2000 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 3.2 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, Tim Eichler, and Jill Rossman worked long hours at night operating and maintaining the trap, marking and releasing fry, and enumerating catches. WDFW Wild Salmon Production and Survival Evaluation Unit biologists Mike Ackley and Pete Topping provided valuable logistical support.

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Executive Summary

Declining adult sockeye salmon returns to Lake Washington in the late 1980's and early 1990's prompted the creation of a multi-agency effort to investigate causes for this decline. To determine in which life-stage sockeye were experiencing lower survival, an evaluation of fry production was undertaken in the Cedar River beginning in 1992. Assessing the sockeye population at this location and life-stage separates freshwater production into river and lake components. This report documents our investigations during 2000, the ninth year of this project. As in previous years, the primary study goal was to estimate the season total migration of Cedar River wild and hatchery sockeye fry into Lake Washington. These estimates enable calculating the survival rate from egg deposition to lake entry, the survival of hatchery fry by release group, and the incidence of hatchery fry in the population at lake entry.

A floating inclined-plane screen trap was operated on 89 nights from January 20 through April 26 in the Cedar River at River Mile 0.9. This trap captured a portion of the sockeye fry migrating into Lake Washington. To estimate its capture efficiency, on 43 nights over the season, dye-marked fry were released upstream of the trap. Unlike previous years, regression analysis failed to show a relationship between flow and capture efficiency. Instead, capture rates declined over the season. We determined that significant predation in the half mile reach above the fry trap increasingly biased capture rates. Consequently, we estimated nightly migration with the capture rate derived early in the season while predation rates were low.

In total, 3.2 million hatchery produced sockeye fry were released into the Cedar River from February through March. Fry were released from two locations over 16 nights. All of the hatchery fry were internally marked via an innovative process involving deliberate variation of water temperatures during incubation to induce recognizable growth patterns in otoliths. Nightly hatchery fry migrations were estimated through a combination of analyzing otolith samples and through subtracting interpolated wild migrations from nightly total fry estimates.

Over the 89 nights that were trapped, 755,230 sockeye fry were captured. From this catch and the capture rate data, we estimated a total of 10.1 million sockeye fry entered Lake Washington in 2000. This production includes 8.1 million wild fry and 2.0 million hatchery produced fry. Relating this latter estimate to the 3.2 million hatchery fry released estimates that 63% survived to enter the lake. In-river survival of hatchery produced sockeye fry was related to migration distance. Fry released at river mile 13.9 and 1.9 survived to the trap at average rates of 48% and 77%, respectively.

Egg to migrant survival for the 1999 brood natural spawning sockeye was estimated at 9.5%. This rate is higher than that predicted by the relationship between peak flow and estimated egg to migrant survival. During incubation, on December 18, 1999, flow in the Cedar River peaked at 2,680 cfs. At this flow, the relationship derived with nine years of fry production evaluation and incorporating higher estimates of egg deposition, predicts an egg to migrant survival rate of 6.7%.

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 some 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 are being used to assess and guide restoration of 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 had averaged 13.5%, varying fourteen-fold (2.6% to 36.6%), for the 1967 to 1992 broods with no apparent trend 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 per 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 to 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. In 1997, monitoring to quantify fry production from the Sammamish watershed was initiated (Seiler *et al.* 2002). Measuring sockeye fry production from these two systems accounts for the vast majority of sockeye entering Lake Washington.

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 1994, 1995). 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 subsequent years, a portion of the hatchery fry production was also released below the fry trap at the mouth of the Cedar River. In 1995, we evaluated the effect of flow on survival using ten groups of marked hatchery fry 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 eight brood years of this evaluation (1991 to 1998), 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 *et al.* 2001). 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.

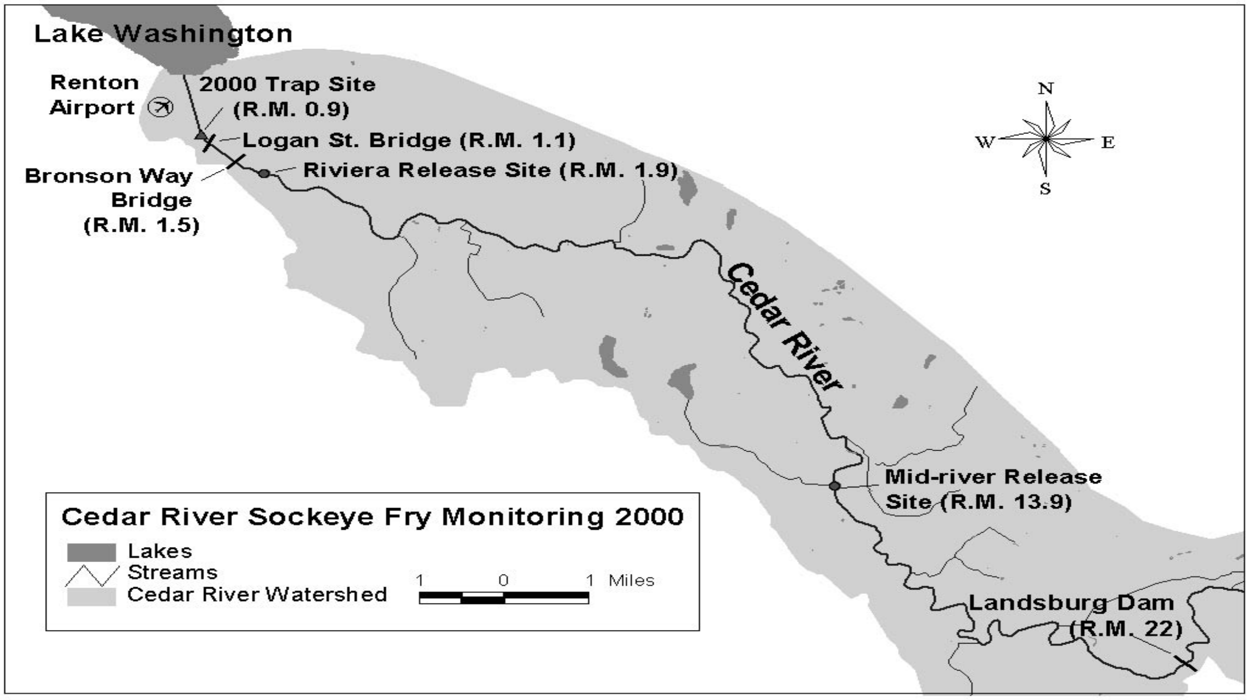

Figure 1. Site map of the lower Cedar River watershed depicting the sockeye fry trap location, hatchery release sites, and other features relevant to the 2000 sockeye production evaluation study.

Our ability to capture fry and estimate migration depends on selecting a trapping site with sufficient velocity over the flow range. Optimal flow characteristics direct a relatively high percentage of downstream migrants into the trap and have sufficient velocity to capture targeted species without bias to size. 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, in the 1998 season the streambed was substantially aggraded relative to the previous six seasons. The difference in bed elevations between the lower river channel and the lake created sufficient stream energy to cut a distinct channel which, at low discharge, confined flow. With the trap positioned in this channel, the resulting velocities were high enough 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 its flooding potential (USACOE 1997). This project lowered the stream bed creating a wider and deeper channel, which reduced the velocity to near zero where the fry trap was located (RM 0.25). In response to this dramatic change in the channel, we moved the trap as far upstream as we could to just below the Boeing Company's south bridge for the 1999 season. As a result of the low velocity at this site, the 1999 season trap efficiency averaged only 3-4%, considerably lower than in 1998 when it averaged over 9%. In 1999, we also began assessing juvenile chinook production. As these migrants are larger than sockeye fry, their unbiased capture requires even higher trap entrance velocity. Consequently, for the 2000 season we moved the fry trapping operation upstream to just below the Logan Street Bridge where velocity was considerably higher.

This report documents the *2000 Cedar River Sockeye Salmon Fry Production Evaluation*. This trapping project estimated the numbers of 1999 brood Cedar River wild and hatchery-produced fry that entered Lake Washington during 2000. Chinook production estimates will be documented in a separate report.

Goals and Objectives

Goals of this project are to estimate:

1. Total Cedar River fry production. Relating the smolt population the following spring to this estimate measures rearing survival in the lake. Over time, these rates will help assess lake carrying capacity.

2. Survival of natural production. Relating wild fry production 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, flows and species interactions will be assessed.

3. Migration timing of natural production. Relating wild migration timing to temporal and spatial distribution of spawners, temperature and flows during discreet intervals and life stages will help explain physical and biological factors affecting in-river survival.

4. 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.

5. 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.

From these annual estimates, over time, we can assess:
- the performance of this sockeye population in freshwater,
- the health of river and lake habitats, and
- management efforts to increase production.

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, indicating the spike was due largely to hatchery fish; much of the hatchery production was released in the lower river just upstream of I-405 and therefore the potential for loss to predators was minimal; and the budget for otolith analysis was limited. In 1999 and 2000, we resumed collecting fry for otolith analysis on most nights that hatchery fry were released.

Trapping Gear and Operation

The fry trap consists of a small low-angle inclined-plane screen trap (3 ft wide by 2 ft deep by 9 ft long). In 2000, we suspended this trap from our screw trap platform, a 30 ft long by 15 ft wide steel pontoon barge. This structure, which resembled the larger scoop traps we use to capture smolts in big river systems (Seiler *et al.* 1981), includes overhead davits for lifting the trap. When lowered to the fishing depth of 16 inches, a cross-sectional area of 4 ft^2 was sampled. At a velocity of 4 ft per second, a volume of 16 cfs passed through the trap.

We positioned the trap in the thalweg 200 yards downstream of the Logan Street Bridge near the left bank (Figure 1). At this point, the left bank, which is armored with riprap, forms the outside of a bend. As a result, current vectors concentrate and direct relatively high velocity flow near this bank.

Nightly trapping began before dusk and continued past dawn. Captured fish were removed from the trap and counted every hour, on the hour. Large fry catches were counted using an electronic fish counter (Northwest Marine Technology, model FC-1). Calibration of this counter in previous seasons determined that it counted 96.6% of the actual number of fish that passed through it (Seiler *et al.* 1997, 2001).

Trapping began on the night of January 20 and continued every other night until February 6. From this date through April 26 we trapped throughout every night. Over the season, the trap was operated a total of 89 nights. In addition, to assess the daytime sockeye fry migration, we fished during the day on four dates between March 5 and April 16.

Trap Calibration

Two assumptions critical for accurate trap calibration are: 1) a known number of marked fry pass the trap in a discreet time interval, and 2) their capture susceptibility is the same as unmarked fry. The first assumption 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 trapping gear in the fast current, 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 they become distributed as unmarked fry because they are subjected to the same currents.

Relocating the trap upstream to just below the Logan Street Bridge required selecting a new release location further upstream. After surveying the reach upstream of Logan Street, we elected to release the marked fry from the Bronson Way Bridge. This bridge is the third one upstream from Logan Street and approximately one half mile upstream from the trap site. Fry captured the previous night, or in the early hours of the release night, were marked by immersion in a solution of Bismarck brown dye (14 ppm for 1.5 hours). Marked fry were distributed in approximately equal proportions between left bank, mid-channel, and right bank release points. Recovery rates were correlated with mean nightly discharge to assess the effect of flow on capture rate.

Hatchery Releases

Throughout the season, 3,244,000 hatchery-produced fry were released into the Cedar River (Table 1). Unlike previous years, no fry were released directly from the hatchery at Landsburg or downstream of the trap. The releases occurred from two locations, the Riviera Apartment site at RM 1.9 and a middle river site at RM 13.9. Forty-seven percent of the total production was released from the Riviera site (1,526,000 fry), and 53% (1,718,000 fry) was released from the middle river site. Releases at Riviera occurred on seven nights between February 8 and February 28 with group sizes ranging from 190,000 to 234,000 sockeye fry. Fry were released on nine nights at the middle river site between February 17 and March 30 with group sizes ranging from 13,000 to 247,000 fry. Due to the low production, only two otolith codes were used to represent 1999 brood hatchery fry.

Sampling Fry for Thermal Marks

As otolith marks are internal, their detection requires lethal sampling of the fry. A systematic random sample of fry was collected from the catch every night that hatchery-produced fry were released and every night following releases. To insure that the samples were not biased by differences in migration timing between wild and hatchery fry, we retained a constant fraction of each hour's 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, to insure that 150 were available for analysis.

Table 1. Hatchery-produced sockeye fry released at two locations, Cedar River 2000.			
Release Date	**Number Released**		**Total**
	Riviera	**Middle**	
02/08	227,000		227,000
02/09	224,000		224,000
02/10	222,000		222,000
02/17		247,000	247,000
02/18		245,000	245,000
02/22		244,000	244,000
02/23	232,000		232,000
02/24	234,000		234,000
02/25	190,000		190,000
02/28	197,000		197,000
03/02		205,000	205,000
03/03		219,000	219,000
03/09		206,000	206,000
03/16		217,000	217,000
03/23		122,000	122,000
03/30		13,000	13,000
Total	1,526,000	1,718,000	3,244,000

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, and
- Average daily 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, and
- 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,

$$
\begin{aligned}
MSE &= \textit{the mean square error for the regression},\\
n &= \textit{the number of observations in the regression},\\
s_f^2 &= \textit{the sample variance of the observed flows, and}\\
\bar{f} &= \textit{the mean of observed flows in } 2000.
\end{aligned}
$$

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

$$\bar{e} = \frac{\sum_{i=1}^{n} \hat{e}_i}{n} \tag{3}$$

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

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

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

If trap efficiency was predicted using the regression equation (Equation 1), the nightly total out-migration, N_i, was estimated using the estimated trap efficiencies;

$$\hat{N}_i = \frac{c_i}{\hat{e}_i} \tag{6}$$

and the variance by;

$$V(\hat{N}_i) = V(\hat{e}_i)\,\frac{c_i^2}{\hat{e}_i^4} \tag{7}$$

If trap efficiency was estimated using mean trap efficiency, then $\bar{e}$ and $V(\bar{e})$ were substituted for $\hat{e}$ and $V(\hat{e})$ in Equations 6 and 7.

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

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

and its variance by;

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

The number of fry from hatchery group *h* migrating on night *i* was estimated by;

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

and its variance using the variance of products (Goodman 1960) by;

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

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 used to estimate the composition of hatchery fry in catches on only three nights from each release location due to budget constraints. On the other 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.

To estimate wild migration during un-fished nights when the trap was operated every other night, straight-line interpolation was used. The interpolated value was found by the mean of the preceding and following night's estimates, therefore the variances for the nightly wild fry migration estimate, $V(W)$, and the nightly hatchery fry migration estimate, $V(H_{hi})$, were found by;

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

$$V(\hat{H}_{hi}) = V(\hat{N}_i) + V(\bar{W}) \quad \textbf{(13)}$$

where,

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

Where the wild migration estimate was interpolated for two or more consecutive nights, the interpolated values were found by,

$$M_{u1} = M_{k1} - \frac{(M_{k1} - M_{k2})}{(n + 1)} \qquad \textbf{(14)}$$

$$M_{u2} = M_{u1} - \frac{(M_{k1} - M_{k2})}{(n + 1)} \qquad \textbf{(15)}$$

where,

$$n = \textit{the number of unknown vaules},$$
$$M_{u1} = \textit{the larger of the unknown values},$$
$$M_{u2} = \textit{the smaller of the unknown values},$$
$$M_{k1} = \textit{the larger of the known values, and}$$
$$M_{k2} = \textit{the smaller of the known values.}$$

The variance for each interpolated migration estimate was found by comparing the CVs of M_{k1} and M_{k2}. If the CV of M_{k1} is larger than the CV of M_{k2}, then the variances were found by,

$$V(M_{u1}) = \left(\left(\frac{\sqrt{V(M_{k1})}}{M_{k1}} - \frac{\left(\frac{\sqrt{V(M_{k1})}}{M_{k1}} - \frac{\sqrt{V(M_{k2})}}{M_{k2}} \right)}{(n + 1)} \right) \times M_{u1} \right)^2 \qquad \textbf{(16)}$$

$$V(M_{u2}) = \left(\left(\frac{\sqrt{V(M_{u1})}}{M_{u1}} - \frac{\left(\frac{\sqrt{V(M_{k1})}}{M_{k1}} - \frac{\sqrt{V(M_{k2})}}{M_{k2}} \right)}{(n + 1)} \right) \times M_{u2} \right)^2 \qquad \textbf{(17)}$$

If the CV of M_{k1} is smaller than the CV of M_{k2}, then the variances were found by,

$$V(M_{u2}) = \left(\left(\frac{\sqrt{V(M_{k2})}}{M_{k2}} - \frac{\left(\frac{\sqrt{V(M_{k2})}}{M_{k2}} - \frac{\sqrt{V(M_{k1})}}{M_{k1}}\right)}{(n+1)}\right) \times M_{u2}\right)^2 \tag{18}$$

$$V(M_{u1}) = \left(\left(\frac{\sqrt{V(M_{u2})}}{M_{u2}} - \frac{\left(\frac{\sqrt{V(M_{k2})}}{M_{k2}} - \frac{\sqrt{V(M_{k1})}}{M_{k1}}\right)}{(n+1)}\right) \times M_{u1}\right)^2 \tag{19}$$

Nightly estimates of the wild fry migrations were expanded to represent daily (24-hour) migrations. Hatchery release groups were assumed to pass the trap during the night of release and were not expanded. The expansion was made using the sample average of the day catch rate to night catch rate ratio found during trapping conducted in 2000. Daily migration (M_d) was calculated by dividing the nighttime migration estimate by the proportion (R_i) of the 24-hour catch caught at night, as determined from trap operation data.

The proportion of the catch on day *d* captured on night *i* was estimated by;

$$R_i = \frac{H_{nd}}{\bar{Q}\,H_{dd} + H_{nd}} \tag{20}$$

and its variance was estimated by;

$$V(R_i) = V(\bar{Q})H_{dd}^2\frac{H_{nd}^2}{(\bar{Q}\,H_{dd} + H_{nd})^4} \tag{21}$$

where,

$$\begin{aligned} H_{nd} &= \textit{hours of night during 24-hour period } d, \\ H_{dd} &= \textit{hours of day during 24-hour period } d, \textit{ and} \\ \bar{Q} &= \textit{average day/night catch ratio.} \end{aligned}$$

The variance for each 24-hour migration estimate on day *d* was approximated by;

$$V(\hat{M}_d) = \hat{M}_d\left(\frac{V(\hat{N}_i)}{N_i^2} + \frac{V(R_i)}{R_i^2}\right) \tag{22}$$

The total out-migration, 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 out-migration estimates for these variables and the variances of the totals were found by the sums of the daily variances.

The total out-migration of hatchery group *h* was estimated by summing all of the daily estimates of out-migrating fry belonging to that group;

$$\hat{H}_{hT} = \sum_{d=1}^{D} \hat{H}_{hd} \tag{23}$$

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;

$$\hat{s}_h = \frac{\hat{H}_{hT}}{R_h} \tag{24}$$

and the variance by;

$$V(\hat{s}_h) = \frac{V(\hat{H}_{hT})}{R_h^{\,2}} \tag{25}$$

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.

Egg-to-Migrant Survival

Survival of naturally produced fry to lake entry is estimated by the ratio of wild fry migration to an estimate of potential egg deposition (PED). 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 2000 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 increased from 91 sockeye fry on the first night of trapping, January 20, to peak at 21,198 fry on February 10. A release of hatchery fry from the Riviera site contributed to this high catch. On our last night of trapping, April 26, we caught 3,386 fry. Over the 89 nights that we trapped, the season catch totaled 755,230 wild and hatchery sockeye fry (Appendix A). In addition, to assess migration during the day we trapped for a total of 21.4 hours over four days. During these daylight periods, we caught 728 fry.

Trap Efficiency and Flow

Marked fry were released on 43 nights between February 8 and April 26 to measure the capture efficiency of the fry trap. In all but two of the tests, approximately equal proportions of fry were released near the right and left banks and into the mid-channel. On two nights all marked fry were released only into the mid-channel. In previous years, within a night, releases were separated by an hour or more to assess the effect of release location on capture rate. Such tests were not conducted in 2000 because at the trap site below the Logan Street Bridge, the new concrete flood barrier precluded a single worker from transporting multiple five gallon buckets of fry over this eight foot high wall. In addition, results in previous years did not find a significant difference in efficiency rates between release locations. Therefore, we assumed that distribution and subsequent recovery of release groups were not biased by release location.

Capture rates from the 43 groups of marked fry released ranged from 3.88% to 10.74% (Table 2). On the nights that efficiency tests were conducted, the daily average flows ranged from 514 to 1,170 cfs. Over the entire trapping period, flows ranged slightly more, from 442 to 1,180 cfs. In 2000, unlike previous years, flow did not explain a significant portion of the variation in capture rates (Figure 2). We attribute this, at least partially to the channel configuration and resultant flow vectors at the location trapped in 2000.

Independent of flow, capture rates generally declined over the season. Monthly average rates dropped from 8% in February, to 6.6% in March to 4.8% in April. Using the non-parametric Mann-Whitney U-test, we found that these means were significantly different ($p < 0.05$). Since a review of previous season's capture rate data indicated that the 2000 results were unique, we reasoned that predation provided the only plausible explanation for the downward trend in capture rate. In previous seasons, we have observed a decline in in-river survival of hatchery fry released at Landsburg over time, which we attributed to an increase in predation on sockeye fry. In March and April, not only does predator abundance increase in the lower river, but so does their metabolism as water temperatures rise. Relating the mean recapture rates in March and April to the less biased rate in February estimates average predation rates in the 0.5 mile reach between Bronson Way and the trap below Logan Street at 18% and 40%, respectively.

Predation on marked fry was also indicated by the differential capture rates between tests conducted on nights with and without hatchery releases. Over the first half of the calibration data, February 8 through March 18, the capture rate for the 22 mark groups released averaged 7.7%. Within this average are the 13 groups released on nights with hatchery releases and 9 groups released on nights without hatchery releases. Respective capture rates averaged 8.2% and 7% (Table 2, Figure 3). These differences were not significant at the 5% level, but they were at the 8% level. This outcome corroborates the finding that predation in the reach between Bronson Way and Logan Street bridges reduced the number of marked sockeye fry reaching the trap. From these data, we conclude that predation rates on marked fry were reduced on nights when hatchery releases occurred as a result of the higher fry density.

To minimize the bias resulting from predation and thereby represent the average actual capture rate of the fry trap, we used the rate of 8.2% estimated with the 13 groups from the first half of the season on nights that hatchery fish were released.

Table 2. Results of trap efficiency tests conducted during nights with and without hatchery fry releases, Cedar River sockeye fry trap, 2000.

Date	Flow	Hatchery Release Location	Trap Efficiency	# Released	# Recaps	Variance
Hatchery Releases						
02/08	677	Riviera	6.03%	3,069	185	1.85E-05
02/09	693	Riviera	8.41%	3,078	259	2.50E-05
02/10	607	Riviera	9.11%	3,095	282	2.68E-05
02/17	514	Middle	10.11%	2,976	301	3.05E-05
02/18	584	Middle	8.73%	3,034	265	2.63E-05
02/22	635	Middle	7.06%	3,058	216	2.15E-05
02/23	639	Riviera	10.53%	3,115	328	3.02E-05
02/24	600	Riviera	5.82%	3,112	181	1.76E-05
02/28	626	Riviera	10.74%	3,026	325	3.17E-05
03/02	959	Middle	7.08%	3,049	216	2.16E-05
03/03	1,040	Middle	7.67%	3,049	234	2.32E-05
03/09	710	Middle	7.19%	3,075	221	2.17E-05
03/16	690	Middle	8.43%	3,097	261	2.49E-05
		Sample Average	8.23%			
		Var (mean)	4.44E-05			
		n	13			
Non-Hatchery Releases						
02/19	579		6.26%	3,068	192	1.91E-05
02/20	568		5.14%	3,072	158	1.59E-05
02/26	607		7.77%	3,089	240	2.32E-05
02/29	814		8.56%	3,119	267	2.51E-05
03/07	911		6.72%	3,080	207	2.04E-05
03/10	693		6.73%	3,106	209	2.02E-05
03/12	641		6.88%	3,054	210	2.10E-05
03/14	691		7.65%	3,057	234	2.31E-05
03/18	652		7.04%	3,053	215	2.14E-05
		Sample Average	6.97%			
		Var (mean)	3.16E-05			
		n	9			

Table 2. Results of trap efficiency tests conducted during nights with and without hatchery fry releases, Cedar River sockeye fry trap, 2000 (Contd.).

Date	Flow	Hatchery Release Location	Trap Efficiency	# Released	# Recaps	Variance
Non-Hatchery Releases						
03/20	643		4.62%	3,075	142	1.43E-05
03/22	674		6.16%	3,050	188	1.90E-05
03/24	774		4.35%	3,084	134	1.35E-05
03/26	699		6.82%	3,094	211	2.05E-05
03/28	681		7.69%	3,081	237	2.30E-05
03/30	641[a]		5.45%	3,268	178	1.58E-05
03/31	617		4.59%	2,786	128	1.57E-05
04/02	578		5.43%	3,096	168	1.66E-05
04/04	619		4.47%	3,107	139	1.38E-05
04/06	643		7.07%	3,112	220	2.11E-05
04/08	618		4.53%	3,111	141	1.39E-05
04/10	609		4.03%	3,151	127	1.23E-05
04/12	612		3.88%	3,091	120	1.21E-05
04/13	630		4.39%	3,101	136	1.35E-05
04/15	1,120		4.46%	3,096	138	1.38E-05
04/17	968		5.88%	2,856	168	1.94E-05
04/19	1,110		4.61%	3,079	142	1.43E-05
04/21	1,170		4.57%	3,083	141	1.42E-05
04/23	1,080		4.43%	3,023	134	1.40E-05
04/24	1,080		5.10%	2,295	117	2.11E-05
04/26	924		4.52%	3,076	139	1.40E-05
		Sample Average	5.10%			
		Var (mean)	2.3E-05			
		n	21			

[a] On this night, a small number (13,000) of sockeye fry were released at the Middle River site.

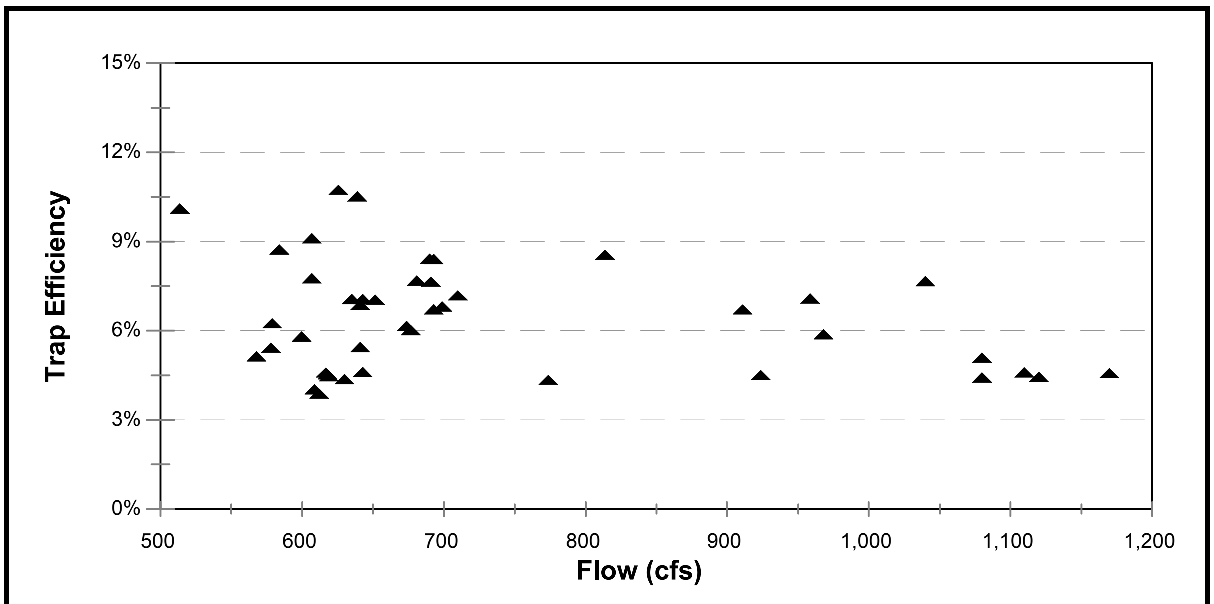

Figure 2. Average daily stream flow and trap efficiency with sockeye fry, Cedar River 2000.

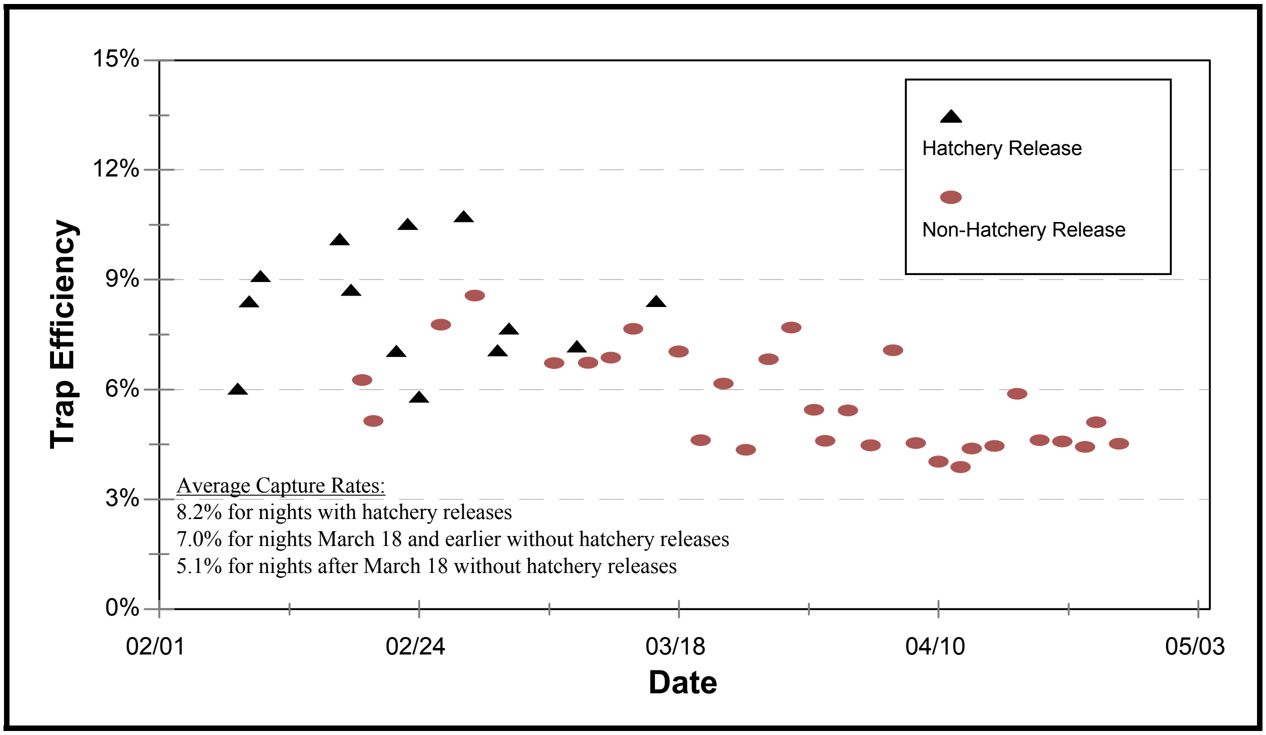

Figure 3. Comparison of trap efficiency tests using sockeye fry conducted during nights with and without hatchery releases, Cedar River 2000.

Otolith Sampling

Sockeye fry samples were taken for otolith analysis on every night that hatchery fry were released and on nights following releases. We selected three nights' samples from each release site for analysis. The incidence of hatchery fry from the nights of Riviera releases ranged from 74% to 92%. Incidence in the samples taken on the nights of the middle river releases ranged from 32% to 70% (Table 3). The sample taken on the night of February 23, when fry were released from the Riviera site, included one fry that was marked as a fry released from the middle river site. This recovery likely came from the group released the night before, February 22. While only one was recovered, it indicated that not all of the migration occurred within the release night. The samples from the other nights that fry were collected for otolith analysis are archived at the WDFW Otolith Lab.

Table 3. Sockeye fry otolith sampling results, Cedar River 2000.

Sample Date	Number Sampled	Number Marked	Percent Marked	Variance	Release Location
02/10/00	150	138	92.00%	0.0004940	Riviera
02/17/00	150	105	70.00%	0.0014094	Middle Site
02/23/00	150	111	74.00%	0.0012913	Riviera
		1	0.67%	0.0000444	Middle Site
	Total	112	74.67%	0.0012695	
02/25/00	150	124	82.67%	0.0009617	Riviera
03/09/00	150	48	32.00%	0.0014604	Middle Site
03/16/00	150	88	58.67%	0.0016274	Middle Site

Diel Migration

While the vast majority of sockeye fry migrate at night, catch data indicated a small proportion of the migration occurred during daylight. Over the four dates that we trapped during daylight intervals, the d:n catch ratios ranged from 3.9% to 5.9% (Table 4). We used the sample average of 4.7% to estimate the proportion of the total daily migration that occurred during daylight hours.

Table 4. Day:night catch ratios of sockeye fry catches, Cedar River scoop trap, 2000.

NIGHTTIME					DAYTIME						DAY:NIGHT	
Trap Down Date	Trap Down Time	Hours Fished	Catch	Catch/ Hour	Date	Time Down	Time Up	Hours Fished	Catch	Catch/ Hour	Ratio (D/N)	Flow (cfs)
03/04	17.00	14.00	6,542	467	03/05	8.00	16.00	8.00	174	22		
03/05	17.00	14.00	6,208	443								
		28.00	12,750	455							4.78%	1,040
03/22	17.00	14.00	14,103	1,007	03/23	15.50	18.00	2.50	90	36		
03/23	18.00	13.00	11,024	848								
		27.00	25,127	931							3.87%	697
04/02	18.00	12.75	18,245	1,431	04/03	14.58	19.00	4.42	254	57		
04/03	19.00	11.75	15,999	1,362								
		24.50	34,244	1,398							4.11%	573
04/15	19.00	11.50	6,916	601	04/16	11.50	18.00	6.50	210	32		
04/16	19.00	11.75	5,782	492								
		23.25	12,698	546							5.92%	1,080
Sample Avg.											4.67%	
Sample Var.											8.39E-05	
Season Totals		102.75	84,819	825				21.42	728	34		

Fry Production

We estimated 10 million sockeye fry entered Lake Washington from the Cedar River in 2000 (Table 5, Figure 4). Wild production was estimated at 8 million fry and the hatchery production contributed 2 million fry. All of the hatchery produced fry passed the trap during the trapping season but wild fry were migrating before we began trapping and continued after we stopped. Using logarithmic extrapolation, we estimated 13,000 and 522,000 wild sockeye fry migrated before and after the trapping interval. These estimates amount to 6.6% of the total wild migration.

Table 5. Estimated 2000 Cedar River wild and hatchery sockeye fry migrations entering Lake Washington with 95% confidence intervals.

Component	Period	Dates	Estimated Migration	$CI_{95\%}$ Low	$CI_{95\%}$ High	CV	Prop. of Total
Wild	Before Trapping	Jan. 1 - 19	12,916	4,927	20,905	31.56%	0.13%
	During Trapping	Jan. 20 - April 26	7,524,406	6,580,682	8,468,130	6.40%	74.77%
	After Trapping	April 27 - July 1	521,587	427,803	615,371	9.17%	5.18%
		Subtotal	**8,058,909**	**7,110,503**	**9,007,315**	**6.00%**	**80.08%**
Riviera	During Trapping	Jan. 20 - April 26	1,180,506	1,071,905	1,289,107	4.69%	11.73%
Middle	During Trapping	Jan. 20 - April 26	824,628	658,087	991,169	10.30%	8.19%
		Subtotal	**2,005,134**	**1,806,312**	**2,203,956**	**5.06%**	**19.92%**
		Total	**10,064,043**	**9,095,020**	**11,033,066**	**4.91%**	**100.00%**

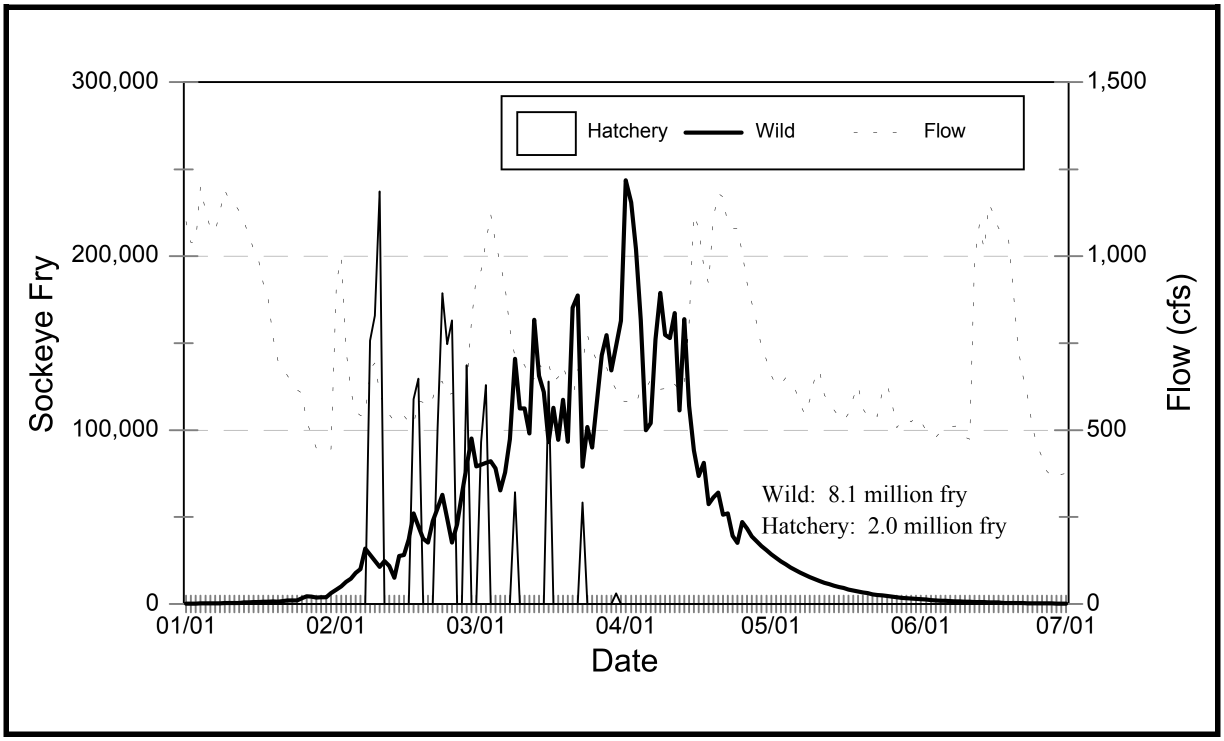

Figure 4. Estimated daily migration of wild and hatchery Cedar River sockeye fry into Lake Washington, 2000.

Survival of Hatchery Release Groups

In-river survival, from release to the trap, was estimated to average 77% and 48% for fry released at the Riviera and middle river sites (Table 6). Except for the one estimate that exceeded 100%, the survival estimates for the other six Riviera releases showed relatively low variation ranging from 64% to 86%. A survival estimate in excess of 100% is of course impossible and indicates error in either the migration estimate, the number released or both. Somewhat higher variation was observed in the survival estimates for eight of the nine releases from the middle river site. Excluding the release on March 23, survival estimates ranged from 31% to 59%. We elected to represent survival for the March 23 release with the average rate (47.8%) estimated from the eight other groups because on this night interpolation estimated only 662 hatchery fry, a survival rate of just 0.5%. This average rate, however, likely overestimates hatchery survival since subtracting the resultant hatchery migration estimate from the total migration results in a wild estimate that is less than half that of the previous night.

While a number of factors can combine to produce error in a single night's survival estimate, we believe the average rates represent the level of in-river survival experienced by the hatchery fry released at these two sites in 2000. To assess potential bias in our two estimation methods, we compared results for the six nights that hatchery incidence was estimated via otolith sampling/analysis and interpolation (Table 7). Results averaged over the six nights sampled indicate that both methods produced nearly identical estimates.

Table 6. In-river survival estimates of hatchery sockeye fry, Cedar River 2000.

Release Date	Sockeye Released	Estimation Method	Est. Migration at Trap	Percent Survival	95% CI +/-	CV
Riviera						
02/08	227,000	Interpolation	151,388	66.69%	15.59%	11.93%
02/09	224,000	Interpolation	165,707	73.98%	19.99%	13.78%
02/10	222,000	Otolith	237,107	106.80%	17.71%	8.46%
02/23	232,000	Otolith	176,870	76.24%	14.13%	9.46%
02/24	234,000	Interpolation	149,320	63.81%	22.84%	18.26%
02/25	190,000	Otolith	162,960	85.77%	15.02%	8.94%
02/28	197,000	Interpolation	137,154	69.62%	24.06%	17.63%
Total	1,526,000		1,180,506	77.36%	7.12%	4.69%
Middle						
02/17	247,000	Otolith	117,659	47.64%	9.08%	9.73%
02/18	245,000	Interpolation	129,461	52.84%	14.84%	14.32%
02/22	244,000	[a]	102,303	41.93%	16.17%	19.68%
03/02	205,000	Interpolation	93,001	45.37%	14.51%	16.31%
03/03	219,000	Interpolation	125,770	57.43%	15.87%	14.10%
03/09	206,000	Otolith	64,206	31.17%	8.84%	14.47%
03/16	217,000	Otolith	127,860	58.92%	12.29%	10.64%
03/23	122,000	[b]	58,277	47.77%	114.39%	122.18%
03/30	13,000	Interpolation	6,091	46.85%	321.13%	349.68%
Total	1,718,000		824,628	48.00%	9.69%	10.30%

[a] This estimate includes 100,709 fry estimated by interpolation on 2/22, plus 1,594 fry on 2/23 based on the recovery of one Middle River mark within an otolith sample.
[b] Hatchery migration was estimated by applying the sample average percent survival to the release group.

Table 7. Comparison of two methods used to estimate hatchery sockeye fry survival rates by release site and date, Cedar River 2000.

Release Date	Sockeye Released	Otolith		Interpolation	
		Est. Migration	% Survival	Est. Migration	% Survival
Riviera					
02/10	222,000	237,107	106.80%	232,203	104.60%
02/23	232,000	176,870	76.24%	193,668	83.48%
02/25	190,000	162,960	85.77%	152,551	80.29%
Average			89.60%		89.45%
Middle River					
02/17	247,000	117,659	47.64%	131,951	53.42%
03/09	206,000	64,206	31.17%	100,522	48.80%
03/16	217,000	127,860	58.92%	104,504	48.16%
Average			45.91%		50.13%

Wild and Hatchery Migration Timing

Hatchery-produced fry, released on 16 nights from February 8 through March 30 (Table 1) had a median migration date of February 23. The wild fry migration was just underway when we began trapping on January 20, peaked in early April, and was declining when trapping ended on April 26 (Figure 4). We estimated that the median date for the wild migration occurred on March 27, 32 days after that of the hatchery fry (Figure 5). Relative to the average median wild and hatchery migration dates estimated over the eight previous brood years, timing for the 1999 brood was just slightly earlier, 2 and 10 days, respectively (Table 8).

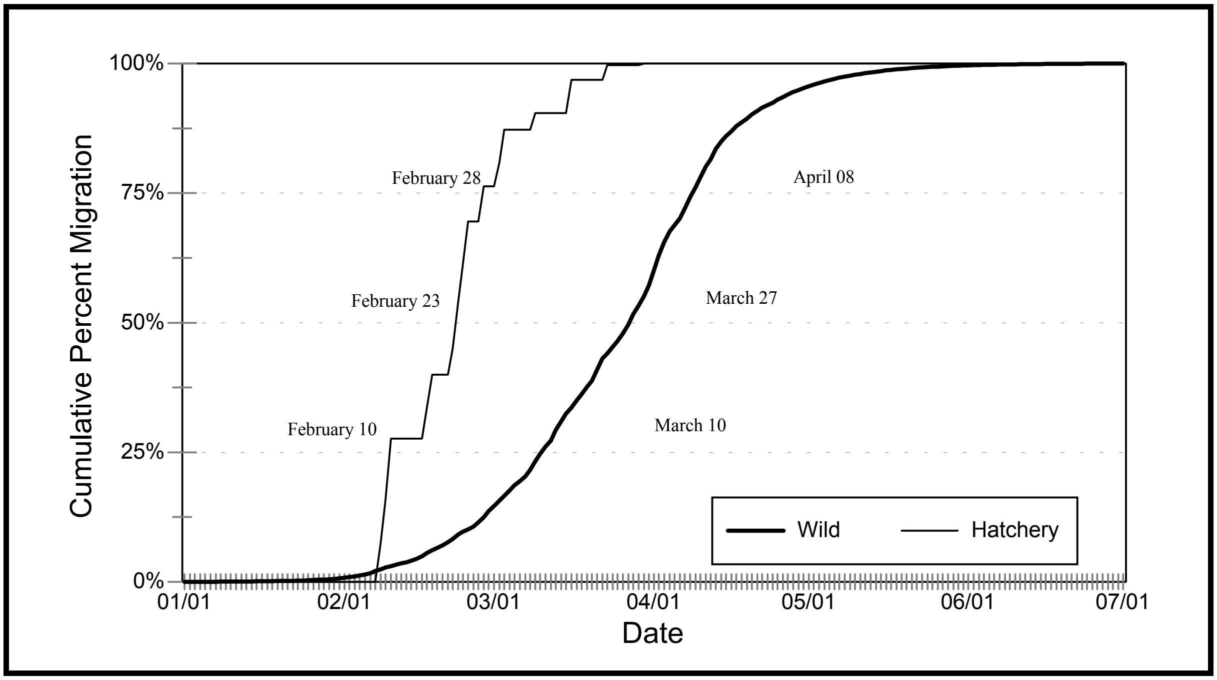

Figure 5. Cumulative wild and hatchery sockeye fry migration timing, Cedar River 2000.

Table 8. Median migration dates of wild, hatchery, and total (combined) sockeye fry in the Cedar River by year.

Brood Year i	Trap Year i+1	Median Date Wild	Hatchery	Combined	Difference (days) W-H
1991	1992	03/18	02/28	03/12	19
1992	1993	03/27	03/07	03/25	20
1993	1994	03/29	03/21	03/26	8
1994	1995	04/05	03/17	03/29	19
1995	1996	04/07	02/26	02/28	41
1996	1997	04/07	02/20	03/16	46
1997	1998	03/11	02/23	03/06	16
1998	1999	03/30	03/03	03/15	27
1999	2000	03/27	02/23	03/20	32
Average (1991-1998)		03/29	03/04	03/16	25
Average (over all years)		03/29	03/03	03/17	25

Over six previous broods (1993-1998) most of the inter-annual variation in median dates for the wild sockeye fry migration have been explained by the sum of daily average stream temperature in the Cedar River during February ($R^2 = 0.84$). For February 2000, however, average daily temperatures from the USGS Cedar River at Renton Station were not available. To estimate the February temperature units in this year, we investigated relationships between the Cedar River at Renton temperatures with those from other USGS temperature recording stations. We found a strong positive correlation between February temperature units in the Cedar River at Renton with those from the North Fork Tolt River ($R^2 = 0.968$). The Tolt River is located about 15-miles northeast of the Cedar River and, although colder, is affected by the same localized climatic conditions. This relationship predicted 161.4 temperature units for the Cedar River in February 2000. Addition of the 1999 brood data, along with that from the 1992 brood, resulted in a somewhat lower correlation coefficient but little change to the relationship (Figure 6).

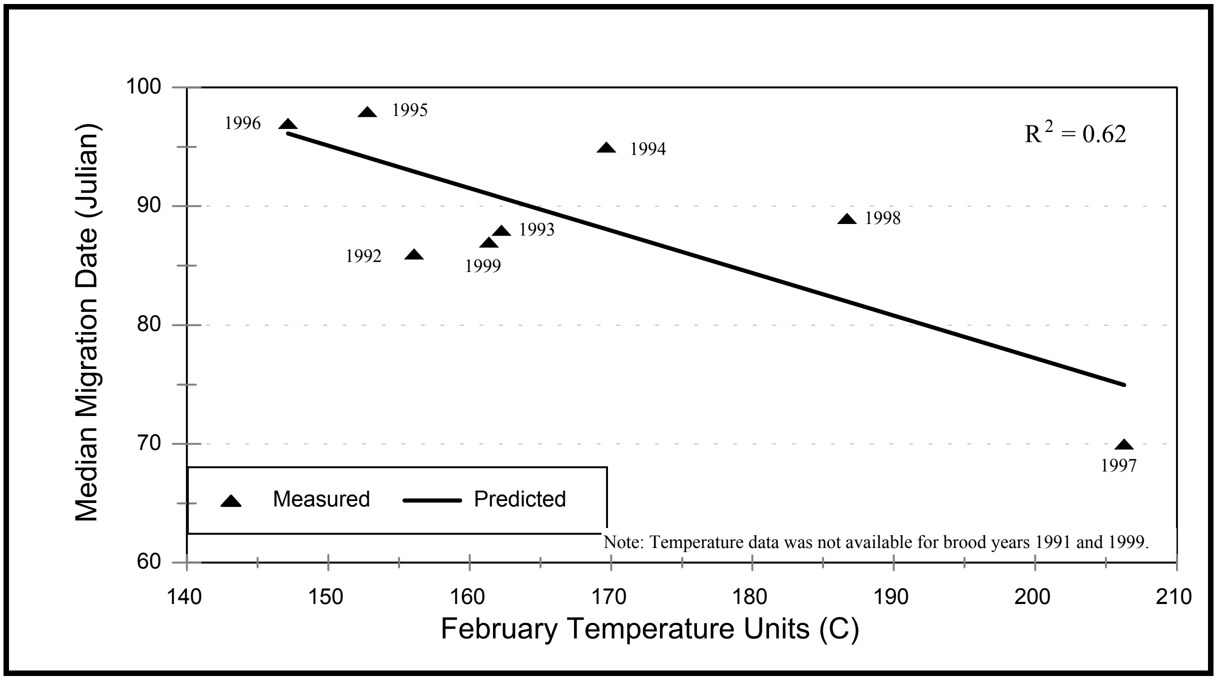

Figure 6. Linear regression of median migration Julian calender date for wild Cedar River sockeye fry as a function of the sum of February 1-28 daily average stream temperatures as measured at the USGS Renton Gaging Station, #12119000 for brood years 1992 to 1999.

Egg-to-Migrant Survival of Naturally-Produced Fry

Overall survival of the 1999 brood sockeye fry to lake entry was estimated at 9.5%. This rate is the ratio of 8.1 million fry to an estimate of 85 million eggs potentially deposited. This PED is based on a spawning escapement estimate of 47,395, an assumed even sex ratio and an average fecundity of 3,591 (Table 9). Of these three values, the estimate of fecundity may be most accurate since it is the average number of eggs per female estimated over the spawning season (Brodie Antipa pers. comm.). For the purpose of this analysis, we computed Cedar River spawners for the 1991 through 1999 broods by subtracting from the estimated sockeye run passing the Ballard Locks the following estimates:

- sockeye harvested in recreational and tribal fisheries,
- sockeye estimated spawning on beaches and in all other tributaries (Steve Foley pers. com.),
- pre-spawning mortality at the rate of 5%, and
- sockeye removed from the Cedar River for brood stock.

This analysis was undertaken because the standard spawner estimation procedure yielded an estimate of just 22,000 sockeye spawning in the Cedar River in 1999. Assuming half were females, and applying the fecundity estimate of 3,591, estimates 39.5 million eggs were potentially deposited. Relating the 8.1 million fry produced from this brood yields an egg to migrant survival rate of over 20%. Not only is this survival rate higher than we have measured in any other year, given the mid-range peak incubation flow on December18 of 2,680 cfs, it is over twice the rate predicted by the flow relationship derived over the previous eight brood years.

Table 9. 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 1991-1999.

Brood Year	Spawners	Females (@50%)	Fecundity	PED	Fry Production	Survival Rate	Peak Incubation Flow (cfs)	Date
1991	75,196	37,598	3,282	123,396,636	9,800,000	7.94%	2,060	01/28/1992
1992	184,854	92,427	3,470	320,721,690	27,100,000	8.45%	1,570	01/26/1993
1993	100,684	50,342	3,094	155,758,148	18,100,000	11.62%	927	01/14/1994
1994	123,663	61,832	3,176	196,376,844	8,700,000	4.43%	2,730	12/27/1994
1995	26,627	13,314	3,466	46,144,591	730,000	1.58%	7,310	11/30/1995
1996	308,014	154,007	3,298	507,915,086	24,390,000	4.80%	2,830	01/02/1997
1997	118,883	59,442	3,292	195,681,418	25,350,000	12.95%	1,790	01/23/1998
1998	79,174	39,587	3,176	125,728,312	9,500,000	7.56%	2,720	01/01/1999
1999	47,395	23,698	3,591	85,097,723	8,058,909	9.47%	2,680	12/18/1999

Incorporating the higher escapement estimates resulting from the "subtraction" methodology proportionally increases estimates of PED. Consequently, estimates of survival from egg deposition to fry entering Lake Washington are reduced relative to the former estimates reported in Seiler *et al.* (2001). The largest change, nearly a doubling of escapement estimates occurred in two brood years (1992 and 1998), which reduced survival to fry migration by nearly 50%.

Regressing these new survival estimates on peak brood year incubation flow resulted in virtually no change in the correlation coefficient (84% vs. 83%), even with the addition of the 1999 brood (Figure 7). The best fit for this data series was derived from fitting the data to the first exponential equation ($y = ba^x$). This function generally describes an exponential decay in egg-to-migrant survival with increasing peak stream flow during the incubation period. As additional data are generated, we will continue to assess this model and others, to increase our understanding of the factors affecting natural sockeye fry production from the Cedar River.

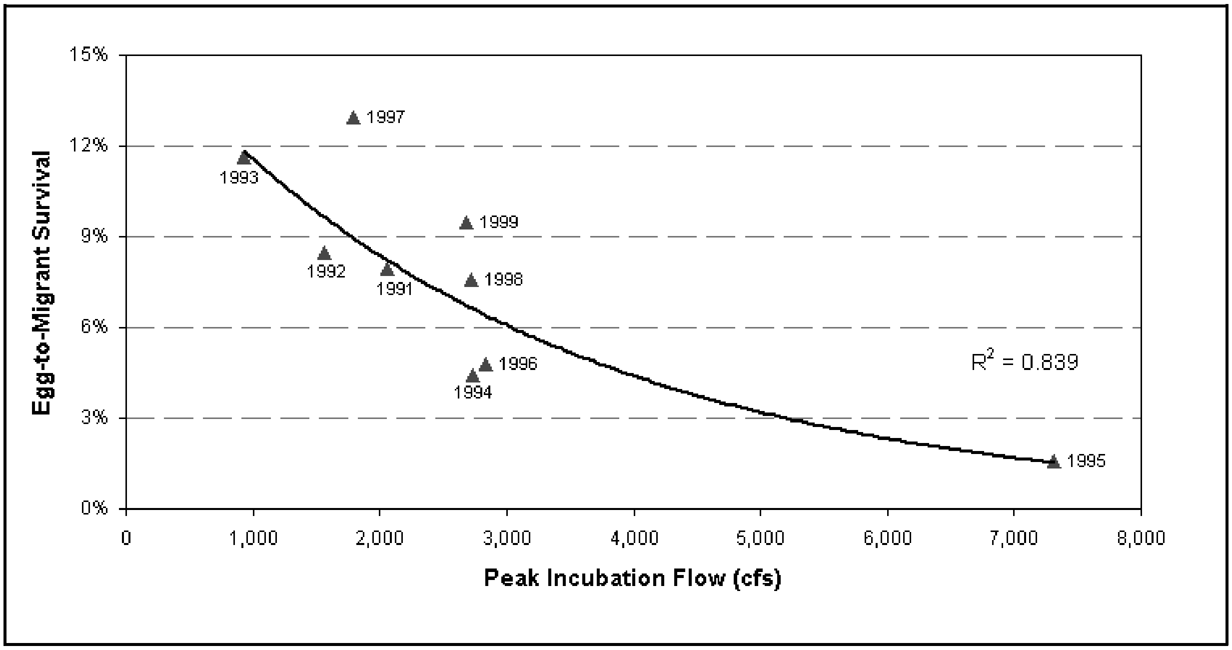

Figure 7. Exponential regression of wild sockeye egg-to-migrant survival from brood years 1991 to 1999 as a function of peak flow during the winter egg incubation period, Cedar River.

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Personal Communications

Steve Foley, Fish and Wildlife Biologist. Washington Department of Fish and Wildlife, Mill Creek. Electronic mail on April 15, 2002.

Brodie Antipa, Complex Manager - Rainier Complex. Washington Department of Fish and Wildlife, Puyallup. Electronic mail on December 14, 2001.

Appendix A

Estimated Cedar River Wild and Hatchery Sockeye Fry Migration into Lake Washington, 2000

Appendix A. Estimated Cedar River wild and hatchery sockeye fry migration into Lake Washington, 2000.

Date	Catch	Flow (cfs)	Hatchery Releases		Nightly Migration at Trap			Daily Migration into Lake Washington	
			Riviera	Middle	Total	Wild	Hatchery	Wild	Hatchery
01/20	91	700			1,106	1,106	0	1,140	0
01/21		681			1,520	1,520	0	1,606	0
01/22	159	656			1,933	1,933	0	1,992	0
01/23		636			1,945	1,945	0	2,059	0
01/24	161	616			1,957	1,957	0	2,022	0
01/25		606			3,131	3,131	0	3,317	0
01/26	354	524			4,304	4,304	0	4,448	0
01/27		486			3,970	3,970	0	4,206	0
01/28	299	448			3,635	3,635	0	3,756	0
01/29		452			3,690	3,690	0	3,935	0
01/30	308	442			3,745	3,745	0	3,920	0
01/31		445			5,763	5,763	0	6,158	0
02/01		926			7,781	7,781	0	8,279	0
02/02	806	996			9,799	9,799	0	10,126	0
02/03		730			11,878	11,878	0	12,604	0
02/04	1,148	611			13,957	13,957	0	14,464	0
02/05		552			16,699	16,699	0	17,744	0
02/06	1,599	542			19,441	19,441	0	20,147	0
02/07	2,541	542			30,893	30,893	0	31,923	0
02/08	14,711	677	227,000		178,856	27,468	151,388	28,384	151,388
02/09	15,607	693	224,000		189,750	24,043	165,707	24,845	165,707
02/10 [a]	21,198	607	222,000		257,725	20,618	237,107	21,249	237,107
02/11	1,952	560			23,732	23,732	0	24,523	0
02/12	1,750	544			21,276	21,276	0	21,985	0
02/13	1,204	525			14,638	14,638	0	15,192	0
02/14	2,185	536			26,565	26,565	0	27,451	0
02/15	2,242	541			27,258	27,258	0	28,167	0
02/16	2,970	523			36,109	36,109	0	37,313	0
02/17 [a]	13,825	514		247,000	168,084	50,425	117,659	52,106	117,659
02/18	14,210	584		245,000	172,765	43,304	129,461	44,748	129,461
02/19	2,976	579			36,182	36,182	0	37,388	0
02/20	2,822	568			34,310	34,310	0	35,454	0
02/21	3,793	592			46,115	46,115	0	47,653	0
02/22	12,670	635		244,000	154,042	53,333	100,709	55,111	100,709
02/23 [a]	19,659	639	232,000		239,014	60,550	178,464	62,719	178,464
02/24	16,177	600	234,000		196,680	47,360	149,320	48,961	149,320
02/25 [a]	16,214	605	190,000		197,129	34,169	162,960	35,342	162,960
02/26	3,635	607			44,194	44,194	0	45,688	0
02/27	5,025	624			61,094	61,094	0	63,131	0
02/28	17,591	626	197,000		213,871	76,717	137,154	79,502	137,154
02/29	7,595	814			92,340	92,340	0	95,164	0
03/01	6,282	941			76,376	76,376	0	79,034	0
03/02	14,018	959		205,000	170,431	77,430	93,001	80,012	93,001
03/03	16,800	1,040		219,000	204,254	78,484	125,770	81,101	125,770
03/04	6,542	1,120			79,538	79,538	0	82,190	0
03/05	6,208	1,040			75,477	75,477	0	77,994	0
03/06	5,194	979			63,149	63,149	0	65,284	0
03/07	5,997	911			72,911	72,911	0	75,448	0
03/08	7,545	790			91,732	91,732	0	94,791	0
03/09 [a]	16,503	710		206,000	200,643	136,437	64,206	140,986	64,206
03/10	8,925	693			108,510	108,510	0	112,286	0

Appendix A. Estimated Cedar River wild and hatchery sockeye fry migration into Lake Washington, 2000.

Date	Catch	Flow (cfs)	Hatchery Releases		Nightly Migration at Trap			Daily Migration into Lake Washington	
			Riviera	Middle	Total	Wild	Hatchery	Wild	Hatchery
03/11	8,921	687			108,461	108,461	0	112,399	0
03/12	7,802	641			94,857	94,857	0	98,158	0
03/13	12,972	648			157,713	157,713	0	163,439	0
03/14	10,409	691			126,552	126,552	0	131,147	0
03/15	9,708	669			118,030	118,030	0	121,852	0
03/16 [a]	17,926	690		217,000	217,944	90,084	127,860	93,088	127,860
03/17	8,953	639			108,850	108,850	0	112,802	0
03/18	7,484	652			90,990	90,990	0	94,339	0
03/19	9,316	684			113,264	113,264	0	117,376	0
03/20	7,424	643			90,261	90,261	0	93,271	0
03/21	13,556	589			164,814	164,814	0	170,309	0
03/22	14,103	674			171,464	171,464	0	177,260	0
03/23 [b]	11,024	697		122,000	134,030	75,753	58,277	78,745	58,277
03/24	8,054	774			97,920	97,920	0	101,788	0
03/25	7,127	728			86,650	86,650	0	90,073	0
03/26	9,237	699			112,303	112,303	0	116,499	0
03/27	11,337	682			137,835	137,835	0	142,985	0
03/28	12,249	681			148,923	148,923	0	154,563	0
03/29	10,629	641			129,227	129,227	0	134,331	0
03/30	12,216	617		13,000	148,522	142,431	6,091	148,548	6,091
03/31	12,801	584			155,634	155,634	0	162,899	0
04/01	19,294	582			234,576	234,576	0	243,460	0
04/02	18,245	578			221,822	221,822	0	230,958	0
04/03	15,999	573			194,516	194,516	0	203,982	0
04/04	12,823	619			155,902	155,902	0	163,179	0
04/05	7,901	620			96,060	96,060	0	99,854	0
04/06	8,164	643			99,258	99,258	0	103,891	0
04/07	11,947	639			145,251	145,251	0	152,031	0
04/08	14,045	618			170,759	170,759	0	178,730	0
04/09	12,158	619			147,817	147,817	0	154,717	0
04/10	12,008	609			145,993	145,993	0	152,808	0
04/11	13,138	632			159,732	159,732	0	167,188	0
04/12	8,739	612			106,249	106,249	0	111,209	0
04/13	12,868	630			156,449	156,449	0	163,752	0
04/14	8,926	808			108,522	108,522	0	113,803	0
04/15	6,916	1,120			84,085	84,085	0	88,351	0
04/16	5,782	1,080			70,297	70,297	0	73,718	0
04/17	6,340	968			77,082	77,082	0	81,160	0
04/18	4,475	921			54,407	54,407	0	57,285	0
04/19	4,801	1,110			58,370	58,370	0	61,332	0
04/20	4,997	1,180			60,753	60,753	0	63,836	0
04/21	4,009	1,170			48,741	48,741	0	51,214	0
04/22	4,077	1,090			49,568	49,568	0	52,083	0
04/23	3,039	1,080			36,948	36,948	0	39,165	0
04/24	2,725	1,080			33,130	33,130	0	35,118	0
04/25	3,689	1,010			44,851	44,851	0	47,127	0
04/26	3,386	924			41,167	41,167	0	43,536	0
Total	755,230		1,526,000	1,718,000	9,238,446	7,233,312	2,005,134	7,524,406	2,005,134

a Hatchery migration was estimated from otolith samples.
b Hatchery migration was estimated using the average survival rate from otolith samples.