1994). In these three seasons, however, flows during most upriver releases were at or near minimum levels. To avoid this high in-river mortality, beginning in the second year (1993), the majority of the hatchery production was transported and released in the lower river just upstream of Highway I-405 (Figure 1). In 1995, we evaluated the effect of flow on survival using ten groups released over a range of flows. Results corroborated the earlier estimates, demonstrating that in-river fry survival is largely a function of flow (Seiler and Kishimoto 1996).

Over the first five brood years of this evaluation, we have also determined that the survival from egg deposition to fry emigration is largely a function of the severity of peak flows in the Cedar River during the egg incubation period (Seiler and Kishimoto 1997). Therefore, over the range of spawning population levels we have thus far evaluated, the numbers of naturally produced fry entering Lake Washington are the product of the number of eggs deposited and the flow-effected survival rate. In 1998, WDFW biologists estimated that 50,000 adult sockeye spawned in the Cedar River, the second lowest escapement recorded since 1967.

Our ability to capture fry and make a precise estimate of migration is predicated on selection of trapping sites with optimal flow characteristics for trapping. Optimal flow characteristics are reflected in sites that direct a relatively high percentage of downstream migrants into the trap and that have sufficient velocity so that targeted species are captured without bias to size or

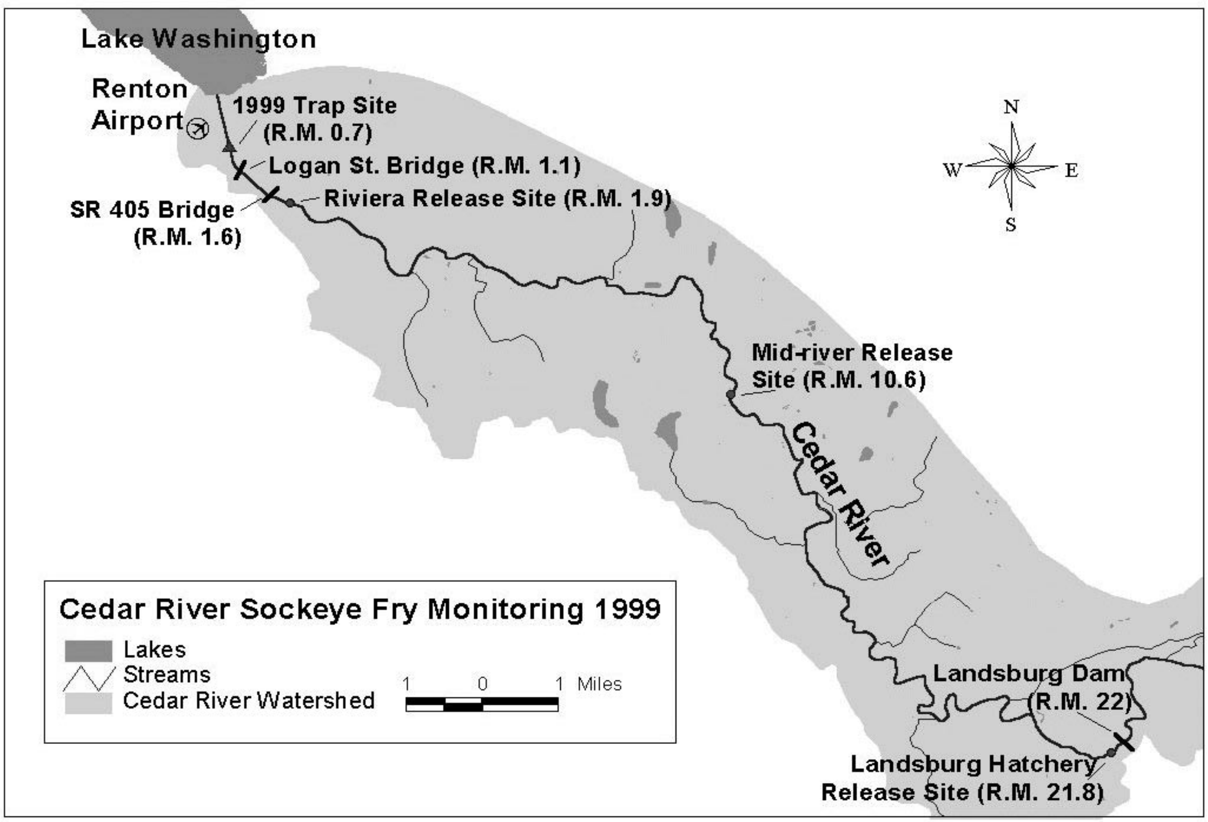


**Figure 1**. Site map of the lower Cedar River watershed depicting the sockeye fry trap location, hatchery sockeye fry release sites, and other features relevant to the 1999 sockeye production evaluation study.

swimming ability. The importance of velocity to unbiased capture is illustrated by the 1998 fry trap results. As a result of extensive sediment deposition in the lower Cedar River, the streambed in the 1998 season was substantially aggrading; resulting in sizable bed elevation increases compared to observations from the previous six seasons. The resulting difference in bed elevations between the lower river channel and the lake created sufficient stream energy to cut a distinct channel which, at low flow discharge, confined flow. The resulting velocities were high enough in the trap even at minimum flows to capture large chinook smolts. This was also evident by the high numbers of coho smolts (which are larger than chinook smolts) that we captured relative to catches in all other years. In 1998, we caught 646 coho smolts, compared to an average catch for the previous seasons of just 92 coho smolts (WDFW unpublished data).

In the summer of 1998, the lower Cedar River was dredged to reduce the flooding potential (USACOE 1997). This project lowered the stream bed and created a wider and deeper channel, which reduced the velocity to near zero where the fry trap was located (RM 0.25). Given this dramatic change in the channel, it was clear that capturing an unbiased sample of migrants over the entire flow range would require a different trap location in 1999. In addition, the scope of our trapping program was expanded in 1999 to also evaluate the production of juvenile chinook (Seiler *et al.*, *in press*). Therefore, a new trapping site was selected in 1999 to enable the monitoring of both species given the altered channel form of the lower Cedar River.

This report documents the ***1999 Cedar River Sockeye Salmon Fry Production Evaluation***. This trapping project estimated the numbers of 1998 brood Cedar River wild and hatchery-produced fry that entered Lake Washington during 1999.

# Goals and Objectives

The primary goal of this project is to estimate total sockeye salmon fry production from the Cedar River. Additional goals include estimating the hatchery and wild composition of the nightly fry emigration throughout the season. Accomplishing these goals will produce the following estimates, which are critical for understanding the components of this stock's decline in survival and the carrying capacity of Lake Washington for rearing sockeye.

1. **The season total of wild and hatchery fry entering the lake**. Relating the smolt population the following spring to this estimate measures rearing survival in the lake. This information over a range of years will help to assess the lake's carrying capacity.

2. **Survival of natural production**. Relating the estimate of wild fry produced to the estimated egg deposition measures the overall success of natural spawning in the Cedar River. Significant variation in this rate among broods, as a function of spawner abundance and flows, will also be assessed. In addition, analysis of wild emigration timing will provide insight into survival among temporally and spatially distributed components of natural spawners.

3. **Survival of hatchery fry by release group.** Correlating in-river survival of hatchery fry release groups with release location, timing, flow and total fry density will help explain the impact of habitat and environmental conditions on the survival of wild fry. It will also provide guidance for release location decisions.

4. **Incidence of hatchery fry in the population at lake entry**. Comparing this estimate with the incidence of hatchery fish in the population at later life stages (smolts and adults) will assess relative hatchery and wild survival rates.

# Methods

The number of sockeye fry migrating from the lower Cedar River was estimated by operating a trap throughout the migration period and calibrating the capture efficiency of this gear. During the first four years of this program, we estimated the hatchery and wild composition of nightly and seasonal migrations based on the proportion of marked otoliths in samples taken each night. From 1996 to 1998, we reduced the numbers of fry sampled for otoliths for several reasons: catches of fry were often relatively low before spiking upward following a hatchery release, suggesting the spike was due largely to hatchery fish; much of the hatchery production was released in the lower river just upstream of I-405 (above the trap); and the budget for otolith analysis was limited. In 1999, otolith analysis was used to estimate the hatchery component following most hatchery fry releases. Otolith sampling/analysis provided more precise estimates of hatchery and wild fry migration than alternative approaches.

## Trapping Gear and Operation

The trap employed two low-angle inclined-plane screen traps (3x2x9 ft) that were suspended from a 40x15-ft steel pontoon barge (Seiler and Kishimoto 1997). This structure resembled the larger traps we use to capture smolts throughout the state (Seiler *et al.* 1981). Each night, the traps were operated to capture migrants in the top 16-in of water. At this depth, the cross-sectional area trapped was 4-$ft^2$ for each trap. At a velocity of 4-ft/second, a flow of 16-cfs passed through each trap.

Inadequate velocity following dredging required moving the trap upstream of the position used in 1998, to just below the South Boeing Bridge (Figure 1). Trap operation began on January 23, and continued every other night through the end of that month. From February 1 through May 16, we fished the trap throughout each night, and then fished every other night between May 17 and May 25. At the South Boeing Bridge location, trap placement was adjusted to maximize our capture rates resulting in the use of three different trapping positions over the sockeye migration period. The trap was initially placed near the west bank of the channel (Position 1). On February 13, decreasing velocity and low capture rates prompted a trap move to the east bank of the channel (Position 2). On February 17, the trap was again re-positioned approximately 10-ft west toward the middle of the channel (Position 3), where it remained for the rest of the trapping season.

On most nights, we operated only one fry trap to avoid catching too many sockeye fry. On ten nights, from February 1 through March 7, we operated both fry traps to evaluate relative capture rates between the two traps. We refer to the traps as Trap 2 and Trap 3 which denotes their position. Trap 2 is inboard of the port pontoon and Trap 3 is inboard of the starboard pontoon.

On nearly every date the trap was operated, we began trapping before dusk and continued past dawn. Daytime trapping did not occur in 1999. Each hour, on the hour, captured fish were removed from the trap and enumerated. Large fry catches were counted with an electronic fish counter. In 1999, we calibrated the counter by passing known numbers of fry through it. In these trials the electronic counter counted an average of 96.4% of the actual number of fish that passed through it. In previous years, we estimated the proportion counted at 96.5% and 96.6%. The counter failed one night and was not used. The majority of sockeye fry captured by the trap that night were estimated volumetrically.

## Trap Calibration

Two assumptions critical for accurate trap calibration involve a known number of marked fry passing the trap and their capture susceptibility. The first assumption is that all of the marked fry released pass the gear within a certain recovery period. This requirement argues for releasing fish immediately upstream of the trap to minimize their exposure to predation. Marked fry, however, must also be captured at the same rate as unmarked fry in order to satisfy the second assumption. As fry have little ability to avoid the gear in the fast current where the trap was positioned, satisfying this assumption was achieved by creating the same lateral distribution with marked fry as that of unmarked fry. The further upstream fry are released, the more likely they become distributed as unmarked fry because they are subjected to the same currents.

As in previous years, we estimated capture rate by releasing marked fry at the Logan Street bridge (Figure 1). Fry captured the previous night were marked in a solution of Bismarck brown dye (14-ppm for 1.5-hours). The bridge is approximately one mile upstream from the trap, and was selected as a compromise between the opposing needs of releasing fish close enough to minimize predation loss and distant enough to ensure natural distribution. To assess whether the calibration groups were distributed naturally, we released fry in three groups based on release location: right bank, left bank, and mid-channel. Release times at these locations were, on five occasions, separated by an hour or more to enable analysis of capture rates as a function of release location while using only one mark.

Over the season, from February 6 to May 1, we released groups of dye-marked fry on 54 nights to evaluate three different trap positions. Marked fry were usually distributed evenly between left bank, mid-channel, and right bank release points at the Logan Street Bridge. Occasionally, just left bank and right bank releases were made. Pooled (left bank, mid-channel, and right bank) group recovery rates were correlated with mean nightly discharge to assess the effect of flow on capture rate.

## Hatchery Releases

Over the season, 9,636,000 hatchery-produced fry were released into the Cedar River (Table 1). Thirty percent of this production (2,850,000) was released directly from the hatchery at

Landsburg, 33% (3,211,000) was released at a mid-river location (river-mile 13.5), and 37% (3,575,000) was transported to the lower river and released at the Riviera Apartments release site, above the Highway I-405 bridge (Figure 1). Fry were released at the Riviera site on ten nights between February 11 and March 18. Fry were released at the mid-river site on eleven nights between February 18 and April 8. Upper river releases from Landsburg occurred on eight nights, between January 27 and March 15. Group sizes ranged from 7,000 to 562,000 fry. Hatchery fry were identified by nine otolith codes, representing early, middle, and late releases at the three different release sites. No releases were made downstream of the trap site in 1999.

**Table 1.** Hatchery-produced sockeye fry released at three locations, Cedar River 1999.

| Release Date | Code | Number Released | | | Total |
|---|---|---|---|---|---|
| | | Landsburg (1) | Mid-River (2) | Riviera (3) | |
| 01/27 | E | 110,000 | | | 110,000 |
| 02/03 | E | 430,000 | | | 430,000 |
| 02/05 | E | 409,000 | | | 409,000 |
| 02/11 | E | | | 562,000 | 562,000 |
| 02/16 | E | | | 535,000 | 535,000 |
| 02/17 | E | | | 240,000 | 240,000 |
| 02/18 | E | | 494,000 | | 494,000 |
| 02/22 | E | | 526,000 | | 526,000 |
| 02/23 | M | 255,000 | | | 255,000 |
| 02/25 | M | 538,000 | | | 538,000 |
| 03/01 | M | 190,000 | | 195,000 | 385,000 |
| 03/02 | M | | | 215,000 | 215,000 |
| 03/03 | M | | | 429,000 | 429,000 |
| 03/04 | M | | | 203,000 | 203,000 |
| 03/08 | M | | 487,000 | | 487,000 |
| 03/09 | M | | 399,000 | | 399,000 |
| 03/10 | M | | 269,000 | | 269,000 |
| 03/11 | L | 518,000 | | | 518,000 |
| 03/15 | L | 400,000 | | | 400,000 |
| 03/16 | L | | | 359,000 | 359,000 |
| 03/17 | L | | | 283,000 | 283,000 |
| 03/18 | L | | | 554,000 | 554,000 |
| 03/23 | L | | 334,000 | | 334,000 |
| 03/24 | L | | 333,000 | | 333,000 |
| 03/25 | L | | 170,000 | | 170,000 |
| 03/31 | L | | 135,000 | | 135,000 |
| 04/05 | L | | 57,000 | | 57,000 |
| 04/08 | L | | 7,000 | | 7,000 |
| Total | | 2,850,000 | 3,211,000 | 3,575,000 | 9,636,000 |

Codes — Release Timing
E-Early Release
M-Mid-Season Release
L-Late Release

## Sampling Fry for Thermal Marks

As otolith-marks are internal, their detection requires lethal sampling of the fry. A sample of fry was collected from the catch nearly every night that hatchery-produced fry were released or may have been present in the lower river (post-release nights). To insure that the samples were not biased by differences in migration timing between hatchery and wild fry, we retained a constant proportion of each hours' catch over the entire night. Each morning, we gently stirred the retention tank to thoroughly mix the fry, then we collected 155 fry for the sample, of which 150 were analyzed.

## Fry Estimation

Estimation of total sockeye fry migration and of the hatchery and wild components occurred in several steps. The data collected every night, $i$, consisted of:

- Count of total fry taken in the trap - $c_i$
- Flow - $f_i$

Nighttime data taken less frequently included:

- Proportion of marked fry released above the trap and subsequently recaptured (i.e., trap efficiency) - $e_i$
- Sample of otoliths from fry passing the trap - $o_i$
- Number of otoliths sampled from hatchery group $h$ - $m_{hi}$

Regression analysis was used to estimate the relationship between flow and trap efficiency, providing an estimate of trap efficiency, $e_i$, and its variance, at any flow, $f_i$;

$$\hat{e}_i = \alpha + \beta f_i \tag{1}$$

The variance of the predicted efficiency at any flow on any day d was estimated by;

$$V(\hat{e}_i) = MSE\left(1 + \frac{1}{n} + \frac{(f_d - \bar{f})^2}{(n - 1)s_f^2}\right) \tag{2}$$

where,

$MSE$ = *the mean square error for the regression*,
$n$ = *the number of observations in the regression*,
$s_f^2$ = *the sample variance of the observed flows*, *and*
$\bar{f}$ = *the mean of observed flows in* 1999.

Where flow was not found to be a significant predictor of trap efficiency, the mean of the trap efficiency tests was used;

$$\bar{e} = \frac{\sum_{i=1}^{n} \hat{e}_i}{n} \qquad \textbf{(3)}$$

The variances of the individual trap efficiency estimates, *V(ê)*, and the mean trap efficiency estimate, $V(\bar{e})$, were found using;

$$V(\hat{e}_i) = \frac{\hat{e}_i(1 - \hat{e}_i)}{(n - 1)} \qquad \textbf{(4)}$$

$$V(\bar{e}) = \frac{\sum (\hat{e}_i - \bar{e})^2}{n(n - 1)} + \frac{\sum V(\hat{e}_i)}{n} \qquad \textbf{(5)}$$

If trap efficiency was predicted using the regression equation (equation 1), the nightly total outmigration, $N_i$, was estimated using the estimated trap efficiencies;

$$\hat{N}_i = \frac{c_i}{\hat{e}_i} \qquad \textbf{(6)}$$

and the variance by;

$$V(\hat{N}_i) = \hat{N}_i^2 \frac{V(\hat{e}_i)}{\hat{e}_i^2} \qquad \textbf{(7)}$$

If trap efficiency was estimated using mean trap efficiency, then ‘ was substituted for *ê* in Equation 6 and *V(‘)* was substituted for *V(ê)* in Equation 7.

The proportion of hatchery fry released by group in the nightly outmigration ($p_{hi}$), was estimated using the number of otolith-marks observed in the nightly sample by;

$$\hat{p}_{hi} = \frac{m_{hi}}{o_i} \qquad \textbf{(8)}$$

and its variance by;

$$V(\hat{p}_{hi}) = \frac{\hat{p}_{hi}\,(1 - \hat{p}_{hi})}{(o_i - 1)} \qquad \textbf{(9)}$$

The number of hatchery group *h* outmigrating on night *i* was estimated by;

$$\hat{H}_{hi} = \hat{N}_i\,\hat{p}_{hi} \qquad \textbf{(10)}$$

and its variance by;

$$V(\hat{H}_{hi}) = V(\hat{N}_i)\,\hat{p}_{hi}^{\,2} + \hat{N}_i^2\,V(\hat{p}_{hi}) + V(\hat{p}_{hi})\,V(\hat{N}_i) \qquad \textbf{(11)}$$

The total number of hatchery fry migrating past the trap on night *i* and the variance of the estimate was calculated by modifying Equations 10 and 11, respectively. The modifications involve substituting the proportion of hatchery fry from all groups in the nightly catch, $p_i$, and the variance of this proportion, $V(p_i)$, for the proportion of hatchery fry from each release group, $p_{hi}$, and its variance, $V(p_{hi})$, respectively.

Otolith sampling was not used to estimate the composition of hatchery fry in catches following releases on six nights due to budget constraints. On these nights, interpolation was used in lieu of otolith sampling to estimate nightly wild migration based on the wild migration estimates for the preceding and following nights. The estimate of nightly wild fry migration was subtracted from the estimated total nightly migration to estimate the nightly hatchery fry migration.

Where wild fry migration required interpolation for only a single night, the interpolated value was found by the mean of the preceding and following night's estimates, therefore the variance for the nightly wild fry migration estimate, *V(W)*, and the nightly hatchery fry migration estimate, $V(H_{hi})$, were found by;

$$V(\bar{W}) = \frac{\sum (\hat{W}_i - \bar{W})^2}{n(n-1)} + \frac{\sum V(\hat{W}_i)}{n} \qquad \textbf{(12)}$$

$$V(\hat{H}_{hi}) = V(\hat{N}_i) + V(\bar{W})$$

where,

$n$ = *the number of sample nights used in the interpolation,*
$\hat{W}_i$ = *the preceeding and following nightly wild migration estimates, and*
$\bar{W}$ = *the interpolated nightly wild migration estimate.*

Where the wild migration estimate was interpolated for two or more consecutive nights, the variance for each interpolated migration estimate was found by interpolating between the coefficients of variation for the two adjacent measured nightly wild migration estimates.

Nightly estimates of the total and wild fry migrations were expanded to represent daily (24-hour) migrations. Estimates of nightly hatchery fry migration from Landsburg and Mid-River release groups were expanded as well, since migrations of individual release groups from these sites usually last two or more days. Riviera release groups were assumed to pass the trap during the night of release and, therefore, were not expanded except where otolith analysis indicated capture on subsequent nights. No daytime trapping was done in 1999 upon which to base the expansion. Therefore, the expansion was made using the estimate of the daytime/total catch ratio found during trapping conducted in 1998. Daily migration was calculated by dividing the nighttime migration estimate by the proportion of the 24-hour catch caught at night, as determined from the 1998 daytime trap operation data. A generic variance equation for each of these 24-hour migration estimates on day *d* is;

$$V(\hat{M}_{vd}) = \frac{V(\hat{M}_{vi})}{R_i^2} \qquad \textbf{(14)}$$

where,

$V(\hat{M}_{vd})$ = *the variance of the migration estimate for variable v on day d*
$V(\hat{M}_{vi})$ = *the variance of the migration estimate for variable v on night i*
$R_i$ = *the estimated proportion of the catch on day d captured on night i*

The total outmigration, $N_T$, total wild migration, $W_T$, and total hatchery migration, $H_T$, during the trapping period were found by the sums of all the daily respective outmigration estimates for these variables and the variances of the totals were found by the sums of the daily variances.

The total outmigration of hatchery group h was estimated by summing all of the daily estimates of outmigrating fry belonging to that group;

$$\hat{H}_{hT} = \sum_{d=1}^{D} \hat{H}_{hd} \qquad \textbf{(15)}$$

and its variance was found by the sum of the daily variance estimates.

The total survival of each release group *h* past the trap location was then estimated by;

$$\hat{s}_h = \frac{\hat{H}_{hT}}{R_h} \qquad \textbf{(16)}$$

and the variance by;

$$V(\hat{s}_h) = \frac{V(\hat{H}_{hT})}{R_h^{\,2}} \qquad \textbf{(17)}$$

This variance under-estimated the true variance of the survival ratio because we treated the number of fry released from the hatchery, $R_h$, as a known value instead of as an estimate.

To estimate wild migration during un-fished nights when the trap was operated every other night, straight-line interpolation was used. In addition, straight-line extrapolation was used to estimate fry migration prior to and following the trapping period assuming a migration starting date of January 1 and an ending date of July 1. The extrapolations were based on the estimated mean migration for the first two days of trapping and the last two days of trapping, respectively. The CVs for the mean migrations over the first two days and the last two days were found by;

$$CV(\bar{M}) = \frac{\sqrt{\left(\frac{\sum_{d=1}^{2}(\hat{M}_d - \bar{M})^2}{2} + \frac{\sum_{d=1}^{2}Var(\hat{M}_d)}{2}\right)}}{\bar{M}} \quad \textbf{(18)}$$

The variances for the estimated migrations prior to and following trapping were found by;

$$Var(\hat{M}_{before/after}) = (CV_{\bar{M}} \times \hat{M}_{before/after})^2 \quad \textbf{(19)}$$

This variance estimate only related to the variability that might be expected if we were estimating migration from trapping data, if trapping were occurring. It did not reflect imprecision in selecting the migration starting or ending dates, or the linear shape of the extrapolated data.

## Egg-to-Migrant Survival

Survival-to-lake-entry for naturally produced fry was calculated from the wild fry migration estimate and the estimate of potential egg deposition (PED). The estimate of PED is based on the following estimates, assumptions, and counts:

1. an estimated natural spawning population of 50,000 adults in 1998 (Foley, pers. comm.);
2. an even sex ratio; and
3. an average fecundity of 3,176 eggs per female (Brodie Antipa pers. comm.).

These yielded an estimated PED of 79,400,000 eggs.

The severity of peak flow during egg incubation had been found to explain most of the inter-annual variation in egg to migrant survival that we have measured in the Cedar River over eight broods. A number of regression equations were used to evaluate this relationship once the 1999 data was appended to the data-set. These include:

| | | |
|---|---|---|
| Linear: | | $y = ax + b$ |
| Logarithmic: | 1. | $y = a(\ln x) + b$ |
| | 2. | $\ln y = a(\ln x) + b$ |
| Inverse: | | $y = a/x + b$ |
| Quadratic: | | $y = a_1x^2 + a_2x + b$ |
| Exponential: | 1. | $y = ba^x$ |
| | 2. | $y = be^{ax}$ |
| | 3. | $y = ba^{\ln x}$ |
| Power: | | $y = bx^a$ |

Where *y* is egg to migrant survival, *x* is flow, and *a* and *b* are the slope and intercept parameters for the regression equations. The equation that resulted in the best fit with the data was found by comparing the coefficients of determination ($r^2$) for each.

# Results and Discussion

## Catch

Nightly catches of sockeye fry increased from 169 sockeye on January 23, our first night of trapping, to peak at 36,477 fry on February 22, when large numbers of hatchery fish were released at both Landsburg and Mid-River. By May 28, our last night of trapping, we caught only 193 sockeye fry. Over the season, our combined catch of hatchery and wild sockeye fry totaled 756,897 for the 115 nights we trapped (Appendix A).

## Efficiency and Flow

Tests to ascertain the capture efficiency of the fry trap at various flow levels were made on 54 nights between February 6 and May 11. During each test, dye marked sockeye fry were released from the Logan Street Bridge, approximately one mile upstream from the trap site. In all but three tests, approximately equal portions of fry were released at the left bank, right bank and mid-channel of the river. Fry were released only from the left bank and right bank during the other three tests. Few releases (three to four) from each location were separated by an hour or more, enabling evaluation of differences in capture efficiencies between the left bank, right bank and mid-channel locations. Given the small sample sizes and high variability in capture efficiencies for groups released from each location, analysis of variance failed to find a significant ($p<0.05$) difference in capture efficiencies between sites even though differences in average capture efficiencies appeared substantial (Table 2). There were more releases from these same locations that were separated by an hour or more in 1998. Average trap efficiency between release sites in 1998 were nearly identical given this larger sample. They were also not found to be statistically different at the 95% significance level. These results increased our confidence in assuming that fry released at Logan Street Bridge were thoroughly mixed by the time they reached the trap and had the same chance of being trapped as all other fry passing the trap. As a result of this outcome, we calculated trap efficiency by pooling the nightly release groups from the three release locations.

Three different trap positions were used during the 1999 outmigration period; position 1 was fished from January 23 to February 13, position 2 was fished from February 13 to February 17, and position 3 was fished from February 17 through May 28. Each move was initiated to try and achieve better capture efficiency. The use of two traps in three different positions resulted in six possible strata for evaluating capture efficiency. Efficiency tests were made in four of the strata: Trap 2, positions 1, 2, and 3; and Trap 3, position 3 only. Of the remaining strata, Trap 3 in positions 1 and 2, Trap 3 only operated a total of 3 nights. Trap 3 capture efficiencies on those nights were estimated by multiplying the Trap 2 capture efficiency for the night by the ratio of the nightly Trap 3 to Trap 2 catch.

**Table 2.** Comparison of trap efficiency estimates made from dye-marked fry releases of at least one-hour apart from the left bank, mid-channel, and right bank of the Cedar River at the Logan Street Bridge, 1999.

| Date | Left Bank | | | Mid-Channel | | | Right Bank | | |
|---|---|---|---|---|---|---|---|---|---|
| | # Rel | # Recov | Eff | # Rel | # Recov | Eff | # Rel | # Recov | Eff |
| 02/19 | 1,046 | 53 | 5.07% | 1,003 | 55 | 5.48% | 997 | 59 | 5.92% |
| 02/21 | | | | | | | 1,036 | 68 | 6.56% |
| 02/26 | 1,038 | 108 | 10.40% | 1,035 | 39 | 3.77% | 1,041 | 21 | 2.02% |
| 03/03 | 1,026 | 86 | 8.38% | | | | | | |
| 03/05 | 832 | 55 | 6.61% | 785 | 24 | 3.06% | 917 | 5 | 0.55% |
| Average | | | 7.62% | | | 4.10% | | | 3.76% |

Note: F-test found no significant differences between release locations (p<0.05).

Recapture rates from the 54 calibration tests ranged from 1.3% to 7.5% (Table 3). Linear regression analysis was used to evaluate the relationship between capture efficiency and flow while the traps were fishing in position 3. A weak ($r^2 = 0.26$), but significant relationship ($p<0.05$) was found for Trap 3 (Figure 1). A stronger ($r^2 = 0.76$) relationship was found for Trap 2 (Figure 2). However, this relationship was not significant at the 95% significance level as a result of low sample size. It was significant at a 94% significance level and we elected to use this regression equation because we believed it provided a more accurate estimate of capture efficiency than the sample mean. Because few efficiency tests were made while Trap 2 fished in Positions 1 and 2 (2 tests and 1 test, respectively), we were not able to evaluate the effects of flow on capture rate for these strata. Therefore, the mean capture efficiencies were used to estimate migration past the trap during these periods. On the nights that calibration tests were conducted for Position 3, the period in which the regression equations were used to predict trap efficiency, flows ranged between 563 to 1,190-cfs. Over the entire period that the traps fished in Position 3, flows were outside this range four times, ranging from 543 to 1,610-cfs. Flows ranged from 543 to 2,060-cfs over the entire trapping period (Appendix A).

**Table 3.** Trap efficiency estimates from catches of dye-marked sockeye fry released above the fry trap relative to flow, trap position, and trap number, Cedar River 1999.

| Date | Flow (cfs) | Efficiency | Trap Position | Number Released | Number Recovered | Variance |
|---|---|---|---|---|---|---|
| **Trap 2** | | | | | | |
| 02/06 | 629 | 3.20% | 1 | 3,124 | 100 | 0.00000992 |
| 02/12 | 814 | 1.31% | 1 | 3,060 | 40 | 0.00000422 |
| | Avg | 2.25% | | | | |
| | Var(mean) | 0.00009673 | | | | |
| | n | 2 | | | | |
| 02/16 | 775 | 1.95% | 2 | 2,672 | 52 | 0.00000714 |
| | Avg | 1.95% | | | | |
| | Var(mean) | 0.00000714 | | | | |
| | n | 1 | | | | |
| 02/17 | 631 | 7.52% | 3 | 3,032 | 228 | 0.00002373 |
| 02/19 | 656 | 5.42% | 3 | 3,046 | 165 | 0.00001683 |
| 02/21 | 575 | 5.23% | 3 | 3,095 | 162 | 0.00001603 |
| 03/06 | 1,100 | 2.13% | 3 | 1,266 | 27 | 0.00001650 |
| 03/07 | 1,080 | 3.25% | 3 | 2,216 | 72 | 0.00001419 |
| | Avg Flow (cfs) | 823.4 | | | | |
| | MSE | 0.00014115 | $r^2$ | 0.757 | | |
| | n | 5 | F | 9.3602 | | |
| | Intercept | 0.10489468 | Significance | p = 0.055 | | |
| | Slope | -0.00007018 | | | | |
| **Trap 3** | | | | | | |
| 02/17 | 631 | 6.76% | 3 | 3,032 | 205 | 0.00002080 |
| 02/19 | 656 | 7.52% | 3 | 3,046 | 229 | 0.00002283 |
| 02/21 | 575 | 7.17% | 3 | 3,095 | 222 | 0.00002152 |
| 02/24 | 767 | 3.30% | 3 | 3,065 | 101 | 0.00001040 |
| 02/26 | 785 | 5.39% | 3 | 3,115 | 168 | 0.00001639 |
| 03/01 | 785 | 2.60% | 3 | 2,995 | 78 | 0.00000847 |
| 03/02 | 1,190 | 2.87% | 3 | 3,030 | 87 | 0.00000921 |
| 03/03 | 1,050 | 4.23% | 3 | 3,053 | 129 | 0.00001326 |
| 03/04 | 1,010 | 1.80% | 3 | 3,063 | 55 | 0.00000576 |
| 03/05 | 1,110 | 3.35% | 3 | 2,534 | 85 | 0.00001280 |
| 03/06 | 1,100 | 3.16% | 3 | 1,266 | 40 | 0.00002419 |
| 03/07 | 1,080 | 4.60% | 3 | 2,216 | 102 | 0.00001982 |
| 03/08 | 1,060 | 3.40% | 3 | 2,350 | 80 | 0.00001400 |
| 03/09 | 1,020 | 3.03% | 3 | 3,041 | 92 | 0.00000965 |
| 03/10 | 943 | 4.65% | 3 | 3,032 | 141 | 0.00001463 |
| 03/11 | 789 | 5.25% | 3 | 3,021 | 158 | 0.00001641 |
| 03/12 | 729 | 4.24% | 3 | 3,140 | 133 | 0.00001292 |
| 03/13 | 848 | 4.34% | 3 | 3,109 | 135 | 0.00001336 |
| 03/15 | 866 | 4.46% | 3 | 2,803 | 125 | 0.00001521 |
| 03/16 | 80 | 3.69% | 3 | 3,011 | 111 | 0.00001180 |

**Table 3.** Trap efficiency estimates from catches of dye-marked sockeye fry released above the fry trap relative to flow, trap position, and trap number, Cedar River 1999 (cont'd).

| Date | Flow (cfs) | Efficiency | Trap Position | Number Released | Number Recovered | Variance |
|---|---|---|---|---|---|---|
| 03/17 | 741 | 4.73% | 3 | 3,023 | 143 | 0.00001491 |
| 03/18 | 705 | 4.15% | 3 | 3,085 | 128 | 0.00001290 |
| 03/19 | 679 | 4.65% | 3 | 3,075 | 143 | 0.00001442 |
| 03/20 | 670 | 5.77% | 3 | 3,174 | 183 | 0.00001712 |
| 03/21 | 697 | 5.03% | 3 | 2,940 | 148 | 0.00001627 |
| 03/23 | 689 | 5.73% | 3 | 2,826 | 162 | 0.00001913 |
| 03/24 | 755 | 3.23% | 3 | 3,159 | 102 | 0.00000989 |
| 03/25 | 942 | 4.88% | 3 | 3,175 | 155 | 0.00001463 |
| 03/26 | 959 | 3.25% | 3 | 3,043 | 99 | 0.00001035 |
| 03/28 | 1,000 | 4.85% | 3 | 1,960 | 95 | 0.00002354 |
| 03/29 | 983 | 3.14% | 3 | 1,591 | 50 | 0.00001914 |
| 03/30 | 890 | 2.53% | 3 | 1,977 | 50 | 0.00001248 |
| 03/31 | 853 | 4.36% | 3 | 2,593 | 113 | 0.00001608 |
| 04/01 | 759 | 6.25% | 3 | 3,136 | 196 | 0.00001869 |
| 04/03 | 748 | 6.23% | 3 | 2,986 | 186 | 0.00001957 |
| 04/05 | 683 | 4.96% | 3 | 2,785 | 138 | 0.00001692 |
| 04/06 | 671 | 4.42% | 3 | 3,077 | 136 | 0.00001373 |
| 04/07 | 666 | 4.92% | 3 | 3,153 | 155 | 0.00001483 |
| 04/09 | 668 | 4.32% | 3 | 2,988 | 129 | 0.00001383 |
| 04/10 | 647 | 4.55% | 3 | 3,008 | 137 | 0.00001446 |
| 04/12 | 582 | 4.88% | 3 | 3,010 | 147 | 0.00001544 |
| 04/14 | 573 | 5.58% | 3 | 2,992 | 167 | 0.00001762 |
| 04/19 | 563 | 4.24% | 3 | 2,691 | 114 | 0.00001508 |
| 04/21 | 623 | 3.79% | 3 | 3,061 | 116 | 0.00001192 |
| 04/23 | 690 | 4.98% | 3 | 3,095 | 154 | 0.00001528 |
| 04/26 | 731 | 4.43% | 3 | 3,071 | 136 | 0.00001379 |
| 04/27 | 769 | 3.84% | 3 | 3,024 | 116 | 0.00001220 |
| 05/03 | 823 | 3.21% | 3 | 2,838 | 91 | 0.00001094 |
| 05/06 | 657 | 3.71% | 3 | 3,101 | 115 | 0.00001152 |
| 05/07 | 648 | 3.98% | 3 | 2,712 | 108 | 0.00001410 |
| 05/11 | 611 | 4.14% | 3 | 1,908 | 79 | 0.00002081 |

| | | | |
|---|---|---|---|
| Avg Flow (cfs) | 833.9 | | |
| MSE | 0.00010490 | $r^2$ | 0.256 |
| n | 51 | F | 16.8651 |
| Intercept | 0.06943554 | Significance | p = 0.0002 |
| Slope | -0.00003048 | | |

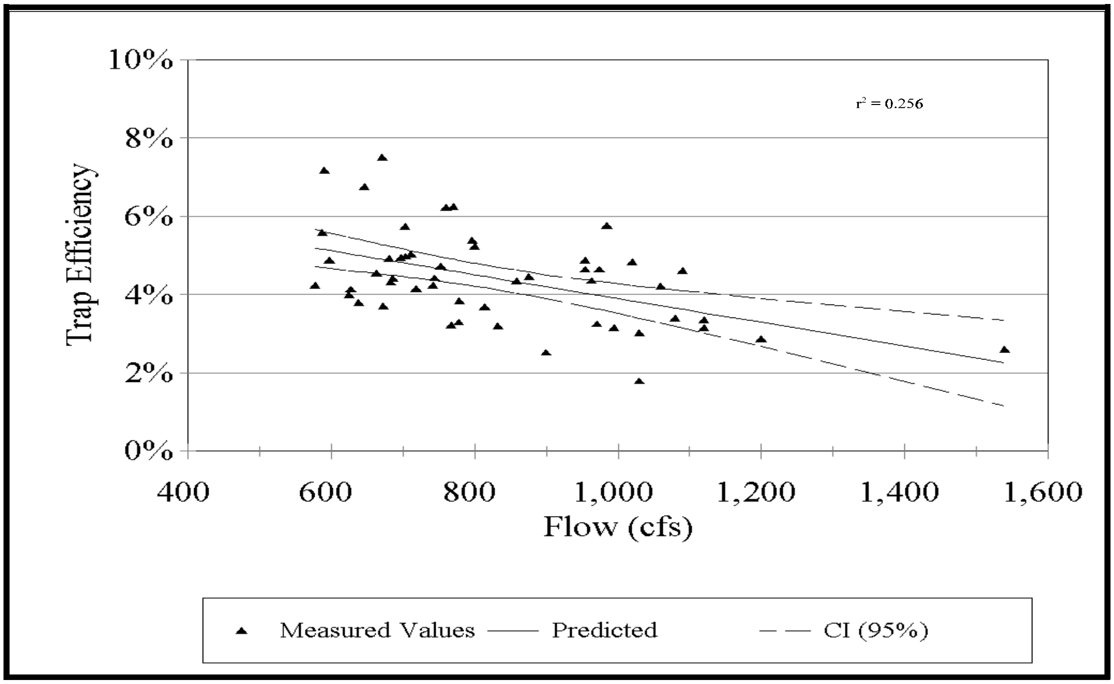


**Figure 2**. Regression analysis of the relationship between average daily stream flow and trap efficiency measured with sockeye fry caught in Trap 3, position 3, Cedar River 1999.

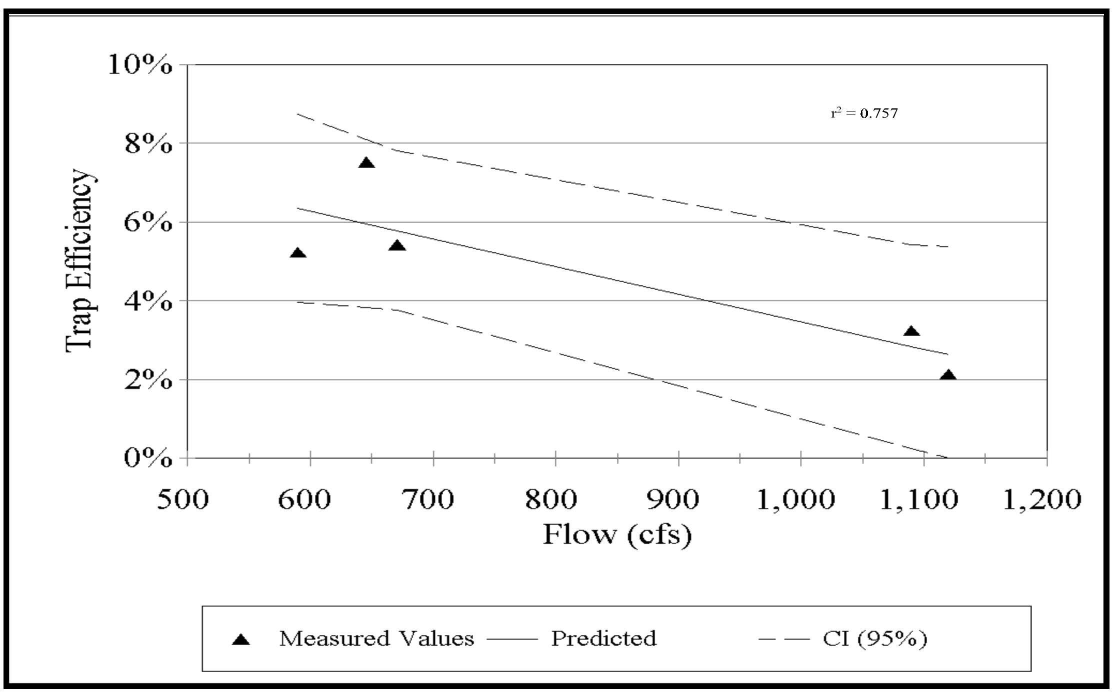


**Figure 3**. Regression analysis of the relationship between average daily stream flow and trap efficiency measured with sockeye fry caught in Trap 2, position 3, Cedar River 1999.

## Otolith Sampling

Otolith sampling was completed on 29 nights when releases occurred or on the night following a release. Sampling did not occur on six nights when hatchery fry were released, including three releases from Landsburg on January 27, February 3, and February 5, one release from mid-river on April 5, and two releases from Riviera on February 11 and March 17. Over the 29 nights where catch was sampled, hatchery-produced fry comprised 58% of the 4,212 sockeye otoliths that were examined (Table 4). The incidence of hatchery fry in samples taken on the release nights ranged from 31% to 91% for Landsburg releases, 43% to 89% for Mid-River releases, and 38% to 89% for Riviera releases.

Otolith sampling uncovered a few instances where otolith marked fish were recovered before they should be. On February 16 and 17, 6.67% and 15.24% of the otoliths sampled, respectively, were identified as Mid-River early releases (Table 4). No Mid-River releases had been made on or prior to these dates. Similarly on March 11, a fish with a late Riviera release otolith mark was recovered prior to any late releases of Riviera fish. When these anomalies in the data were found, the otoliths were re-examined and were found to have been read correctly. We surmise that these fish either escaped from the hatchery prior to release or were inadvertently released with another release group.

**Table 4.** Sockeye fry otolith sampling results, Cedar River 1999.

| Sample Date | Number Sampled | Number Marked | Percent Marked | Variance | Release | |
|---|---|---|---|---|---|---|
| | | | | | Code | Location |
| 02/16 | 90 | 56 | 62.22% | 0.002641 | E3 | Riviera |
| | | 6 | 6.67% | 0.000699 | E2 | Mid-river |
| 02/17 | 105 | 65 | 61.90% | 0.002268 | E3 | Riviera |
| | | 16 | 15.24% | 0.001242 | E2 | Mid-river |
| 02/18 | 150 | 130 | 86.67% | 0.000776 | E2 | Mid-river |
| 02/19 | 150 | 18 | 12.00% | 0.000709 | E2 | Mid-river |
| 02/20 | 150 | 0 | 0.00% | 0.000000 | | |
| 02/22 | 150 | 90 | 60.00% | 0.001611 | E2 | Mid-river |
| | | 43 | 28.67% | 0.001372 | E1 | Landsburg |
| 02/23 | 150 | 46 | 30.67% | 0.001427 | M1 | Landsburg |
| | | 10 | 6.67% | 0.000418 | M2 | Mid-river |
| 02/25 | 150 | 130 | 86.67% | 0.000776 | M1 | Landsburg |
| 02/26 | 119 | 33 | 27.73% | 0.001698 | M1 | Landsburg |
| 03/01 | 150 | 73 | 48.67% | 0.001677 | M1 | Landsburg |
| | | 57 | 38.00% | 0.001581 | M3 | Riviera |
| 03/02 | 150 | 126 | 84.00% | 0.000902 | M3 | Riviera |
| 03/03 | 150 | 134 | 89.33% | 0.000640 | M3 | Riviera |
| | | 1 | 0.67% | 0.000044 | M1 | Landsburg |
| 03/04 | 150 | 101 | 67.33% | 0.001476 | M3 | Riviera |

| Table 4. Sockeye fry otolith sampling results, Cedar River 1999 (cont'd). | | | | | | |
|---|---|---|---|---|---|---|
| Sample Date | Number Sampled | Number Marked | Percent Marked | Variance | Release | |
| | | | | | Code | Location |
| 03/08 | 150 | 133 | 88.67% | 0.000674 | M2 | Mid-river |
| 03/09 | 150 | 121 | 80.67% | 0.001047 | M2 | Mid-river |
| 03/10 | 150 | 101 | 67.33% | 0.001476 | M2 | Mid-river |
| 03/11 | 150 | 131 | 87.33% | 0.000742 | L1 | Landsburg |
| | | 1 | 0.67% | 0.000044 | L3 | Riviera |
| 03/12 | 150 | 41 | 27.33% | 0.001333 | L1 | Landsburg |
| 03/15 | 150 | 136 | 90.67% | 0.000568 | L1 | Landsburg |
| 03/16 | 148 | 108 | 72.97% | 0.001342 | L3 | Riviera |
| | | 3 | 2.03% | 0.000135 | L1 | Landsburg |
| 03/18 | 150 | 123 | 82.00% | 0.000991 | L3 | Riviera |
| 03/19 | 150 | 2 | 1.33% | 0.000088 | L3 | Riviera |
| | | 1 | 0.67% | 0.000044 | M3 | Riviera |
| 03/23 | 150 | 98 | 65.33% | 0.001520 | L2 | Mid-river |
| 03/24 | 150 | 115 | 76.67% | 0.001201 | L2 | Mid-river |
| 03/25 | 150 | 64 | 42.67% | 0.001642 | L2 | Mid-river |
| 03/26 | 150 | 6 | 4.00% | 0.000258 | L2 | Mid-river |
| 03/31 | 150 | 94 | 62.67% | 0.001570 | L2 | Mid-river |
| 04/01 | 150 | 7 | 4.67% | 0.000299 | L2 | Mid-river |
| 04/08 | 150 | 5 | 3.33% | 0.000216 | L2 | Mid-river |
| **Total** | 4,212 | 2,425 | 57.57% | 0.000058 | | |

In addition, on February 22 nearly 29% of the fry in the otolith sample were identified as early Landsburg releases. The latest prior early Landsburg release had occurred on February 5. Since that release occurred, five nights of otolith sampling had failed to recover any early Landsburg release fish and flows had been relatively high, over 1,000-cfs, for a number of nights following this release. Therefore, we conclude that these fish also had either escaped from the hatchery or had been released with another release group. Finally on March 19, a single mid-season Riviera marked fish was recovered in the otolith sample. The latest prior mid-season Riviera release had occurred on March 4 and since that time, flows had exceeded 1,000-cfs for 6 days. No releases had occurred on March 19. Proper identification of the mark was verified, therefore, we are unsure if this fish exhibited protracted migration timing, was released with another group, or escaped from the hatchery.

## Diel Migration

In most years, trapping during daylight intervals indicated that very few sockeye fry migrate during daytime hours. We therefore concentrated all our trapping effort during the hours of darkness. In 1998, a limited number of daytime migration rate measurements were made which suggested daytime migration makes up between 8 to 13% of the total migration. No daytime migration estimates were made in 1999. We opted to use an intermediate value, 10%, to estimate the proportion of the total daily migration which occurred during daylight hours.

## Fry Production

We estimated 18.5-million sockeye fry entered Lake Washington from the Cedar River in 1999 (Table 5, Figure 3). The total was almost evenly split between wild fry production (9.5 million fry) and hatchery production (9.0 million fry). Linear extrapolation from January 1 to January 22 and from May 29 to July 1 resulted in the addition of 73,100 wild fry and 130,800 wild fry, respectively, to the 18.3-million fry estimated to have migrated during the trapping period. This increase accounted for only 1% of the total estimate.

**Table 5.** Estimated 1999 Cedar River wild and hatchery sockeye fry migrations entering Lake Washington with 95% confidence intervals.

| Component | Period | Dates | Est. Migration | $CI_{95\%}$ Low | $CI_{95\%}$ High | CV | Prop. of Total |
|---|---|---|---|---|---|---|---|
| Wild | Before Trapping | January 1-22 | 73,138 | 0 | 147,114 | 51.61% | 0.39% |
| | During Trapping | January 23-May 28 | 9,320,530 | 7,795,083 | 10,845,979 | 8.35% | 50.27% |
| | After Trapping | May 29-July 1 | 130,751 | 0 | 263,262 | 51.71% | 0.71% |
| | | **Subtotal** | **9,524,419** | **7,991,441** | **11,057,398** | **8.21%** | **51.37%** |
| Landsburg | During Trapping | January 23-May 28 | 3,272,271 | 2,386,007 | 4,158,535 | 13.82% | 17.65% |
| Mid-River | During Trapping | January 23-May 28 | 2,827,026 | 2,351,921 | 3,302,131 | 8.57% | 15.25% |
| Riviera | During Trapping | January 23-May 28 | 2,915,991 | 2,116,424 | 3,415,558 | 13.99% | 15.73% |
| | | **Subtotal** | **9,015,288** | **7,730,571** | **10,300,005** | **7.27%** | **48.63%** |
| | | **Total** | **18,539,707** | **16,539,578** | **20,539,837** | **5.50%** | **100.0%** |

Note: All hatchery releases occurred during trapping. Variances used to calculate confidence intervals were based on trap-based estimates only.

## Wild and Hatchery Migration Timing

Releases of hatchery-produced fry began on January 27 and continued through April 8 (Figure 3). The wild fry migration was under way when we began trapping on January 23, peaked during late March and early April, and declined to low levels when fry trapping was concluded on May 28. The median migration date for hatchery fry occurred on March 3, while the median date for the wild migration occurred on March 30 (Figure 4).

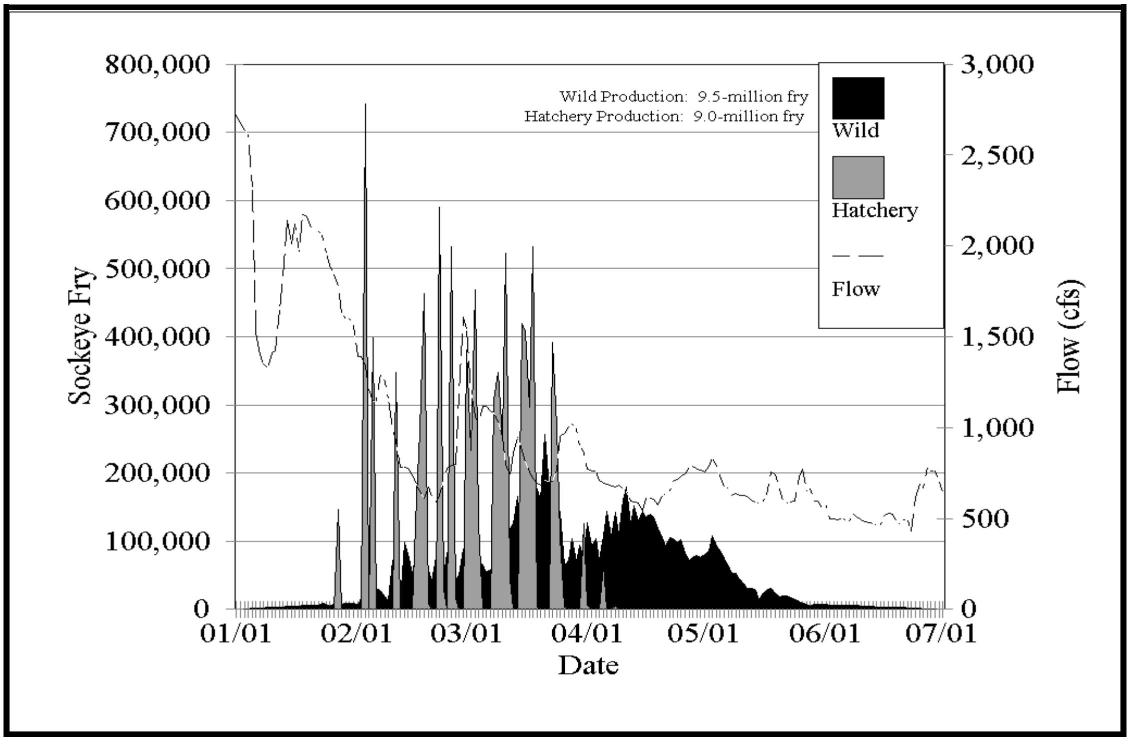


**Figure 4.** Estimated daily migration of wild and hatchery Cedar River sockeye fry into Lake Washington, 1999.

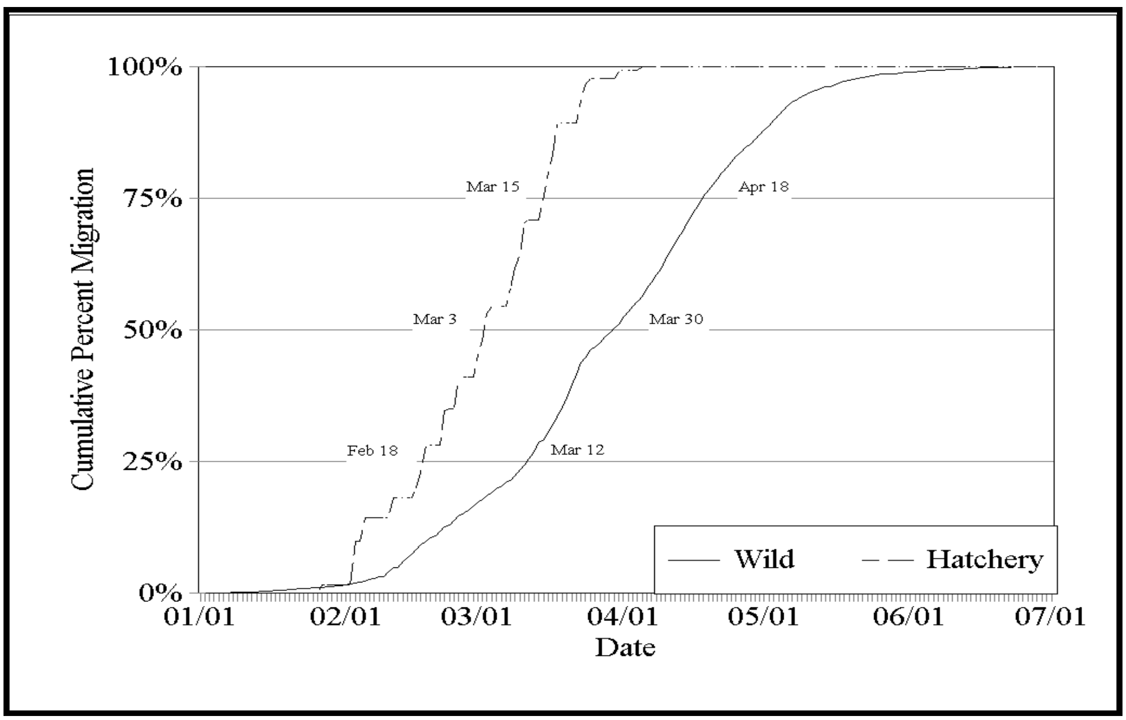


**Figure 5.** Cumulative wild and hatchery sockeye fry migration timing, Cedar River 1999.

Wild timing in 1999 was average for the eight broods evaluated thus far. Median migration dates for wild fry ranged from March 11 to April 7. In 1998, we determined that wild fry migration timing appeared related to stream temperature, with warmer temperatures resulting in earlier migration timing (Seiler et al. 2001). After evaluating temperature data from throughout the period of fry incubation and migration, February stream temperatures best predicted migration timing ($r^2 = 0.84$) (Figure 5). February stream temperature averaged 6.7C, compared to 7.4C in 1998 and 5.3C in 1997. Timing of hatchery fry in 1999 was near the average for the eight broods evaluated thus far (Table 6).

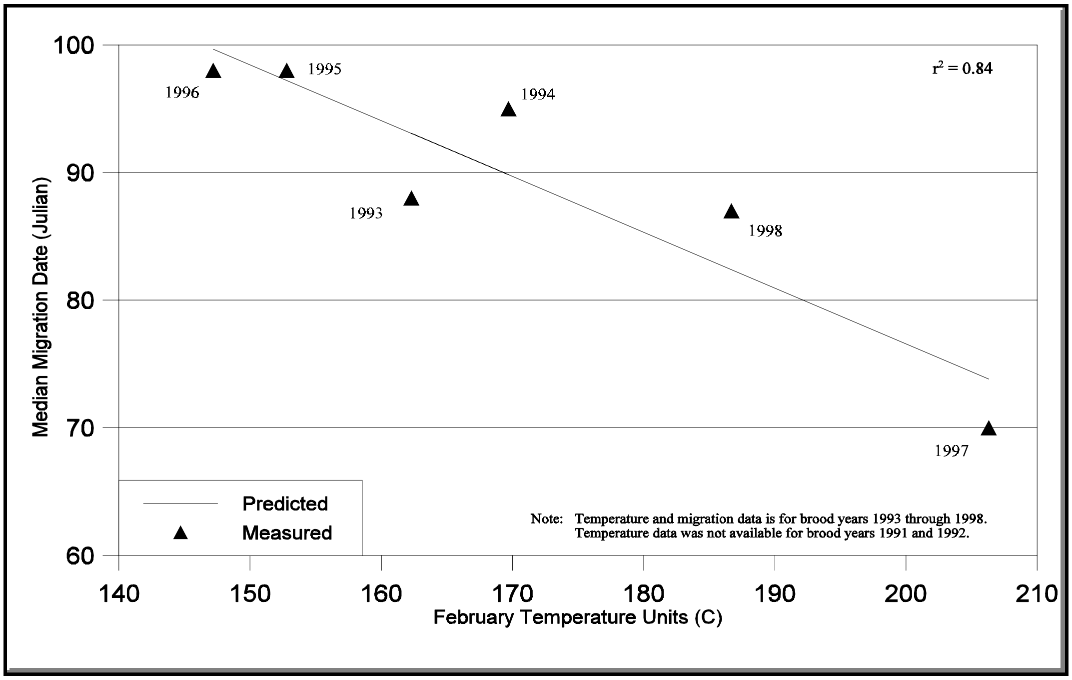


**Figure 6.** Linear regression of median migration Julian Calendar date (dates numbered sequentially beginning Jan 1 = 1) for wild Cedar River sockeye fry as a function of the sum of February 1-28 daily average stream temperature as measured at the USGS Renton Gaging Station, #12119000 for brood years 1993 to 1998.

**Table 6.** Median migration dates of wild, hatchery, and total (combined) sockeye fry populations, Cedar River.

| Brood Year i | Trap Year i+1 | Median Date | | | Difference (days) W-H |
|---|---|---|---|---|---|
| | | Wild | Hatchery | Combined | |
| 1991 | 1992 | 03/18 | 02/28 | 03/12 | 18 |
| 1992 | 1993 | 03/27 | 03/07 | 03/25 | 20 |
| 1993 | 1994 | 03/29 | 03/21 | 03/26 | 8 |
| 1994 | 1995 | 04/05 | 03/17 | 03/29 | 19 |
| 1995 | 1996 | 04/07 | 02/26 | 02/28 | 40 |
| 1996 | 1997 | 04/07 | 02/20 | 03/16 | 46 |
| 1997 | 1998 | 03/11 | 02/23 | 03/06 | 16 |
| 1998 | 1999 | 03/30 | 03/03 | 03/15 | 27 |
| | **Average** | 03/29 | 03/04 | 03/12 | 25 |

## Survival of Hatchery Release Groups

Fry survival from the hatchery release sites to the trap were assessed for hatchery release groups released from the Landsburg, Mid-River, and Riviera sites. The majority of hatchery sockeye fry migrated downstream rapidly. Fry released from the Riviera site typically migrated past the trap within two to three hours of release. Landsburg and Mid-River released fry took longer to reach the trap. Hatchery fry from these sites continued to be caught two nights after releases occurred.

Estimates of survival for individual hatchery release groups ranged from 9% to 173% for the 30 groups released from all sites; however, these estimates were not very precise (Table 7). Of the two methods used to estimate migration past the trap for individual release groups, otolith sampling resulted in coefficients of variation (CVs) ranging from 16% to 53%, and averaging 29%. Interpolation resulted in CVs ranging from 45% to 86%, and averaging 61%. The lack of precision resulted in relatively wide 95% confidence intervals about the release group survival estimates.

Survival estimates above 100% are obviously not accurate. Three possible sources of error include:

1. Overestimation of release group migration past the trap,
2. Underestimation of the size of the release group, and
3. Mis-allocation of total nightly hatchery migration estimates to the proper release group.

The lack of precision associated with the estimates of release group survival suggest that overestimation of release group migration could be a problem. This lack of precision is due to the compounding error associated with making estimates on top of estimates (e.g., estimates of survival based on estimates of hatchery migration based on estimates of total migration and estimates of the proportion of hatchery fish in the catch as a result of otolith sampling; or by subtracting estimates of wild migration from estimates of total migration).

The confidence intervals and CVs only account for the precision of trap-based estimates and do not include error associated with hatchery derived estimates of the size of the releases. The precision of these estimates is unknown. Over-estimation and under-estimation of the number of fish released in a group would manifest itself in the survival estimates.

Where groups of fish with the same release code (i.e., otolith mark) are released within a few days of each other, it is nearly impossible to accurately allocate estimates of nightly migration of fish with that release code to the appropriate groups. Therefore, release groups were pooled in some cases to enable estimation of survival for the pooled group when estimation of individual group survival was not possible (Table 7 - 9).

**Table 7.** Hatchery sockeye fry release group survival estimates, Landsburg release site, Cedar River 1999.

| Release Date | Sockeye Released | Recovery Date | Est. Migration at Trap | % Survival | 95% CI +/- | CV | Grouped Evaluation % Survival | Grouped Evaluation 95% CI +/- | Grouped Evaluation CV |
|---|---|---|---|---|---|---|---|---|---|
| **Landsburg** | | | | | | | | | |
| 01/27 | 110,000 | 01/27 | 146,177[1] | 132.89% | 119.13% | 45.74% | | | |
| 02/03 | 430,000 | 02/03 | 741,880[1] | 172.53% | 150.77% | 44.58% | | | |
| 02/05 | 409,000 | 02/05 | 399,148[1] | 97.59% | 88.51% | 46.27% | | | |
| | | 02/22 | 190,814[2] | | | | | | |
| 02/23 | 255,000 | 02/23 | 23,828 | 9.34% | 6.45% | 35.24% | 81.40% | 33.91% | 21.26%[3] |
| 02/25 | 538,000 | 02/25 | 532,393 | | | | | | |
| | | 02/26 | 16,417 | | | | | | |
| | | Total | 548,810 | 102.01% | 44.79% | 22.40% | | | |
| 03/01 | 190,000 | 03/01 | 223,657 | | | | | | |
| | | 03/02 | 0 | | | | | | |
| | | 03/03 | 3,856 | | | | | | |
| | | Total | 227,513 | 119.74% | 120.94% | 51.53% | | | |
| 03/11 | 518,000 | 03/11 | 518,027 | | | | | | |
| | | 03/12 | 44,666 | | | | | | |
| | | Total | 562,693 | 108.63% | 45.65% | 21.44% | | | |
| 03/15 | 400,000 | 03/15 | 419,174 | | | | | | |
| | | 03/16 | 12,236 | | | | | | |
| | | Total | 431,410 | 107.85% | 50.18% | 23.74% | | | |
| **Total** | **2,850,000** | | **3,272,271** | **114.82%** | **31.10%** | **13.82%** | | | |

Notes:

1 Otolith sampling did not occur on the night of these releases. Hatchery migration estimates were made by subtracting the wild migration estimate (interpolated) from the total migration estimate.

2 These otolith marked fry were not associated with a specific release. We surmise that these fish were either escapees from the hatchery, inadvertently released a day earlier than reported or with another group, or exhibited delayed migration.

3 Reflects survival statistics for the group of Landsburg releases and subsequent captures at the trap occurring between 2/23 and 3/3.

**Table 8.** Hatchery sockeye fry release group survival estimates, Mid-River release site, Cedar River 1999.

| Release Date | Sockeye Released | Recovery Date | Est. Migration at Trap | % Survival | 95% CI +/- | CV | Grouped Evaluation % | Grouped Evaluation 95% CI +/- | Grouped Evaluation CV |
|---|---|---|---|---|---|---|---|---|---|
| **Mid-River** | | | | | | | | | |
| | | 02/16 | 17,672[1] | | | | | | |
| | | 02/17 | 56,060[1] | | | | | | |
| 02/18 | 494,000 | 02/18 | 464176 | | | | | | |
| | | 02/19 | 7,992 | | | | | | |
| | | Total | 472,168 | 95.58% | 41.76% | 22.29% | | | |
| 02/22 | 526,000 | 02/22 | 399,379 | | | | | | |
| | | 02/23 | 5,180 | | | | | | |
| | | Total | 404,559 | 76.91% | 35.18% | 23.34% | | | |
| 03/08 | 487,000 | 03/08 | 307,552 | 63.15% | 35.79% | 28.92% | 78.30% | 24.91% | 16.23%[2] |
| 03/09 | 399,000 | 03/09 | 347,613 | 87.12% | 47.41% | 27.76% | | | |
| 03/10 | 269,000 | 03/10 | 249,167 | 92.63% | 47.90% | 26.39% | | | |
| 03/23 | 334,000 | 03/23 | 391,913 | 117.34% | 51.70% | 22.48% | 92.65% | 23.30% | 12.83%[3] |
| 03/24 | 333,000 | 03/24 | 267,521 | 80.34% | 36.14% | 22.95% | | | |
| 03/25 | 170,000 | 03/25 | 106,970 | | | | | | |
| | | 03/26 | 2,678 | | | | | | |
| | | Total | 109,648 | 64.50% | 33.98% | 26.88% | | | |
| 03/31 | 135,000 | 03/31 | 125,266 | | | | | | |
| | | 04/01 | 6,240 | | | | | | |
| | | Total | 131,506 | 97.41% | 44.63% | 23.37% | | | |
| 04/05 | 57,000 | 04/05 | 66,733[4] | 117.08% | 198.25% | 86.40% | | | |
| 04/08 | 7,000 | 04/08 | 4,914 | 70.21% | 68.64% | 49.88% | | | |
| **Total** | **3,211,000** | | **2,827,026** | **88.17%** | **15.88%** | **9.19%** | | | |

Notes:
1. Estimated migration of sockeye fry marked with Mid-River otolith marks that were captured prior to any Mid-River releases. We surmise that these fish either escaped from the hatchery or were inadvertently released with another group.
2. Reflects survival statistics for the group of Mid-River releases and subsequent captures at the trap occurring between 3/8 and 3/10.
3. Reflects survival statistics for the group of Mid-River releases and subsequent captures at the trap occurring between 3/23 and 4/1.
4. Otolith sampling did not occur on the night of this release. The hatchery migration estimate was made by subtracting the wild migration estimate (interpolated) from the total migration estimate.

**Table 9.** Hatchery sockeye fry release group survival estimates, Riviera release site, Cedar River 1999.

| Release Date | Sockeye Released | Recovery Date | Est. Migration at Trap | % Survival | 95% CI +/- | CV | Grouped Evaluation % Survival | Grouped Evaluation 95% CI +/- | Grouped Evaluation CV |
|---|---|---|---|---|---|---|---|---|---|
| **Riviera** | | | | | | | | | |
| 02/11 | 562,000 | 02/11 | 348,102[1] | 61.94% | 91.44% | 75.32% | | | |
| 02/16 | 535,000 | 02/16 | 148,449 | 27.75% | 8.74% | 16.07% | | | |
| 02/17 | 240,000 | 02/17 | 204,970 | 85.40% | 53.70% | 32.08% | | | |
| 03/01 | 195,000 | 03/01 | 157,173 | 80.60% | 83.49% | 52.85% | | | |
| 03/02 | 215,000 | 03/02 | 234,002 | 108.84% | 69.87% | 32.75% | | | |
| 03/03 | 429,000 | 03/03 | 464,946 | 108.38% | 60.26% | 28.37% | | | |
| 03/04 | 203,000 | 03/04 | 125,624 | 61.88% | 34.06% | 28.08% | | | |
| | | 03/11 | 3,954[2] | | | | | | |
| 03/16 | 359,000 | 03/16 | 396,442 | 110.43% | 51.39% | 23.74% | | | |
| 03/17 | 283,000 | 03/17 | 296,584[1] | 104.80% | 135.99% | 66.21% | | | |
| 03/18 | 554,000 | 03/18 | 532,297 | | | | | | |
| | | 03/19 | 3,447 | | | | | | |
| | | Total | 535,744[3] | 96.51% | 41.76% | 22.08% | | | |
| **Total** | **3,575,000** | | **2,915,991** | **81.57%** | **22.37%** | **13.99%** | | | |

Notes:

[1] Otolith sampling did not occur on the night of these releases. Hatchery migration estimates were made by subtracting the wild migration estimate (interpolated) from the total migration estimate.

[2] Estimated migration of unaccounted for otolith marked sockeye fry. We surmise that these fish were either escapees from the hatchery, inadvertently released earlier or later than reported or with another group, or exhibited delayed migration.

[3] A portion of the Riviera marked fish captured on 3/19 were otolith marked with an earlier release code and were therefore not included in the two day migration total for the 3/18 release.

### Landsburg

Survival of individual Landsburg release groups ranged from 9% to 173% (Table 7). The weighted average survival was 115%. Survival was estimated using otolith sampling for all of the middle and late release groups; however, all three early release groups were estimated by interpolation of the wild migration estimate, and subtracting this value from total migration to estimate hatchery migration.

### Mid-River

Survival of individual Mid-River release groups ranged from 63% to 117% (Table 8). The weighted average survival was 88%. Survival of all release groups except the April 5 group was estimated using migration estimates derived from otolith sampling. Interpolation was used to estimate survival of the April 5 release group.

### Riviera

Survival of individual Riviera release groups ranged from 28% to 110% (Table 9). The weighted average survival for all Riviera releases was 82%. Otolith sampling was used to estimate migration of all Riviera release groups past the trap except for the first early group released on February 11 and for the second late group released on March 17.

### Conclusions

Given the data anomalies found in marked groups released from all three release locations (see Otolith Sampling), survival estimates for individual release groups are not very useful. We have only marginally more confidence in survival estimates for the nine release codes given the wide confidence intervals about the estimates. Survival for the nine release strategies ranged from 52% (95% CI = 40%) to 156% (95% CI = 78%); however, the upper survival range estimate was based almost exclusively on interpolated results (Table 10). Of those strategies evaluated primarily by otolith sampling, survival ranged from 52% to 108% (95% CI = 35%).

Analysis of previous year's data suggested survival was positively influenced by releasing fish close to the trap, earlier in the season, and at higher flows; however, no such correlations were identified using the 1999 data. The quality of the estimates derived in 1999 precludes drawing any firm conclusions concerning correlations with survival.

Table 10. Survival from release to the trap of pooled early, middle, and late release groups from the Landsburg, Mid-River, and Riviera Release Sites, Cedar River 1999.

| Release Location | Strategy | # Released | Est Migration at Trap | % Survival | 95% CI +/- | CV |
|---|---|---|---|---|---|---|
| Landsburg | Early | 949,000 | 1,478,019[1] | 155.74% | 80.12% | 26.25% |
| | Middle | 983,000 | 800,150 | 81.40% | 33.91% | 21.26% |
| | Late | 918,000 | 994,102 | 108.29% | 33.79% | 15.92% |
| Mid-River | Early | 1,020,000 | 945,279 | 92.67% | 27.53% | 15.16% |
| | Middle | 1,155,000 | 909,512 | 78.75% | 24.91% | 16.14% |
| | Late | 1,036,000 | 972,235 | 93.85% | 24.43% | 13.28% |
| Riviera | Early | 1,337,000 | 701,521 | 52.47% | 39.78% | 38.68% |
| | Middle | 1,042,000 | 982,910 | 94.32% | 33.34% | 18.03% |
| | Late | 1,196,000 | 1,231,612 | 102.96% | 40.60% | 20.11% |

[1] Estimate is based almost entirely on interpolation instead of on otolith sampling.

## Egg-to-Migrant Survival of Naturally-Produced Fry

Survival-to-lake-entry of 1998 brood sockeye fry resulting from the PED from natural spawners was estimated at 12% (Table 11). This rate represents an overall average value which is the ratio of 9.5 million fry to an estimated PED of 79.4 million.

Table 11. Estimated egg-to-migrant survival of naturally-produced sockeye fry in the Cedar River relative to peak mean daily flows during the incubation period as measured at the USGS Renton Gage, brood years 1991-1998.

| Brood Year | Estimated Escapement | Females (@50%) | Fecundity[a] | P.E.D @ 3,000x | Fry Production | Survival Rate | Peak Incubation Flow (cfs) |
|---|---|---|---|---|---|---|---|
| 1991 | 77,000 | 38,500 | 3,282 | 126,357,000 | 9,800,000 | 7.76% | 2,060 |
| 1992 | 100,000 | 50,000 | 3,470 | 173,500,000 | 27,100,000 | 15.62% | 1,570 |
| 1993 | 76,000 | 38,000 | 3,094 | 117,572,000 | 18,100,000 | 15.39% | 927 |
| 1994 | 109,000 | 54,500 | 3,176 | 173,092,000 | 8,700,000 | 5.03% | 2,730 |
| 1995 | 22,000 | 11,000 | 3,466 | 38,126,000 | 730,000 | 1.91% | 7,310 |
| 1996 | 230,000 | 115,000 | 3,298 | 379,270,000 | 24,390,000 | 6.43% | 2,830 |
| 1997 | 104,000 | 52,000 | 3,292 | 171,184,000 | 25,350,000 | 14.81% | 1,790 |
| 1998 | 50,000 | 25,000 | 3,176 | 79,400,000 | 9,500,000 | 11.96% | 2,720 |

[a] Fecundity (egg-per-female) estimates are from sockeye captured at the adult weir and spawned at the Landsburg Hatchery (Brodie Antipa pers. comm.).
[b] Fecundity was estimated by the mean of the 1992 to 1998 fecundity estimates. Measured fecundity was thought to be biased low in 1991 (2,957) due to the use of a different capture technique (seining), the capture of partially spawned females, and spawning of unripe females during this first year of operation.

Regression analysis using survival and peak incubation flow estimates over the eight broods investigated showed substantial correlation between these variables. The highest $r^2$ found for this data series was derived from fitting the data to the first exponential equation ($y = ba^x$). Fitting the data to this equation resulted in an $r^2$ of 0.825 (Figure 6). It generally describes an exponential decay in egg-to-migrant survival with increasing peak streamflow during the incubation period. This model provides a useful tool for estimating egg-to-migrant survival into Lake Washington.

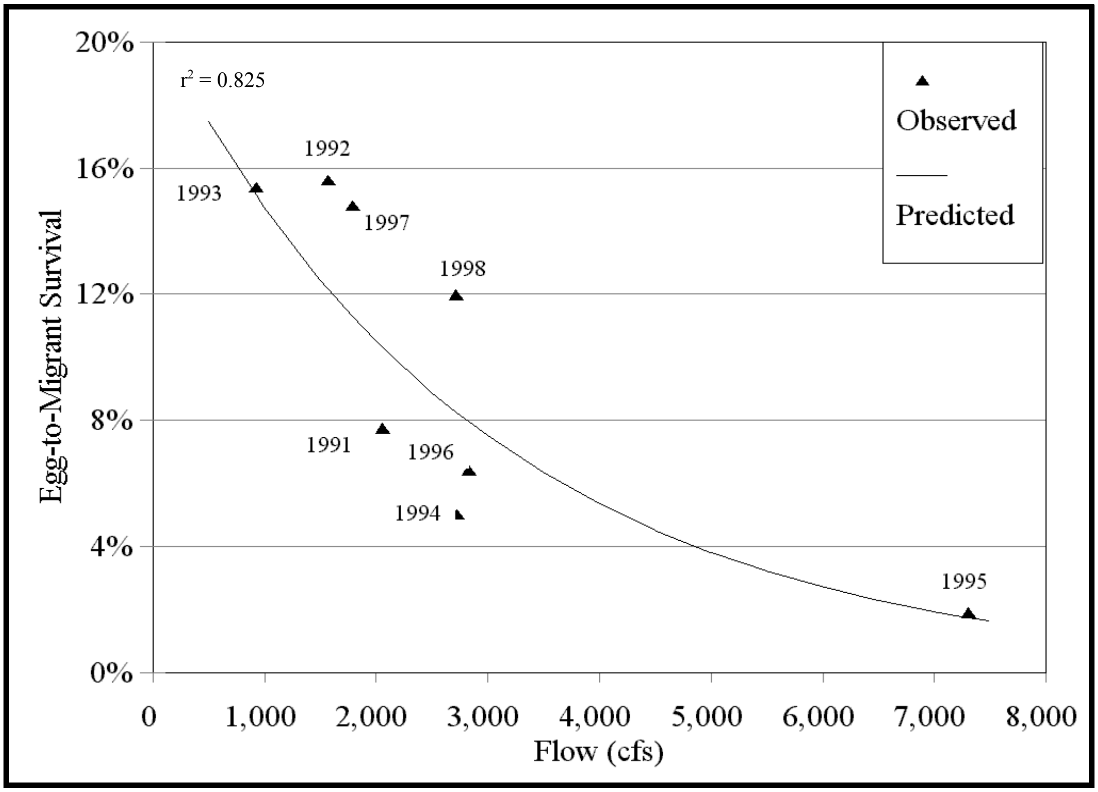


**Figure 7**. Exponential regression of wild sockeye egg-to-migrant survival from brood years 1991 to 1998 as a function of peak flow during the winter egg incubation period, Cedar River.

# Citations

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## Personal Communications

Steve Foley, Fish and Wildlife Biologist. Washington Department of Fish and Wildlife, Mill Creek Office. Telephone conversation on January 27, 2000.

# Appendix A

# Estimated Cedar River Wild and Hatchery Sockeye Fry Migration into Lake Washington, 1999

Appendix A. Estimated Cedar River Wild and Hatchery Sockeye Fry Migration into Lake Washington, 1999.

| | Catch | | Flow | Trap Efficiency | | Hatchery Releases | | | Nightly Migration at Trap | | | Daily Migration into Lake Washington | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Trap 2 | Trap 3 | (cfs) | Trap 2 | Trap 3 | Landsburg | Mid-River | Riviera | Total | Wild | Hatchery | Wild | Hatchery |
| 01/23 | 169 | 0 | 2,060 | 2.25% | | | | | 7,497 | 7,497 | 0 | 8,330 | 0 |
| 01/24 | 0 | 0 | 1,960 | | | | | | 5,989 | 5,989 | 0 | 6,654 | 0 |
| 01/25 | 101 | 0 | 1,890 | 2.25% | | | | | 4,481 | 4,481 | 0 | 4,979 | 0 |
| 01/26 | 0 | 0 | 1,840 | | | | | | 6,145 | 6,145 | 0 | 6,827 | 0 |
| 01/27 | 3,104 | 0 | 1,780 | 2.25% | | 110,000 | | | 137,704 | 6,145 | 131,599 | 6,828 | 146,177 |
| 01/28 | 0 | 0 | 1,630 | | | | | | 6,145 | 6,145 | 0 | 6,827 | 0 |
| 01/29 | 176 | 0 | 1,600 | 2.25% | | | | | 7,808 | 7,808 | 0 | 8,676 | 0 |
| 01/30 | 0 | 0 | 1,600 | | | | | | 7,653 | 7,653 | 0 | 8,503 | 0 |
| 01/31 | 169 | 0 | 1,560 | 2.25% | | | | | 7,497 | 7,497 | 0 | 8,330 | 0 |
| 02/01 | 120 | 222 | 1,390 | 2.25% | 4.17% | | | | 5,324 | 5,324 | 0 | 5,916 | 0 |
| 02/02 | 343 | 0 | 1,390 | 2.25% | | | | | 15,217 | 15,217 | 0 | 16,908 | 0 |
| 02/03 | 15,375 | 0 | 1,340 | 2.25% | | 430,000 | | | 682,088 | 14,396 | 667,692 | 15,996 | 741,880 |
| 02/04 | 306 | 0 | 1,210 | 2.25% | | | | | 13,575 | 13,575 | 0 | 15,083 | 0 |
| 02/05 | 8,565 | 0 | 1,140 | 2.25% | | 409,000 | | | 379,973 | 20,740 | 359,266 | 23,044 | 399,148 |
| 02/06 | 629 | 0 | 1,150 | 2.25% | | | | | 27,905 | 27,905 | 0 | 31,006 | 0 |
| 02/07 | 550 | 0 | 1,300 | 2.25% | | | | | 24,400 | 24,400 | 0 | 27,111 | 0 |
| 02/08 | 379 | 0 | 1,250 | 2.25% | | | | | 16,814 | 16,814 | 0 | 18,682 | 0 |
| 02/09 | 258 | 0 | 1,160 | 2.25% | | | | | 11,446 | 11,446 | 0 | 12,718 | 0 |
| 02/10 | 1,449 | 0 | 996 | 2.25% | | | | | 64,283 | 64,283 | 0 | 71,426 | 0 |
| 02/11 | 9,479 | 12,797 | 929 | 2.25% | 3.04% | | | 562,000 | 420,521 | 72,419 | 348,102 | 80,465 | 348,102 |
| 02/12 | 180 | 0 | 780 | 2.25% | | | | | 7,985 | 7,985 | 0 | 8,872 | 0 |
| 02/13 | 1,726 | 1,630 | 780 | 1.95% | 1.84% | | | | 88,690 | 88,690 | 0 | 98,544 | 0 |
| 02/14 | 1,432 | 0 | 775 | 1.95% | | | | | 73,583 | 73,583 | 0 | 81,759 | 0 |
| 02/15 | 916 | 336 | 740 | 1.95% | | | | | 47,068 | 47,068 | 0 | 52,298 | 0 |
| 02/16 | 4,643 | 0 | 690 | 1.95% | | | | 535,000 | 238,579 | 74,225 | 164,354 | 82,472 | 166,122 |
| 02/17 | 19,571 | 16,620 | 646 | 5.96% | 4.97% | | | 240,000 | 331,105 | 75,681 | 255,424 | 84,090 | 261,030 |
| 02/18 | 29,858 | 0 | 612 | 6.19% | | | 494,000 | | 482,029 | 64,271 | 417,758 | 71,412 | 464,176 |
| 02/19 | 2,699 | 3,702 | 671 | 5.78% | 4.90% | | | | 59,942 | 52,749 | 7,193 | 58,610 | 7,992 |
| 02/20 | 1,740 | 2,357 | 619 | 6.15% | 5.06% | | | | 36,573 | 36,573 | 0 | 40,637 | 0 |

Appendix A. Estimated Cedar River Wild and Hatchery Sockeye Fry Migration into Lake Washington, 1999.

| Date | Catch | | Flow | Trap Efficiency | | Hatchery Releases | | | Nightly Migration at Trap | | | Daily Migration into Lake Washington | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Trap 2 | Trap 3 | (cfs) | Trap 2 | Trap 3 | Landsburg | Mid-River | Riviera | Total | Wild | Hatchery | Wild | Hatchery |
| 02/21 | 3,363 | 4,603 | 590 | 6.35% | 5.15% | | | | 69,305 | 69,305 | 0 | 77,006 | 0 |
| 02/22 | 36,477 | 0 | 627 | 6.09% | | | 526,000 | | 599,068 | 67,894 | 531,174 | 75,438 | 590,193 |
| 02/23 | 3,247 | 3,925 | 713 | 5.49% | 4.77% | 255,000 | | | 69,930 | 43,823 | 26,107 | 48,692 | 29,008 |
| 02/24 | 0 | 3,387 | 778 | | 4.57% | | | | 74,074 | 74,074 | 0 | 82,304 | 0 |
| 02/25 | 0 | 25,044 | 792 | | 4.53% | 538,000 | | | 552,870 | 73,716 | 479,154 | 81,907 | 532,393 |
| 02/26 | 0 | 2,407 | 796 | | 4.52% | | | | 53,280 | 38,505 | 14,774 | 42,783 | 16,417 |
| 02/27 | 0 | 1,500 | 1,190 | | 3.32% | | | | 45,224 | 45,224 | 0 | 50,249 | 0 |
| 02/28 | 0 | 1,629 | 1,610 | | 2.04% | | | | 79,977 | 79,977 | 0 | 88,863 | 0 |
| 03/01 | 0 | 9,307 | 1,540 | | 2.25% | 190,000 | | 195,000 | 413,612 | 55,148 | 458,464 | 61,276 | 380,829 |
| 03/02 | 0 | 9,155 | 1,200 | | 3.29% | | | 215,000 | 278,574 | 44,572 | 234,002 | 49,524 | 234,002 |
| 03/03 | 0 | 19,325 | 1,060 | | 3.71% | | | 429,000 | 520,462 | 52,046 | 468,416 | 57,829 | 468,801 |
| 03/04 | 0 | 7,098 | 1,030 | | 3.80% | | | 203,000 | 186,570 | 60,946 | 125,624 | 67,718 | 125,624 |
| 03/05 | 0 | 2,060 | 1,120 | | 3.53% | | | | 58,354 | 58,354 | 0 | 64,838 | 0 |
| 03/06 | 1,245 | 1,769 | 1,120 | 2.63% | 3.53% | | | | 48,936 | 48,936 | 0 | 54,373 | 0 |
| 03/07 | 1,374 | 2,006 | 1,090 | 2.84% | 3.62% | | | | 52,313 | 52,313 | 0 | 58,126 | 0 |
| 03/08 | 0 | 11,401 | 1,080 | | 3.65% | | 487,000 | | 312,177 | 35,380 | 276,797 | 39,311 | 307,552 |
| 03/09 | 0 | 14,755 | 1,030 | | 3.80% | | 399,000 | | 387,833 | 74,981 | 312,852 | 83,312 | 347,613 |
| 03/10 | 0 | 13,442 | 954 | | 4.04% | | 269,000 | | 333,044 | 108,794 | 224,250 | 120,883 | 249,166 |
| 03/11 | 0 | 24,052 | 800 | | 4.51% | 518,000 | | | 533,844 | 64,061 | 469,783 | 71,179 | 521,981 |
| 03/12 | 0 | 6,886 | 742 | | 4.68% | | | | 147,068 | 106,869 | 40,199 | 118,744 | 44,665 |
| 03/13 | 0 | 4,894 | 858 | | 4.33% | | | | 113,060 | 113,060 | 0 | 125,622 | 0 |
| 03/14 | 0 | 6,073 | 947 | | 4.06% | | | | 149,676 | 149,676 | 0 | 166,307 | 0 |
| 03/15 | 0 | 17,783 | 876 | | 4.27% | 400,000 | | | 416,092 | 38,835 | 377,257 | 43,150 | 419,174 |
| 03/16 | 0 | 24,245 | 814 | | 4.46% | | | 359,000 | 543,273 | 135,818 | 407,455 | 150,909 | 408,678 |
| 03/17 | 0 | 19,660 | 753 | | 4.65% | | | 283,000 | 422,916 | 126,332 | 296,584 | 140,369 | 296,584 |
| 03/18 | 0 | 30,869 | 718 | | 4.76% | | | 554,000 | 649,143 | 116,846 | 532,297 | 129,829 | 532,297 |
| 03/19 | 0 | 7,867 | 694 | | 4.83% | | | | 162,929 | 159,670 | 3,259 | 177,412 | 3,500 |
| 03/20 | 0 | 7,015 | 685 | | 4.86% | | | | 144,463 | 144,463 | 0 | 160,514 | 0 |
| 03/21 | 0 | 11,009 | 711 | | 4.78% | | | | 230,474 | 230,474 | 0 | 256,082 | 0 |
| 03/22 | 0 | 7,641 | 701 | | 4.81% | | | | 158,951 | 158,951 | 0 | 176,612 | 0 |

Appendix A. Estimated Cedar River Wild and Hatchery Sockeye Fry Migration into Lake Washington, 1999.

| | Catch | | Flow | Trap Efficiency | | Hatchery Releases | | | Nightly Migration at Trap | | | Daily Migration into Lake Washington | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Trap 2 | Trap 3 | (cfs) | Trap 2 | Trap 3 | Landsburg | Mid-River | Riviera | Total | Wild | Hatchery | Wild | Hatchery |
| 03/23 | 0 | 25,920 | 703 | | 4.80% | | 334,000 | | 539,881 | 187,159 | 351,141 | 207,954 | 391,914 |
| 03/24 | 0 | 14,465 | 767 | | 4.61% | | 333,000 | | 314,046 | 73,277 | 242,214 | 81,419 | 267,521 |
| 03/25 | 0 | 9,107 | 954 | | 4.04% | | 170,000 | | 225,639 | 129,366 | 100,530 | 143,740 | 106,970 |
| 03/26 | 0 | 2,401 | 971 | | 3.98% | | | | 60,262 | 57,852 | 2,527 | 64,279 | 2,678 |
| 03/27 | 0 | 2,499 | 1,010 | | 3.87% | | | | 64,650 | 64,650 | 0 | 71,833 | 0 |
| 03/28 | 0 | 3,561 | 1,020 | | 3.83% | | | | 92,856 | 92,856 | 0 | 103,173 | 0 |
| 03/29 | 0 | 2,416 | 995 | | 3.91% | | | | 61,772 | 61,772 | 0 | 68,636 | 0 |
| 03/30 | 0 | 3,561 | 900 | | 4.20% | | | | 84,772 | 84,772 | 0 | 94,191 | 0 |
| 03/31 | 0 | 7,760 | 863 | | 4.31% | | 135,000 | | 179,903 | 67,164 | 115,446 | 74,626 | 125,266 |
| 04/01 | 0 | 5,532 | 770 | | 4.60% | | | | 120,343 | 114,727 | 5,653 | 127,474 | 6,240 |
| 04/02 | 0 | 3,881 | 760 | | 4.63% | | | | 83,871 | 83,871 | 0 | 93,190 | 0 |
| 04/03 | 0 | 4,310 | 760 | | 4.63% | | | | 93,142 | 93,142 | 0 | 103,971 | 0 |
| 04/04 | 0 | 3,069 | 710 | | 4.78% | | | | 64,209 | 64,209 | 0 | 71,343 | 0 |
| 04/05 | 0 | 7,562 | 697 | | 4.82% | | 57,000 | | 156,909 | 96,850 | 59,779 | 107,611 | 66,733 |
| 04/06 | 0 | 6,284 | 686 | | 4.85% | | | | 129,490 | 129,490 | 0 | 143,878 | 0 |
| 04/07 | 0 | 4,627 | 681 | | 4.87% | | | | 95,047 | 95,047 | 0 | 105,608 | 0 |
| 04/08 | 0 | 6,488 | 674 | | 4.89% | | 7,000 | | 132,694 | 128,271 | 4,384 | 142,523 | 4,915 |
| 04/09 | 0 | 4,771 | 683 | | 4.86% | | | | 98,128 | 98,128 | 0 | 109,031 | 0 |
| 04/10 | 0 | 7,083 | 663 | | 4.92% | | | | 143,877 | 143,877 | 0 | 159,863 | 0 |
| 04/11 | 0 | 8,066 | 646 | | 4.97% | | | | 162,138 | 162,138 | 0 | 180,153 | 0 |
| 04/12 | 0 | 5,665 | 597 | | 5.12% | | | | 110,556 | 110,556 | 0 | 122,840 | 0 |
| 04/13 | 0 | 7,043 | 591 | | 5.14% | | | | 136,960 | 136,690 | 0 | 152,178 | 0 |
| 04/14 | 0 | 6,031 | 587 | | 5.15% | | | | 117,003 | 117,003 | 0 | 130,003 | 0 |
| 04/15 | 0 | 6,852 | 543 | | 5.29% | | | | 129,560 | 129,560 | 0 | 143,956 | 0 |
| 04/16 | 0 | 6,194 | 609 | | 5.09% | | | | 121,749 | 121,749 | 0 | 135,277 | 0 |
| 04/17 | 0 | 6,402 | 613 | | 5.08% | | | | 126,139 | 126,139 | 0 | 140,154 | 0 |
| 04/18 | 0 | 6,176 | 607 | | 5.09% | | | | 121,249 | 121,249 | 0 | 134,721 | 0 |
| 04/19 | 0 | 5,590 | 577 | | 5.19% | | | | 107,810 | 107,810 | 0 | 119,789 | 0 |
| 04/20 | 0 | 4,746 | 625 | | 5.04% | | | | 94,190 | 94,190 | 0 | 104,656 | 0 |
| 04/21 | 0 | 4,173 | 638 | | 5.00% | | | | 83,474 | 83,474 | 0 | 92,749 | 0 |

Appendix A. Estimated Cedar River Wild and Hatchery Sockeye Fry Migration into Lake Washington, 1999.

| | Catch | | Flow | Trap Efficiency | | Hatchery Releases | | | Nightly Migration at Trap | | | Daily Migration into Lake Washington | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Trap 2 | Trap 3 | (cfs) | Trap 2 | Trap 3 | Landsburg | Mid-River | Riviera | Total | Wild | Hatchery | Wild | Hatchery |
| 04/22 | 0 | 4,701 | 652 | | 4.96% | | | | 94,845 | 94,845 | 0 | 105,383 | 0 |
| 04/23 | 0 | 4,481 | 704 | | 4.80% | | | | 93,393 | 93,393 | 0 | 103,770 | 0 |
| 04/24 | 0 | 4,214 | 716 | | 4.76% | | | | 88,503 | 88,503 | 0 | 98,337 | 0 |
| 04/25 | 0 | 4,352 | 731 | | 4.72% | | | | 92,287 | 92,287 | 0 | 102,541 | 0 |
| 04/26 | 0 | 3,526 | 744 | | 4.68% | | | | 75,405 | 75,405 | 0 | 83,783 | 0 |
| 04/27 | 0 | 2,982 | 779 | | 4.57% | | | | 65,260 | 65,260 | 0 | 72,511 | 0 |
| 04/28 | 0 | 3,111 | 788 | | 4.54% | | | | 68,494 | 68,494 | 0 | 76,104 | 0 |
| 04/29 | 0 | 3,270 | 773 | | 4.59% | | | | 71,277 | 71,277 | 0 | 79,197 | 0 |
| 04/30 | 0 | 3,165 | 768 | | 4.60% | | | | 68,760 | 68,760 | 0 | 76,400 | 0 |
| 05/01 | 0 | 3,349 | 755 | | 4.64% | | | | 72,137 | 72,137 | 0 | 80,152 | 0 |
| 05/02 | 0 | 3,477 | 788 | | 4.54% | | | | 76,552 | 76,552 | 0 | 85,058 | 0 |
| 05/03 | 0 | 4,283 | 832 | | 4.41% | | | | 97,166 | 97,166 | 0 | 107,962 | 0 |
| 05/04 | 0 | 3,777 | 787 | | 4.55% | | | | 83,101 | 83,101 | 0 | 92,334 | 0 |
| 05/05 | 0 | 3,688 | 734 | | 4.71% | | | | 78,358 | 78,358 | 0 | 87,064 | 0 |
| 05/06 | 0 | 3,290 | 672 | | 4.90% | | | | 67,204 | 67,204 | 0 | 74,671 | 0 |
| 05/07 | 0 | 2,815 | 663 | | 4.92% | | | | 57,181 | 57,181 | 0 | 63,534 | 0 |
| 05/08 | 0 | 2,416 | 625 | | 5.04% | | | | 47,948 | 47,948 | 0 | 53,276 | 0 |
| 05/09 | 0 | 2,352 | 639 | | 5.00% | | | | 47,077 | 47,077 | 0 | 52,308 | 0 |
| 05/10 | 0 | 2,049 | 626 | | 5.04% | | | | 40,689 | 40,689 | 0 | 45,210 | 0 |
| 05/11 | 0 | 1,719 | 627 | | 5.03% | | | | 34,157 | 34,157 | 0 | 37,952 | 0 |
| 05/12 | 0 | 1,392 | 622 | | 5.05% | | | | 27,576 | 27,576 | 0 | 30,640 | 0 |
| 05/13 | 0 | 1,394 | 601 | | 5.11% | | | | 27,270 | 27,270 | 0 | 30,300 | 0 |
| 05/14 | 0 | 1,314 | 587 | | 5.15% | | | | 25,492 | 25,492 | 0 | 28,324 | 0 |
| 05/15 | 0 | 634 | 584 | | 5.16% | | | | 12,278 | 12,278 | 0 | 13,642 | 0 |
| 05/16 | 0 | 1,136 | 593 | | 5.14% | | | | 22,117 | 22,117 | 0 | 24,574 | 0 |
| 05/17 | 0 | 0 | 631 | | | | | | 24,717 | 24,717 | 0 | 27,463 | 0 |
| 05/18 | 0 | 1,269 | 754 | | 4.65% | | | | 27,316 | 27,316 | 0 | 30,351 | 0 |
| 05/19 | 0 | 0 | 740 | | | | | | 22,047 | 22,047 | 0 | 24,497 | 0 |
| 05/20 | 0 | 827 | 661 | | 4.93% | | | | 16,778 | 16,778 | 0 | 18,642 | 0 |
| 05/21 | 0 | 0 | 601 | | | | | | 17,013 | 17,013 | 0 | 18,903 | 0 |

Appendix A. Estimated Cedar River Wild and Hatchery Sockeye Fry Migration into Lake Washington, 1999.

| | Catch | | Flow | Trap Efficiency | | Hatchery Releases | | | Nightly Migration at Trap | | | Daily Migration into Lake Washington | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Date | Trap 2 | Trap 3 | (cfs) | Trap 2 | Trap 3 | Landsburg | Mid-River | Riviera | Total | Wild | Hatchery | Wild | Hatchery |
| 05/22 | 0 | 889 | 587 | | 5.15% | | | | 17,247 | 17,247 | 0 | 19,163 | 0 |
| 05/23 | 0 | 0 | 589 | | | | | | 14,908 | 14,908 | 0 | 16,564 | 0 |
| 05/24 | 0 | 0 | 595 | | | | | | 12,568 | 12,568 | 0 | 13,965 | 0 |
| 05/25 | 0 | 483 | 729 | | 4.72% | | | | 10,229 | 10,229 | 0 | 11,366 | 0 |
| 05/26 | 0 | 0 | 770 | | | | | | 8,127 | 8,127 | 0 | 9,030 | 0 |
| 05/27 | 0 | 0 | 655 | | | | | | 6,025 | 6,025 | 0 | 6,694 | 0 |
| 05/28 | 0 | 193 | 664 | | 4.92% | | | | 3,923 | 3,923 | 0 | 4,359 | 0 |
| Total | 149,643 | 607,254 | | | | 2,850,000 | 3,211,000 | 3,575,000 | 16,793,252 | 8,388,478 | 8,404,775 | 9,320,531 | 9,015,341 |

Note: Daily Migration into Lake Washington includes daytime migration rate (10%).