Annual Report

1998 Sammamish River Sockeye Salmon Fry Production Evaluation

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Table of Contents

List of Tables

List of Figures

Acknowledgments

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The success of this project relies on the hard work of a number of dedicated permanent and temporary WDFW personnel. WDFW Fish Biologist Steve Wolthausen, and Scientific Technician Chuck Ridley 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.

Executive Summary

As part of the Lake Washington Studies, a multi-agency effort to investigate the recent decline in sockeye salmon abundance within this system, we began assessing fry production in the Cedar River in 1992. Because in some years as much as one third of adult sockeye spawning has occurred in Sammamish Basin tributaries, we also initiated fry monitoring in the Sammamish River in 1997. In this first year of the Sammamish study, we estimated that 953,000 sockeye fry were produced from the 60,000 adults that spawned in the fall of 1996. We attributed the very low egg-to-fry survival rate of just 1% to the record high flows (2,830 cfs) produced by a severe rain-on-snow event in early January 1997, which immediately followed a large ice storm. This report documents results from 1998, the second year that we evaluated production of sockeye salmon fry from the Sammamish Basin.

As in the previous year, we placed a barge that contained two inclined plane screen traps in the Sammamish River near Bothell (R.M. 4.0). From January 31 to April 25 1998, we operated the traps on 61 nights. Early and late in the season, when the migration was low, we trapped every other night. On 33 nights, we estimated capture rate via releasing groups of dye-marked fry upstream of the trap. Over the season, trap efficiency averaged 10.6 % and, as in 1997, was negatively correlated with flow. Expanding catches with the season average capture rate, and interpolating for the nights not fished, produced a season total estimate of 1,243,000 sockeye fry.

Relating this migration to the estimated deposition of 12 million eggs during fall 1997 yields an egg-to-fry survival rate of 10%. We attribute this rate, which is 10 times higher than we estimated for the previous brood, to the more moderate flows during incubation. While other previous years have had much lower peak flows, the peak flow of 1,060 cfs on January 24, 1998 was less than half of the record high flow registered on January 2, 1997 of 2,830 cfs in the Sammamish River at Bothell. Therefore, although we have measured production from just two broods in this system, given the extreme range in flows and the tenfold difference in survival rate, it appears that egg-to-migrant fry survival of sockeye in the Sammamish system follows a similar negative relationship with flow as we have developed in the Cedar River.

1998 Sammamish River Sockeye Salmon Fry Production Evaluation

Introduction

The numbers of adult sockeye salmon returning to the Lake Washington system are estimated as they pass the Ballard Locks and as spawners in the Cedar River, primary tributaries to the Sammamish system, and on certain beaches. The majority of the spawning has occurred in the Cedar River, but in three recent years (1992, 1994, and 1996), biologists have estimated that a quarter to a third of the Lake Washington Basin sockeye have spawned in the Sammamish River Basin (Egan and Ames 1997). Over the other twelve of the last fifteen years for which escapement estimates are available for all areas, the Cedar River accounted for an average of 88% of the total spawners (range = 82% to 98%). This interannual variation may have resulted from differential survival as a function of spawning and emergence timing relative to stream specific hydrology. In addition to run timing differences, recent electrophoretic analysis indicates that the sockeye which spawn in the Sammamish system are genetically distinct from the larger Cedar River population (Shaklee *et al.* 1996).

In 1992, as part of a multi-agency effort to determine the cause(s) of the decline in the Lake Washington sockeye run, we began enumerating sockeye fry production from the Cedar River. Measuring the population at this lifestage and location separates freshwater survival into its two major components; spawning/incubation, which takes place in the river, and rearing which occurs in the lake. Over the past seven broods, natural spawners in the Cedar River have produced fry populations to the lake of 0.7 to 38.3 million. We have determined that the severity of peak flows is the primary factor controlling survival from spawning to fry emigration in this system (Seiler *et al.* 2000). Annual estimates of the numbers of fry entering the lake are also needed to understand the complex ecological relationships which regulate juvenile sockeye survival during their year in the lake. Because the Sammamish system may account for a significant portion of the fry entering Lake Washington in some years, an estimate of this production component is also needed to understand the dynamics of the combined population.

We began enumerating sockeye fry production from the Sammamish system in 1997, in an initial effort to estimate the number of sockeye fry migrating from the Sammamish River into Lake Washington, define the migration timing of the fry migration, and determine where juveniles produced from spawners in this system rear (i.e., Lake Sammamish or Lake Washington). We estimated 953,000 sockeye fry migrated down the Sammamish River at Bothell in 1997 (Seiler and Kishimoto 1997b). Migration timing was from mid-January through mid-May, peaking at over 70,000 fry on March 21. Survival from potential egg deposition to lake entry was estimated at only 1% in 1997. We attributed the low survival rate to the effect of the highest single day flow (2,830 cfs) ever recorded in the Sammamish system. This flow was caused by a severe rain-on-snow event in early January which immediately followed a large ice storm.

In 1998, we continued the work started in 1997, enabling initial evaluation of interannual variation in sockeye fry production in the Sammamish system. Our work in 1998 focused on the following goals and objectives:

Goals and Objectives

1. Estimate the number of sockeye fry migrating from the Sammamish River into Lake Washington.
2. Define the migration timing of this fry migration.
3. Determine whether juveniles produced from spawners in this system rear in Lake Sammamish or Lake Washington.

Methods

While the spawning areas are well known in the Sammamish River system, it was not known where the fry produced from the spawners using these tributaries rear; Lake Sammamish, Lake Washington, or a combination of both. Selection of the trapping location was a critical decision for determining where the fry produced within the Sammamish system rear. When this study began in 1997, we initially planned to measure fry production within Big Bear Creek, the tributary in which the majority of spawning occurs. Enumerating fry production from this tributary, which also is closest to Lake Sammamish, however, would provide no insight into the rearing areas used by these juveniles because once they leave Big Bear Creek and enter the Sammamish River, we would not know whether they migrated upstream into Lake Sammamish or downstream into Lake Washington. To estimate the migration into Lake Washington from all the tributaries, we elected to locate the trap as low in the Sammamish River as possible.

Our approach to estimating sockeye fry migration from the Sammamish River in 1998 incorporated the same trapping system that we used in 1997, which closely resembled the trapping operation we developed and have successfully used in the Cedar River each year since 1992 (Seiler and Kishimoto 1997a). This operation involves trapping throughout the sockeye fry migration and calibrating the efficiency of this gear over the range of flows experienced. The initial challenge in trapping sockeye fry in the slow-moving Sammamish River was selecting a trapping location with sufficient velocity and access. Estimating the total number of sockeye fry entering Lake Washington from the Sammamish River required locating the trap downstream of all the tributaries. Velocities downstream of Swamp Creek, the lowermost tributary, however, were too slow. The location that was lowest in the Sammamish River with marginally-adequate velocity was found near the left bank, just below the foot bridge at the Bothell Station Condominiums (R.M. 4.0) (Figure 1). Velocity at this point increased somewhat due to the curve of the river bank and the slight channel constriction.

Trapping Gear and Operation

The trap barge consisted of two 30 ft x 3 ft x 2.5 ft steel pontoons outfitted with 15 ft wide decks fore and aft, two five ton anchor winches, two "horseshoe" davits with lifting winches, safety railings, and an 8 ft x 8 ft house on the aft deck. Two inclined-plane screen traps (port and starboard) were placed in the opening between the pontoons to double the fishing power. Each trap measured 3 ft wide by 2 ft deep at the entrance, and the inclined ramp was 9 ft long. Captured fish were retained in a livebox located at the end of each inclined screen. All surfaces of the trap and livebox were covered with perforated plate aluminum (thirty-three ⅛ inch holes per square inch).

To minimize the deceleration of flow through these traps, we fished them at a depth of 16 inches rather than the maximum depth of 24 inches. At this depth the incline angle was reduced and more screen surface was presented relative to the flow volume entering the trap. Each trap fished a cross-sectional area of 4 square feet. Velocity at this location was dependent on discharge. Flows varied nearly three-fold over the period trapped, from 200 cfs on April 22 to 559 cfs on January 31.

Trapping began on the night of January 31, and continued every other night until February 16, when we began trapping continuously. We trapped each night through March 26, after which we resumed trapping alternate nights through April 25, our last night. Trapping commenced each night at dusk and continued through dawn. Hourly, throughout each night, captured fish were removed, identified, and enumerated by trap. Daytime trapping was not conducted during the 1998 season.

Trap Calibration

Trap efficiency was estimated throughout the season via releasing groups of marked sockeye fry upstream of the traps. The proportion of these marked fry that were subsequently captured in the fry traps resulted in an efficiency estimate for each night of the releases. Fry retained from the previous night were dyed in a solution (0.014 g/l) of Bismark Brown dye for 1½ hours. Marked fry were released at various times during the middle of the night but generally around midnight. We released 14 of the mark groups 300 yards upstream from the trap off the left bank, and 18 of the mark groups off the right bank. In general, we alternated between left bank and right bank releases during the 32 bank release nights from February 21 through March 26. In addition, we conducted one release off the bridge over the mouth of North Creek on February 23. In total, we released 44,548 marked fry in 33 groups over as many nights from February 21 through March 26.

Operating two traps side by side over identical time intervals provides the opportunity to assess the assumption basic to producing unbiased mark and recapture estimates: that marked individuals represent unmarked individuals. For estimating sockeye fry production, fulfilling this assumption required achieving the same spatial distribution in the stream channel with the marked fry as that of the unmarked population. We compared mark:unmark ratios (m/u) between traps to determine if marked fish were distributed differently than unmarked to assess the effect that release location had on fry distribution.

Fry Estimation

Estimation of total sockeye fry migration occurred in several steps. Data collected each night, i, consisted of the following:

> c_i = Count of total fry captured in the traps
>
> f_i = Flow in cubic feet per second (cfs)

Nighttime data collected less frequently included:

> e_i = Trap efficiency, which is the proportion of marked sockeye fry released above the fry traps and subsequently recaptured in the traps

Regression analysis was used to estimate the relationship between flow (f_i) and trap efficiency (e_i) as follows:

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

The variance of the predicted efficiency on any day d was:

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

where,

$$\begin{aligned} MSE &= \textit{the mean square error for the regression},\\ n &= \textit{the number of observations in the regression},\\ s_f^2 &= \textit{the sample variance of the observed flows, and}\\ \bar{f} &= \textit{the mean of observed flows in } 1998. \end{aligned}$$

However, if regression analysis indicated that the flow relationship was not significant, mean trap efficiency over all tests was used:

$$\bar{e} = \frac{\sum_{i=1}^{n} \hat{e}_i}{n} \tag{4}$$

The variance of individually-tested efficiency values, e_i, was calculated using the following equation:

$$Var(\hat{e}_i) = \frac{\hat{e}_i\,(1-\hat{e}_i)}{(n - 1)} \tag{5}$$

where,

n = the total number of fish released in efficiency test e_i

The variance of the mean efficiency over all tests was:

$$Var(\bar{e}) = \frac{\sum (\hat{e}_i - \bar{e})^2}{n(n-1)} + \frac{\sum Var(\hat{e}_i)}{n} \tag{6}$$

where,

n = the total number of efficiency tests conducted during the season

Total nightly outmigration, M_i, was estimated using the nightly catch divided by the estimated nightly trap efficiency. The regression-based (predicted) efficiency was used to calculate the migration estimate if regression analysis of trap efficiency as a function of flow revealed a significant relationship ($p<0.05$). However, if the flow relationship was not significant, the mean trap efficiency (Equation 4 above) over all tests was inserted in place of the predicted trap efficiency in the following equation:

$$\hat{M}_i = \frac{c_i}{\hat{e}_i} \tag{7}$$

The variance of the nightly outmigration estimate was calculated as:

$$Var(\hat{M}_i) = \hat{M}_i^2 \frac{Var(\hat{e}_i)}{\hat{e}_i^2} \qquad \textbf{(8)}$$

Nightly estimates were expanded to represent total daily migration by dividing the nighttime estimates by the proportion of the 24-hour catch caught at night, as determined from daytime trap operation. Nightly estimates were adjusted for daytime migration using the following equation:

$$M_d = \frac{M_i}{R_i} \qquad \textbf{(9)}$$

where,

M_d = estimate of total migration on day *d*,

M_i = estimate of nighttime migration on night *i*, and

R_i = estimated proportion of the catch on day *d* captured on night *i*

The variance equation for each of these 24-hour migration estimates on day *d* was:

$$Var(\hat{M}_d) = \frac{Var(\hat{M}_i)}{R_i^2} \qquad \textbf{(10)}$$

where,

$$Var(\hat{M}_d) = \text{the variance of the migration estimate on day } d$$
$$Var(\hat{M}_i) = \text{the variance of the migration estimate on night } i$$
$$R_i = \text{the estimated proportion of the catch on day } d \text{ captured on night } i$$

The total outmigration, M_T, during the trapping period was the sum of the daily outmigration estimates, and the variance of the total migration estimate was the sum of the daily variances:

$$M_T = \sum_{d=1}^{n} M_d \tag{11}$$

$$Var(M_T) = \sum_{d=1}^{n} Var(M_d) \tag{12}$$

The confidence interval, $CI_{(95\%)}$, of the migration estimate was**:**

$$CI = \pm\ t_{.05[n-2]}\ x\ SD \tag{13}$$

where,

SD = estimate of the parametric standard deviation of n efficiency tests.

$t_{.05[n-2]}$ *= the t-statistic for n-2 degrees of freedom at a 95% confidence level*

Additional steps used to estimate the total number of sockeye migrating from the Sammamish River in 1998 included the following assumptions:

1. The migration began on January 15 and was over on May 15, and straight-line extrapolation from the levels estimated when trapping began and ended on January 31 and April 25, respectively, represents the migration before and after trapping. Total migration before trapping (January 15-30) was estimated as follows:

$$\hat{M}_{before} = \left(\frac{\sum_{d=1}^{2} \hat{M}_d}{2} \right) \times \frac{t}{2} \tag{14}$$

The variance of this equation was calculated using:

$$CV(\bar{M}) = \frac{\sqrt{\left(\frac{\sum_{d=1}^{2}(\hat{M}_d - \bar{M})^2}{2} + \frac{\sum_{d=1}^{2} Var(\hat{M}_d)}{2}\right)}}{\bar{M}} \qquad \textbf{(15)}$$

$$Var(\hat{M}_{before}) = (CV_{\bar{M}} \times \hat{M}_{before})^2 \qquad \textbf{(16)}$$

where,

> *M_d = daily migration estimates for the first days of actual trapping (first two days used)*
>
> *M_{before} = the estimate of migration before trapping began*
>
> *t = the number of days between the start of the migration and the first trapping day*

Equations (14), (15), and (16) were also used to estimate the migration and variance *after* trapping. For this estimate, M_d = daily migration estimates for the last two days of actual trapping, and t = the number of days between the end of the migration and the last trapping day.

2. The proportion of 24 hour migration occurring at night averaged 95.8% (R_i in equation 9 above). This is the rate projected from our limited sampling of daytime migration in 1997 (Seiler and Kishimoto 1997b). We used the 1997 rate because we did not trap during the daytime in 1998.

3. On nights that the trap was not fishing (periods when the trap fished every other night), migration was estimated by averaging the estimated migrations for the night before and the night after. The variance of averaged migration estimates was calculated as follows:

$$Var(\bar{M}) = \frac{\sum (M_i - \bar{M})^2}{n(n-1)} + \frac{\sum Var(M_i)}{n} \qquad \textbf{(17)}$$

4. Migration during April 20-21, when the trap was out, was estimated by interpolating from the migrations estimated for April 19 and 22. Similarly, migration during April 23-24 was estimated by interpolating the April 22 and 25 migration estimates.

To interpolate two points between two measured values, the following equations were used:

$$M_{u1} = M_{k1} - \frac{(M_{k1} - M_{k2})}{(n + 1)} \quad \textbf{(18)}$$

$$M_{u2} = M_{u1} - \frac{(M_{k1} - M_{k2})}{(n + 1)} \quad \textbf{(19)}$$

where,

$$\begin{aligned} M_{u1} &= \textit{the larger of the unknown values} \\ M_{u2} &= \textit{the smaller of the unknown values} \\ M_{k1} &= \textit{the larger of the known values} \\ M_{k2} &= \textit{the smaller of the known values} \\ n &= \textit{the number of unknown values} \end{aligned}$$

If the CV of M_{k1} was larger than the CV of M_{k2}, then the variances were calculated as:

$$V(M_{u1}) = \left(\left(\frac{\sqrt{V(M_{k1})}}{M_{k1}} - \frac{\left(\frac{\sqrt{V(M_{k1})}}{M_{k1}} - \frac{\sqrt{V(M_{k2})}}{M_{k2}}\right)}{(n + 1)}\right) \times M_{u1}\right)^2 \quad \textbf{(20)}$$

$$V(M_{u2}) = \left(\left(\frac{\sqrt{V(M_{u1})}}{M_{u1}} - \frac{\left(\frac{\sqrt{V(M_{k1})}}{M_{k1}} - \frac{\sqrt{V(M_{k2})}}{M_{k2}}\right)}{(n + 1)}\right) \times M_{u2}\right)^2 \quad \textbf{(21)}$$

If the CV of M_{k1} was smaller than the CV of M_{k2}, then the variances were calculated as:

$$V(M_{u2}) = \left(\left(\frac{\sqrt{V(M_{k2})}}{M_{k2}} - \frac{\left(\frac{\sqrt{V(M_{k2})}}{M_{k2}} - \frac{\sqrt{V(M_{k1})}}{M_{k1}} \right)}{(n + 1)} \right) \times M_{u2} \right)^2 \tag{22}$$

$$V(M_{u1}) = \left(\left(\frac{\sqrt{V(M_{u2})}}{M_{u2}} - \frac{\left(\frac{\sqrt{V(M_{k2})}}{M_{k2}} - \frac{\sqrt{V(M_{k1})}}{M_{k1}} \right)}{(n + 1)} \right) \times M_{u1} \right)^2 \tag{23}$$

Results

Catch

The sockeye fry migration was underway when trapping began on January 31. As shown in Table 1, catches (for both port and starboard traps combined) increased from 148 on the first night of trapping to a peak of 8,031 on March 16. After March 20, nightly catches dropped abruptly, to less than 500 on March 21. On April 25, our last night of trapping, we caught 148 sockeye fry, the same number as our first night of trapping. Over the season, catches totaled 111,546 sockeye fry during the 85 nights fished (Table 1). Compared to the 1997 season, average catch per night increased during 1998. We caught an average of 1,312 fry per night (n=85 samples) in the traps in 1998 compared to 820 fry per night (n=63) in 1997.

While sockeye fry were our target species, we also caught 1,057 coho fry, 4 chum fry, 71 chinook fry and 4 pink salmon fry (Table 2). Catches of coho and chinook fry were higher in 1998 compared to 1997 (354 coho fry and 20 chinook fry were captured in 1997). However, chum fry catches were much lower in 1998 compared to 1997 (4 versus 102). Non-salmonids captured included juvenile lampreys, sticklebacks, cyprinids, smelts, sculpins, perch, sunfish, catfish, crappie, bass, frogs and polywogs (Table 3).

Efficiency and Flow

Recapture rates of the 33 release groups ranged from a low of 3.2% to a high of 25.5%, and averaged 10.6% for both traps combined (Table 4a). On the dates that we conducted efficiency tests, daily mean flows (measured by the U. S. Geological Survey gaging station at Woodinville) ranged from 308 to 517 cfs and averaged 404 cfs.

Regression analysis of trap efficiency as a function of flow indicated a weak but significant relationship ($r^2 = 20\%$, $F=7.68$, $P=0.01$) for both traps combined (Figure 2). Similarly, our previous analysis of 1997 data also revealed a weak but significant correlation ($r^2=25\%$) between flow and efficiency (Seiler and Kishimoto 1997b). We attribute this weak relationship to the influence of two factors: channel shape and turbulence upstream of the traps. The Sammamish Slough is contained by steep banks. Consequently, depth and velocity increase as flow increases, but channel width changes very little. Because sockeye fry migrate near the surface, despite depth, the cross-sectional area of fish-bearing water in the slough changes primarily with the width increment, which is relatively small. The traps fish a constant area, thus capture rate is largely a function of the proportion of fish-bearing water sampled. We believe that the variation in capture rates that we observed, even at relatively constant flows, resulted from turbulence in the form of large boils emanating from the banks upstream of the trap. These boils, occurring frequently but with no apparent pattern, undoubtedly affected the lateral distribution of marked and unmarked sockeye fry and thereby, the instantaneous capture rate.

Effect of Release Location

ANOVA was used to test whether release location influenced capture efficiency. This test showed that mean trap efficiency for left bank releases (10.06%) was not significantly different than the mean efficiency for right bank releases (10.09%), for starboard and port traps combined ($p>0.05$; Table 4b).

Our one release from the North Creek Bridge (NCB) on February 23 resulted in the highest capture rate (25.53%) of the season. In this test, a group of 1,187 fry were released from the bridge upstream of the fry traps. Field observations on the night of February 23 suggested that this release group may have stayed together in a tight group as it traveled downstream. The fry traps were positioned in the thalweg of the channel; therefore, the traps may have captured this group at a disproportionately high recapture rate. Because of these factors, we did not include the North Creek Bridge release in the ANOVA to evaluate the effect of release location on capture rate.

ANOVA was also used to test the distribution of marked fry relative to unmarked fry by comparing the marked/unmarked (m/u) ratio between traps. Analysis of (m/u) ratios indicated that over all calibration tests, the distribution of marked fry was not significantly different ($p>0.05$) than that of unmarked fry. Over the 33 nights that calibration tests were conducted, m/u ratios in the port and starboard traps averaged 4.37% and 4.44%, respectively (Table 5). These results suggest that marked groups had the same spatial distribution as the unmarked fry in the Sammamish River system.

Similar results were found when we compared the m/u ratio between traps within each release location. Analysis of m/u ratios for left bank releases ($n=14$) showed no significant difference between traps ($p>0.05$), with a 3.60% mark rate for the port trap compared to 3.71% for the starboard trap (Table 5). Similarly, m/u ratios for right bank releases ($n=18$) were not significantly different ($p>0.05$), with ratios of 4.57% and 4.93% for port and starboard traps, respectively. Analysis was not done for marked fish released from North Creek Bridge because only a single release occurred, which precluded statistical evaluation. For the one NCB release, m/u ratios were 11.79% in the port trap and 9.32% in the starboard trap, indicating a higher mark recovery rate in the port trap on the night of February 23. Port:starboard overall ratios (the ratio of port m/u ratio to starboard m/u ratio) were 0.97 for left bank releases, 0.93 for right bank releases, and 1.27 for the NCB release (Table 5).

Migration Estimate: Average vs. Predicted Efficiency

We compared the coefficient of variation (CV) for the migration estimate based on the average efficiency over the entire season versus the CV for the estimate using the predicted (regression-based) efficiency. Results showed that the CV for the average efficiency-based estimate (2.07%) was lower than the CV for the regression-based estimate (8.17%).

Given the overall even spatial distribution of release groups in the stream channel, resulting in an unbiased effect on capture rates, the weak correlation between flow and capture rates, and the lower CV for the migration estimate based on the average efficiency, we elected to use the average capture rate estimated over all tests (10.55%; Table 4a) to estimate sockeye fry migration from the Sammamish River.

Fry Production

We estimate that 1,243,000 sockeye fry migrated down the Sammamish River at Bothell during the 1998 season (Figure 3). The breakdown of our estimate by time period (before, during and after trapping) is as follows:

Period	Dates	Estimate	SD	±CI	CV
Before trapping	January 15 - 30	14,588	6,075	13,030	41.64%
During trapping	January 31 - April 25	1,212,946	25,164	50,051	2.07%
After trapping	April 26 - May 15	15,376	2,360	4,958	15.35%
Total	**January 15 - May 15**	**1,242,910**	**25,994**	**51,468**	**2.09%**

Migration timing

We believe that sockeye fry migration timing was expressed by the pattern and rates of catch described above and shown in Figure 3. Over the course of the migration period, 25%, 50% and 75% of the migration occurred by March 2, March 12, and March 18, respectively.

Egg-to-Migrant Survival

Survival from potential egg deposition (P.E.D.) to lake entry as fry is estimated at 10% for brood year 1997 (Table 6). This rate is the ratio of our estimate of 1.2 million fry to a P.E.D. of 12 million. The P.E.D. is based on the following estimate and assumptions:

1. A spawning population in the Sammamish system (downstream of the lake) of 8,000 sockeye in 1997 (Egan and Ames 1997);

2. An even sex ratio; and

3. Average fecundity of 3,000 eggs per female.

Results for the 1998 season are consistent with our previous finding in the Cedar River (Seiler *et al.* 2000) that the egg-to-migrant survival rate for sockeye fry is largely a function of the severity of peak flows during egg incubation. The survival rate measured for brood year 1997 (water year 1998) is a ten-fold increase compared to the survival rate of 1% measured for brood year 1996 (Table 6). We attribute this large increase to differences in peak flows between these years (Figure 4). In 1997, a severe storm occurred on January 2, producing the highest single day flow (2,830 cfs) ever recorded in the 157 sq. mile Sammamish River Basin (USGS at Woodinville) since 1966 when flow monitoring began. This storm was regionally referred to as the "ice storm." It was a classic rain-on-snow event which hit lower elevation systems particularly hard. In such urbanized watersheds as the Sammamish, the runoff rate was exacerbated by the large proportion of impervious surfaces. Peak daily mean flow affecting the 1996 brood in the Sammamish system was 2.7 times higher than the maximum daily mean flow recorded for brood year 1997 (1,060 cfs) and 5.8 times greater than the peak daily mean flow measured for brood year 1992 (492 cfs, the lowest peak flow on record) (Table 6; Figure 4). As indicated from these results, the survival rate of sockeye fry in the Sammamish system appears to be a function of peak flow during egg incubation (Figure 5), which we also concluded in the Cedar River (Seiler and Kishimoto 1997a).

While additional data are needed on subsequent brood years to test the significance of this relationship in the Sammamish system, the record high adult return in 1996 (Table 6) probably resulted primarily from good incubation survival of the 1992 brood. This brood experienced the lowest flows during incubation of any of the last thirteen broods (Table 6; Figure 5). At the high incubation survival rate of 18% that we measured in the Cedar River on this brood, around 8 million fry were produced. A fry-to-smolt survival rate of 8%, followed by a marine survival rate of 10%, would result in a spawning population of the 60,000 adults in 1996.

Rearing Area Determination

In this report, and since the beginning of this work in 1997, we have discussed fry survival for the Sammamish River System with the inherent assumption that all fry produced downstream of Lake Sammamish migrate down the Sammamish River to rear in Lake Washington. While we believe this is the case, our low estimates of fry production during the first year of this study (953,000 sockeye fry) could not confirm this assumption. Results from 1998, however, provided a second data point which estimated an egg-to-migrant survival rate that was ten-fold higher. This large increase tends to refute the scenario that sockeye fry produced in Bear Creek migrate upstream to rear in Lake Sammamish.

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Table 1. Estimated sockeye fry migration during the fry trapping period (1/31-4/25), Sammamish Slough 1998.

Date	Flow (cfs)	Catch	Day Adj.	Est. Efficiency[a]	Est. Migration[b]
1/31	559	148	154	10.55%	1,465
2/1	520				2,425
2/2	485	342	357	10.55%	3,385
2/3	454				2,747
2/4	435	213	222	10.55%	2,108
2/5	407				3,034
2/6	384	400	418	10.55%	3,959
2/7	355				4,731
2/8	349	556	580	10.55%	5,503
2/9	339				4,133
2/10	328	279	291	10.55%	2,762
2/11	317				3,232
2/12	391	374	390	10.55%	3,702
2/13	427				7,102
2/14	383	1,061	1,108	10.55%	10,502
2/15	378				12,210
2/16	352	1,406	1,468	10.55%	13,917
2/17	331	1,526	1,593	10.55%	15,105
2/18	336	1,098	1,146	10.55%	10,868
2/19	377	324	338	10.55%	3,207
2/20	358	634	662	10.55%	6,276
2/21	458	1,271	1,327	10.55%	12,581
2/22	434	2,634	2,749	10.55%	26,072
2/23	388	2,815	2,938	10.55%	27,864
2/24	359	2,044	2,134	10.55%	20,232
2/25	367	2,538	2,649	10.55%	25,122
2/26	371	1,892	1,975	10.55%	18,728
2/27	348	1,507	1,573	10.55%	14,917
2/28	337	464	484	10.55%	4,593
3/1	444	918	958	10.55%	9,087
3/2	517	2,703	2,822	10.55%	26,755
3/3	483	3,431	3,581	10.55%	33,961
3/4	459	2,691	2,809	10.55%	26,636
3/5	429	2,700	2,818	10.55%	26,726
3/6	403	2,784	2,906	10.55%	27,557
3/7	381	2,581	2,694	10.55%	25,548
3/8	373	1,953	2,039	10.55%	19,331
3/9	393	2,354	2,457	10.55%	23,301
3/10	422	2,903	3,030	10.55%	28,735
3/11	410	2,755	2,876	10.55%	27,270
3/12	394	4,191	4,375	10.55%	41,484
3/13	376	4,764	4,973	10.55%	47,156
3/14	360	5,289	5,521	10.55%	52,352
3/15	356	2,618	2,733	10.55%	25,914
3/16	431	8,031	8,383	10.55%	79,494
3/17	384	7,406	7,731	10.55%	73,307
3/18	355	7,562	7,894	10.55%	74,851
3/19	335	4,841	5,053	10.55%	47,918

(Table continued, next page)

Table 1. Estimated sockeye fry migration during the fry trapping period (1/31-4/25), Sammamish Slough 1998 (continued).					
Date	**Flow** (cfs)	**Catch**	**Day Adj.**	**Est. Efficiency**[a]	**Est. Migration**[b]
3/20	316	3,977	4,151	10.55%	39,366
3/21	308	488	509	10.55%	4,830
3/22	402	548	572	10.55%	5,424
3/23	452	582	608	10.55%	5,761
3/24	475	1,469	1,533	10.55%	14,541
3/25	472	1,352	1,411	10.55%	13,383
3/26	510	851	888	10.55%	8,423
3/27	504				8,458
3/28	445	858	896	10.55%	8,493
3/29	407				5,415
3/30	382	236	246	10.55%	2,336
3/31	378				4,212
4/1	363	615	642	10.55%	6,087
4/2	343				5,182
4/3	327	432	451	10.55%	4,276
4/4	316				5,152
4/5	305	609	636	10.55%	6,028
4/6	288				5,984
4/7	295	600	626	10.55%	5,939
4/8	298				5,786
4/9	275	569	594	10.55%	5,632
4/10	270				6,068
4/11	297	657	686	10.55%	6,503
4/12	282				5,533
4/13	267	461	481	10.55%	4,563
4/14	256				4,464
4/15	246	441	460	10.55%	4,365
4/16	237				3,435
4/17	228	253	264	10.55%	2,504
4/18	221				2,341
4/19	219	220	230	10.55%	2,178
4/20	212				2,043
4/21	207				1,907
4/22	200	179	187	10.55%	1,772
4/23	213				1,670
4/24	290				1,567
4/25	247	148	154	10.55%	1,465
Total		**111,546**	**116,436**		**1,212,946**

[a] Estimated efficiency was the average of the nightly observed efficiencies, for port and starboard traps combined (port and starboard traps always fished together during each night of trapping). Efficiency was calculated as the proportion of marked sockeye fry released above the fry traps and subsequently recaptured in the traps.

[b] Estimated nightly migrations were calculated using the nightly (day-adjusted) catch divided by the season average trap efficiency of 10.55%. Shaded cells indicate nights when the trap was not fishing.

Table 2. Incidental salmonid species captured in the Sammamish River sockeye fry traps, 1998.

DATE	FRY[a]			
	Coho	Chum	Chinook	Pink
1/31				
2/1	not trapped			
2/2			20	
2/3	not trapped			
2/4				
2/5	not trapped			
2/6				
2/7	not trapped			
2/8			2	
2/9	not trapped			
2/10				
2/11	not trapped			
2/12			4	
2/13	not trapped			
2/14				
2/15	not trapped			
2/16	4			
2/17	2		2	
2/18	2		6	
2/19				
2/20	1		4	
2/21	5		1	
2/22	6		1	
2/23	9	2		
2/24	5		3	
2/25	7		5	
2/26	2		2	
2/27	3		2	
2/28	7			1
3/1	31		1	
3/2	12			
3/3	43		2	
3/4	42		2	
3/5	30			
3/6	9		1	1
3/7	8	1	1	1
3/8	2			
3/9	69		1	
3/10	106		1	
3/11	118			
3/12	71			
3/13	21			1
3/14	1	1		
3/15	5			
3/16	20		1	
3/17	24			
3/18	26		1	

(Table continued, next page)

Table 2. Incidental salmonid species captured in the Sammamish River sockeye fry traps, 1998 (continued).

DATE	FRY[a] Coho	Chum	Chinook	Pink
3/19	17			
3/20	12			
3/21	3		3	
3/22	44		3	
3/23	68		1	
3/24	60		1	
3/25	46			
3/26	32			
3/27	not trapped			
3/28	23			
3/29	not trapped			
3/30	3			
3/31	not trapped			
4/1	7			
4/2	not trapped			
4/3	5			
4/4	not trapped			
4/5	7			
4/6	not trapped			
4/7	9			
4/8	not trapped			
4/9	5			
4/10	not trapped			
4/11	12			
4/12	not trapped			
4/13	4			
4/14	not trapped			
4/15	3			
4/16	not trapped			
4/17				
4/18	not trapped			
4/19	2			
4/20	not trapped			
4/21	not trapped			
4/22	1			
4/23	not trapped			
4/24	not trapped			
4/25	3			
Total	**1,057**	**4**	**71**	**4**

[a] The catch of incidental salmonids did not include yearlings; only age 0+ salmonids were captured.

Table 3. Incidental non-salmonid species captured in the Sammamish River sockeye fry traps, by statistical week, 1998.

Start Date	End Date	Ammo-coetes	Lamprey	Chub	Sunfish	Polywogs	Stickle-back	Smelt	Perch	Crappie	Lrg. Mouth Bass	Frog	Sculpin	Sm. Mouth Bass	Catfish	Un-ID Bass
Jan 31	Feb 1	1		3	1	30										
Feb 2	Feb 8	1	3	42	43	263	77	184	6	1	6					
Feb 9	Feb 15	1	11	13	6	55	16	270	2		3					
Feb 16	Feb 22	18	5	17	4	64	23	1,034	1							
Feb 23	Mar 1	3	24	14	3	108	8	1,388	1		2					
Mar 2	Mar 8	1	14	10	1	33	4	1,674			1					
Mar 9	Mar 15		34	17	5	36	6	455				2	1			
Mar 16	Mar 22	2	25	17	5	32	1	119				7		1		
Mar 23	Mar 29	1	21	6	9	18		25				2		1	1	
Mar 30	Apr 5		3	3	8	10	1	5				2		3	1	
Apr 6	Apr 12		3	5	11	7	2	1				2	1	3		
Apr 13	Apr 19	1	1	5	9	1	3	4				2		1		2
Apr 20	Apr 26	1		1	4		7	1				1				
TOTAL		**30**	**144**	**153**	**109**	**657**	**148**	**5,160**	**10**	**1**	**12**	**18**	**2**	**9**	**2**	**2**

Table 4a. Nightly release/recapture statistics for sockeye fry captured in the Sammamish Slough scoop traps, 1998.

Night	Releases	Locat'n	Time	Flow (cfs)	PORT TRAP		STBD TRAP		COMBINED CATCH		Recap. Ratio
					Recap.	Eff.	Recap.	Eff.	Recap.	Eff.	Port:Star
2/21	631	RB	9:30	458	8	1.27%	12	1.90%	20	3.17%	66.67%
2/22	1,194	LB	8:40	434	62	5.19%	46	3.85%	108	9.05%	134.78%
2/23	1,187	NCB	1:15	388	194	16.34%	109	9.18%	303	25.53%	177.98%
2/24	1,398	RB	12:25	359	59	4.22%	51	3.65%	110	7.87%	115.69%
2/25	1,286	LB	11:20	367	47	3.65%	57	4.43%	104	8.09%	82.46%
2/26	1,282	RB	11:25	371	51	3.98%	38	2.96%	89	6.94%	134.21%
2/27	1,100	RB	11:25	348	43	3.91%	41	3.73%	84	7.64%	104.88%
2/28	1,296	LB	10:20	337	65	5.02%	100	7.72%	165	12.73%	65.00%
3/1	456	RB	10:20	444	12	2.63%	9	1.97%	21	4.61%	133.33%
3/2	802	LB	11:00	517	22	2.74%	36	4.49%	58	7.23%	61.11%
3/3	1,181	RB	11:25	483	38	3.22%	60	5.08%	98	8.30%	63.33%
3/4	1,196	LB	11:25	459	30	2.51%	46	3.85%	76	6.35%	65.22%
3/5	1,256	RB	11:25	429	39	3.11%	64	5.10%	103	8.20%	60.94%
3/6	1,145	LB	10:15	403	98	8.56%	53	4.63%	151	13.19%	184.91%
3/7	1,266	RB	11:15	381	155	12.24%	140	11.06%	295	23.30%	110.71%
3/8	1,386	LB	10:20	373	90	6.49%	120	8.66%	210	15.15%	75.00%
3/9	1,140	RB	11:20	393	86	7.54%	73	6.40%	159	13.95%	117.81%
3/10	1,176	LB	10:30	422	66	5.61%	81	6.89%	147	12.50%	81.48%
3/11	1,079	RB	11:25	410	48	4.45%	72	6.67%	120	11.12%	66.67%
3/12	1,088	LB	10:35	394	77	7.08%	80	7.35%	157	14.43%	96.25%
3/13	1,314	RB	11:30	376	82	6.24%	95	7.23%	177	13.47%	86.32%
3/15	1,096	RB	11:15	356	87	7.94%	104	9.49%	191	17.43%	83.65%
3/16	1,142	LB	12:20	431	46	4.03%	43	3.77%	89	7.79%	106.98%
3/17	1,275	RB	11:25	384	78	6.12%	75	5.88%	153	12.00%	104.00%
3/18	1,276	LB	11:25	355	73	5.72%	74	5.80%	147	11.52%	98.65%
3/19	1,470	RB	11:30	335	51	3.47%	93	6.33%	144	9.80%	54.84%
3/20	1,193	LB	11:30	316	61	5.11%	65	5.45%	126	10.56%	93.85%
3/21	1,204	RB	10:15	308	66	5.48%	93	7.72%	159	13.21%	70.97%
3/22	425	LB	10:15	402	13	3.06%	22	5.18%	35	8.24%	59.09%
3/23	545	RB	10:15	452	11	2.02%	16	2.94%	27	4.95%	68.75%
3/24	538	RB	11:30	475	19	3.53%	21	3.90%	40	7.43%	90.48%
3/25	1,111	LB	11:30	472	18	1.62%	26	2.34%	44	3.96%	69.23%
3/26	1,348	RB	11:30	510	51	3.78%	61	4.53%	112	8.31%	83.61%
Total	36,482				1,946		2,076		4,022		
Pooled Avg.						5.33%		5.69%		11.02%	93.74%
Sample Avg.				404		5.09%		5.46%		**10.55%**	92.99%
SD Sample Avg.										**1.27%**	

Table 4b. Summary of sockeye fry trap efficiency (port and starboard traps combined), by release location, Sammamish Slough 1998.

Left Bank Releases			Right Bank Releases		
Night	Flow (cfs)	Efficiency Both Traps	Night	Flow (cfs)	Efficiency Both Traps
			21-Feb	458	3.17%
			24-Feb	359	7.87%
			26-Feb	371	6.94%
			27-Feb	348	7.64%
22-Feb	434	9.05%	01-Mar	444	4.61%
25-Feb	367	8.09%	03-Mar	483	8.30%
28-Feb	337	12.73%	05-Mar	429	8.20%
02-Mar	517	7.23%	07-Mar	381	23.30%
04-Mar	459	6.35%	09-Mar	393	13.95%
06-Mar	403	13.19%	11-Mar	410	11.12%
08-Mar	373	15.15%	13-Mar	376	13.47%
10-Mar	422	12.50%	15-Mar	356	17.43%
12-Mar	394	14.43%	17-Mar	384	12.00%
16-Mar	431	7.79%	19-Mar	335	9.80%
18-Mar	355	11.52%	21-Mar	308	13.21%
20-Mar	316	10.56%	23-Mar	452	4.95%
22-Mar	402	8.24%	24-Mar	475	7.43%
25-Mar	472	3.96%	26-Mar	510	8.31%
Sample Avg.	406	**10.06%**		404	**10.09%**
SD Sample Avg.		**1.28%**			**1.48%**

Table 5. Ratio of marked to unmarked sockeye fry catches by release location, Sammamish Slough 1998.

Night	PORT TRAP Marks	PORT TRAP Unmks	PORT TRAP Ratio	STARBOARD TRAP Marks	STARBOARD TRAP Unmks	STARBOARD TRAP Ratio	Port:Starboard Ratio
Left Bank:							
02/22/1998	62	1,401	4.43%	46	1,233	3.73%	1.19
02/25/1998	47	1,381	3.40%	57	1,157	4.93%	0.69
02/28/1998	65	205	31.71%	100	256	39.06%	0.81
03/02/1998	22	1,224	1.80%	36	1,479	2.43%	0.74
03/04/1998	30	1,156	2.60%	46	1,535	3.00%	0.87
03/06/1998	98	1,438	6.82%	53	1,346	3.94%	1.73
03/08/1998	90	946	9.51%	120	1,007	11.92%	0.80
03/10/1998	66	1,294	5.10%	81	1,609	5.03%	1.01
03/12/1998	77	1,894	4.07%	80	2,237	3.58%	1.14
03/16/1998	46	3,912	1.18%	43	4,119	1.04%	1.13
03/18/1998	73	3,734	1.96%	74	3,828	1.93%	1.02
03/20/1998	61	1,902	3.21%	65	2,075	3.13%	1.03
03/22/1998	13	234	5.56%	22	314	7.01%	0.79
03/25/1998	18	640	2.81%	26	712	3.65%	0.77
Subtotal	768	21,361		849	22,907		
Pooled Avg.			3.60%			3.71%	**0.97**
(n=14) Sample Avg.			6.01%			6.74%	
Right Bank:							
02/21/1998	8	547	1.46%	12	724	1.66%	0.88
02/24/1998	59	1,099	5.37%	51	945	5.40%	0.99
02/26/1998	51	1,070	4.77%	38	822	4.62%	1.03
02/27/1998	43	870	4.94%	41	637	6.44%	0.77
03/01/1998	12	432	2.78%	9	486	1.85%	1.50
03/03/1998	38	1,580	2.41%	60	1,851	3.24%	0.74
03/05/1998	39	1,186	3.29%	64	1,514	4.23%	0.78
03/07/1998	155	1,398	11.09%	140	1,183	11.83%	0.94
03/09/1998	86	1,111	7.74%	73	1,243	5.87%	1.32
03/11/1998	48	1,146	4.19%	72	1,380	5.22%	0.80
03/13/1998	82	2,373	3.46%	95	2,391	3.97%	0.87
03/15/1998	87	1,309	6.65%	104	1,309	7.94%	0.84
03/17/1998	78	3,611	2.16%	75	3,795	1.98%	1.09
03/19/1998	51	2,244	2.27%	93	2,597	3.58%	0.63
03/21/1998	66	233	28.33%	93	255	36.47%	0.78
03/23/1998	11	241	4.56%	16	341	4.69%	0.97
03/24/1998	19	687	2.77%	21	737	2.85%	0.97
03/26/1998	51	404	12.62%	61	447	13.65%	0.92
Subtotal	984	21,541		1,118	22,657		
Pooled Avg.			4.57%			4.93%	**0.93**
(n=18) Sample Avg.			6.16%			6.97%	
Total LB + RB	1,752	42,902		1,967	45,564		
Pooled Avg.			4.08%			4.32%	0.94
(n=32) Sample Avg.			6.09%			6.87%	
North Creek Bridge (NCB):							
02/23/1998	194	1,646	11.79%	109	1,169	9.32%	**1.27**
TOTAL with NCB	**1,946**	**44,548**		**2,076**	**46,733**		
Pooled Avg.			**4.37%**			**4.44%**	**0.98**
(n=33) Sample Avg.			**6.27%**			**6.95%**	

Table 6. Record of peak daily mean flow during egg incubation, estimated escapement, potential egg deposition, and initial estimates of egg-to-fry survival for Sammamish River sockeye, brood years 1985-1997.

Water Year	Brood Year	Date	Peak Daily Mean Flow (cfs)	Est. Esc.	P.E.D. (millions)	Fry (millions)	Survival (Fry/P.E.D.)	ESCAPEMENT Big Bear	Other Tribs
1986	1985	01/19	2,080	23,000	34.5			20,160	3,000
1987	1986	11/25	1,440	26,000	39.0			22,982	3,000
1988	1987	01/15	537	20,000	30.0			18,844	1,000
1989	1988	01/13	817	9,000	13.5			8,779	500
1990	1989	01/10	2,140	2,000	3.0			1,795	500
1991	1990	11/25	1,650	11,000	16.5			10,115	500
1992	1991	01/31	1,350	8,000	12.0			7,691	500
1993	1992	12/21	492	30,000	45.0	8.1	*18.0%	27,533	2,000
1994	1993	12/12	559	11,000	16.5			9,848	1,000
1995	1994	12/27	1,310	41,000	61.5			39,645	1,000
1996	1995	02/09	2,430	3,000	4.5			2,329	500
1997	1996	01/02	2,830	60,000	90.0	1.0	1.1%	45,401	14,117
1998	1997	01/24	1,060	8,000	12.0	1.2	10.0%	6,714	1,000

* Note: Fry survival for brood year 1992 is the value measured in the Cedar River.

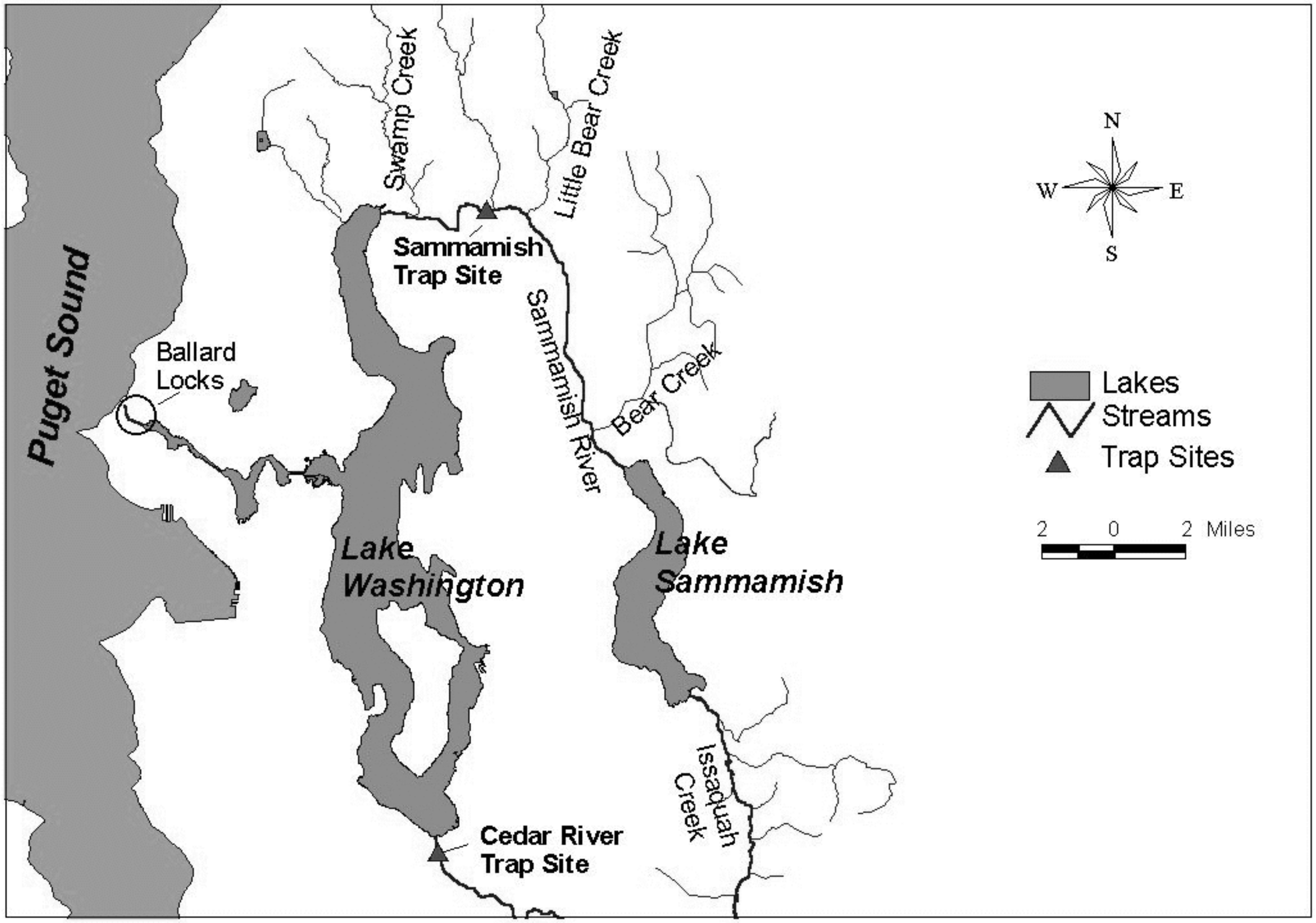

Figure 1. Map of the Lake Washington Basin, showing the 1998 Sammamish River trap site (R.M. 4.0) and the Cedar River trap site (R.M. 0.4).

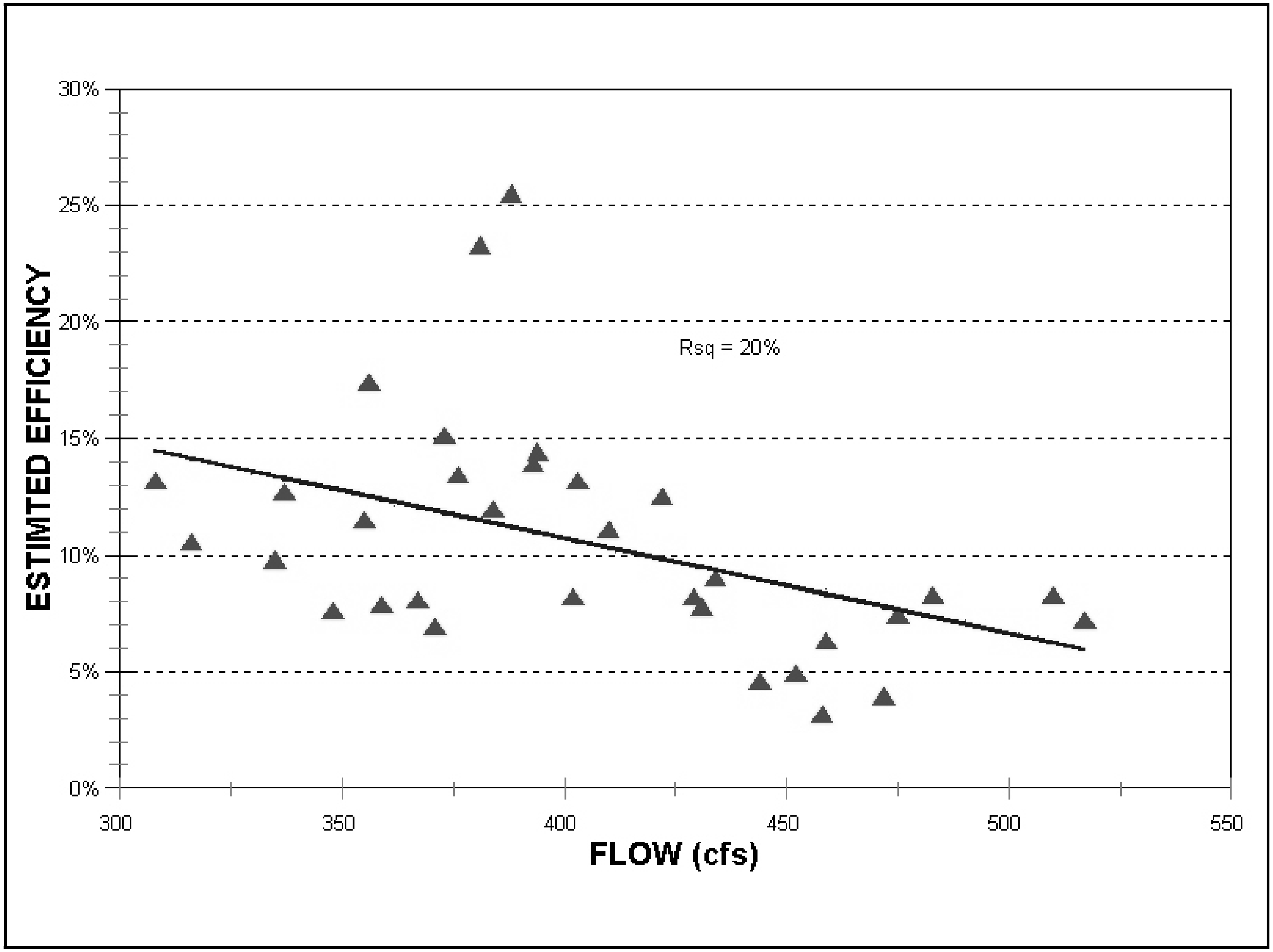

Figure 2. Trap efficiency for sockeye fry (port and starboard traps combined) and flow (cfs), Sammamish Slough near Woodinville 1998.

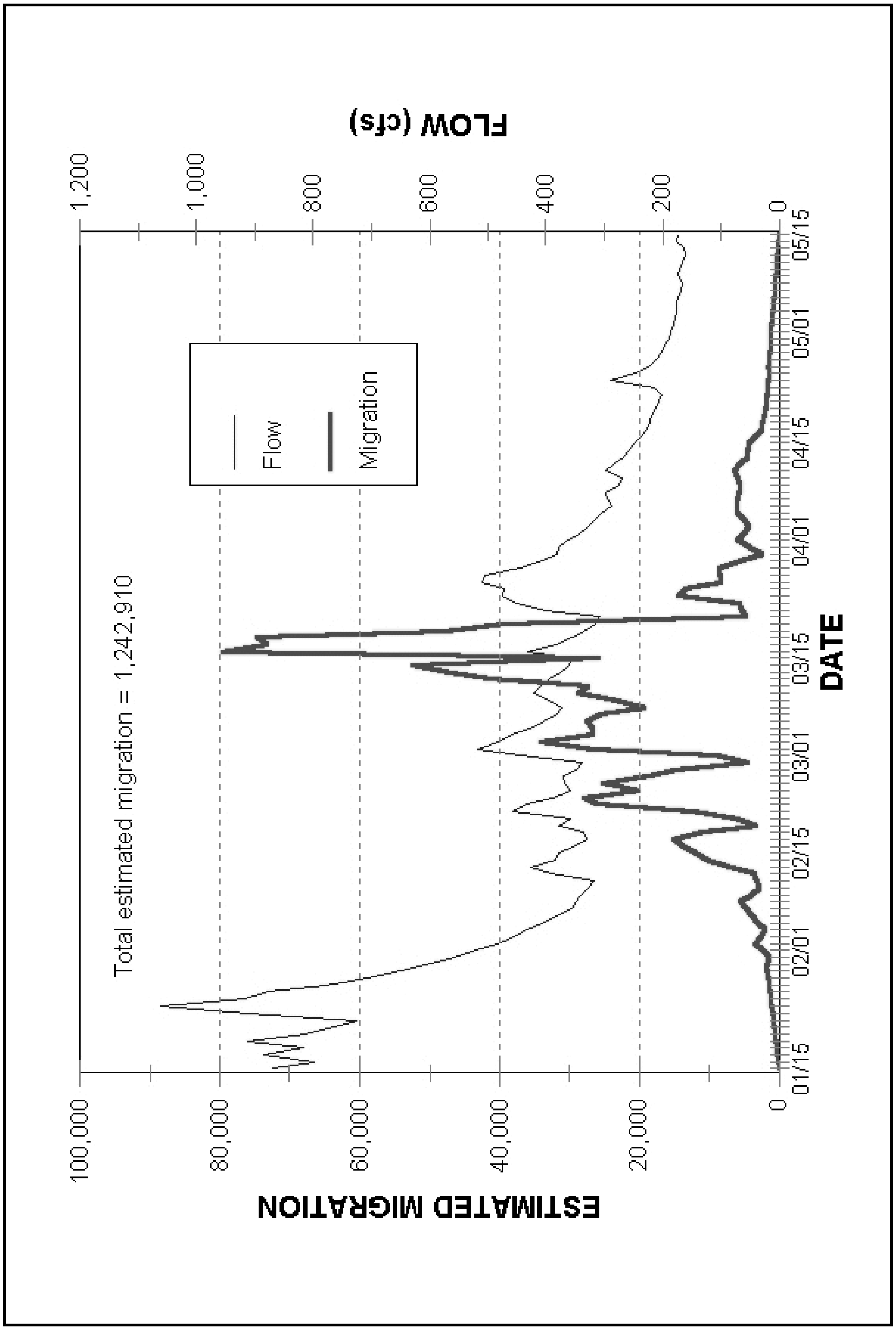

Figure 3. Estimated sockeye fry migration and daily mean flow (cfs), Sammamish Slough near Bothell 1998.

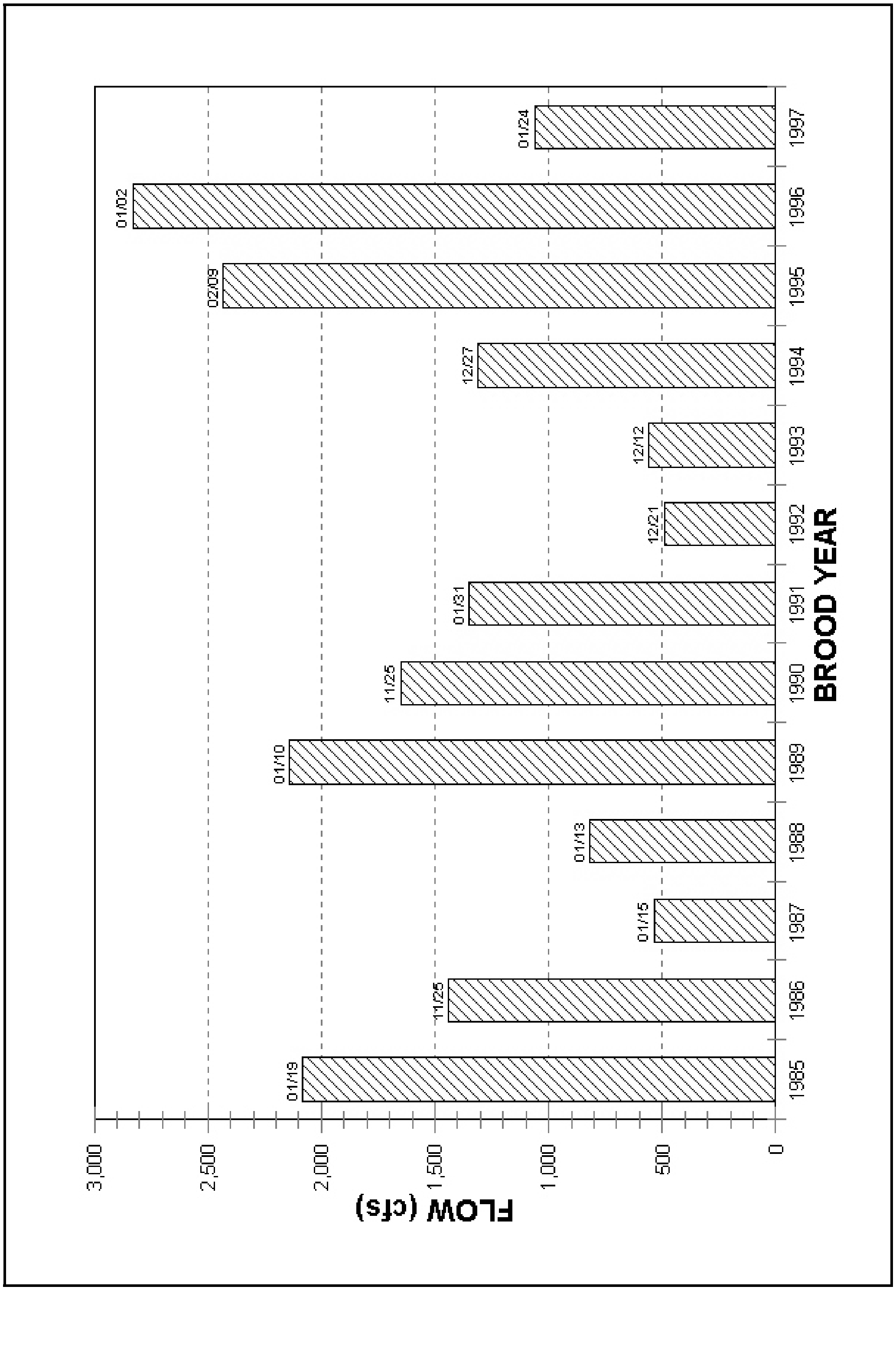

Figure 4. Peak daily mean flow (cfs) during sockeye egg incubation in the Sammamish Slough, brood years 1985-1997.

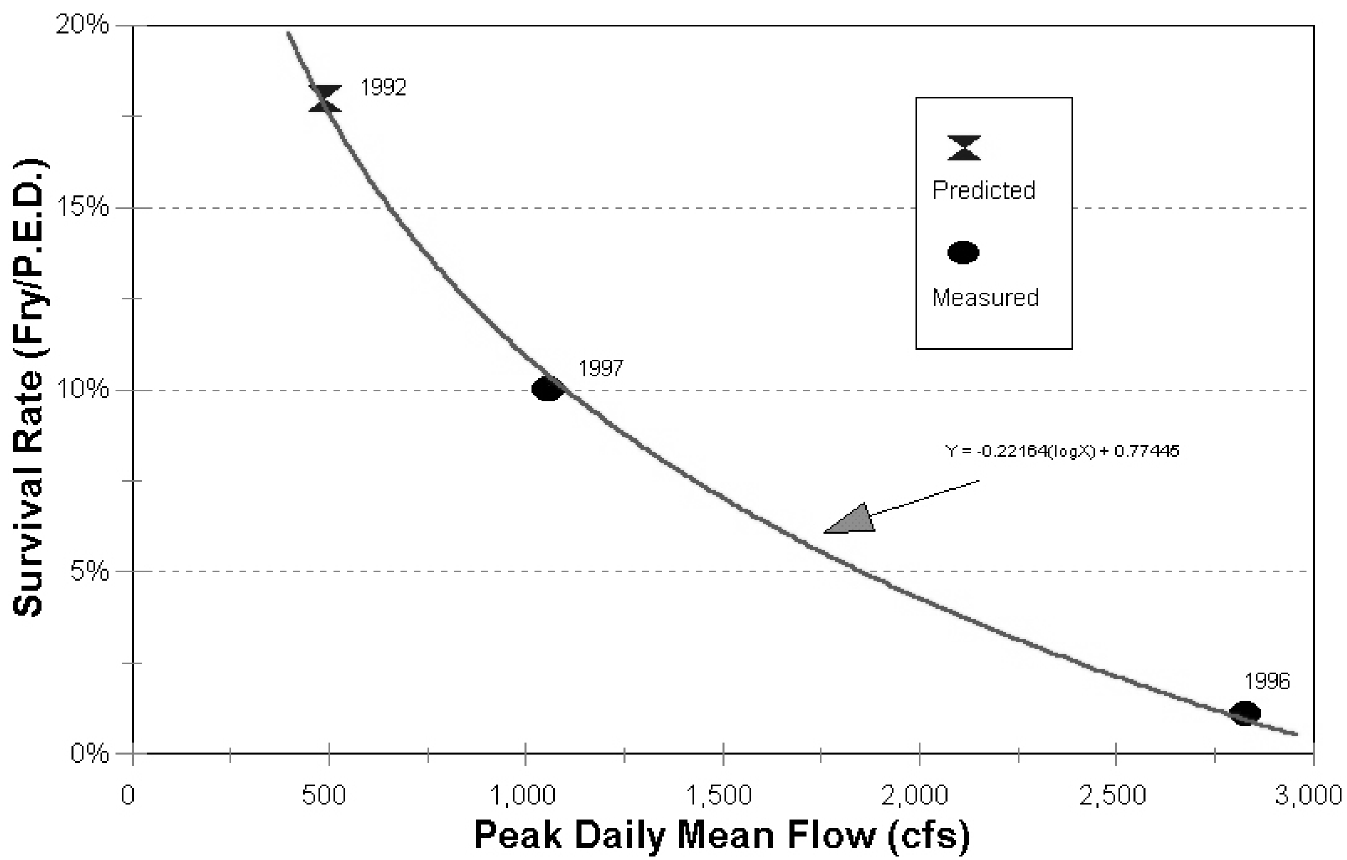

Figure 5. Egg to migrant survival rate of sockeye versus peak daily mean flow (cfs) during egg incubation in the Sammamish Slough, brood years 1992, 1996 and 1997. The survival rate for brood year 1992 is the value estimated in the Cedar River.