2004 LAKE WASHINGTON SOCKEYE SMOLT SAMPLE ANALYSES

INTRODUCTION

In May of 2004, Dave Seiler and his staff collected out-migrating sockeye smolts in Lake Union. These samples were brought into the Otolith Lab where they were measured (fork lengths), aged via scales by John Sneva, sexed, and had their otoliths extracted, processed, and examined for thermal marks. The otolith decode data resulting from this effort were recently analyzed. Below is a synopsis of the results. Immediately below that is a more detailed explanation of the information recovered from these specimens.

Summary of Findings:

1) On each sampling date, approximately 24% of the smolts sampled came from hatchery releases
2) Ninety-eight percent of the NOR smolts and 99.6% of the hatchery-origin smolts recovered were 1.0+ in age. The remainder were 2.0+ smolts
3) A series of Chi-Square tests were performed that compared the fry-to-smolt survival of various hatchery release treatments. These treatments were also compared to the fry-to-smolt survival rates of NOR smolts
    a) Sockeye released as fed fry had higher fry-to-smolt survival rates than those released as unfed fry when both were liberated from the Airport site
    b) Release location had no affect on hatchery fry-to-smolt survival rates when comparisons were made among the unfed fry groups
    c) Fed fry released from the Airport site apparently had similar fry-to-smolt survival rates as unfed NOR fry
    d) Unfed NOR fry had significantly higher fry-to-smolt survival rates than unfed hatchery-origin fry
    e) Unfed hatchery-origin fry released during the last one-third of the run had higher fry-to-smolt survival rates than middle and early fry. Middle and early fry had similar fry-to-smolt survivals
    f) Fed fry released in the latter third of the fry migration achieved higher fry-to smolt survival rates than those liberated during the first two-thirds of the fry migration period.
4) The sex of a smolt did not affect its fork length
5) Smolts produced from unfed early hatchery releases were larger than smolts originating from NOR and late hatchery release fry. Smolts produced from unfed fry released during the middle of the run were comparable in size to those produced by NOR and late release fry.
6) Sampling date did not appear to affect smolt size
7) These results should not be generalized across brood years for two reasons. Interactions between fry types and smolt survival and traits are likely to vary from one year to the next. Secondly, some treatments may produce significant numbers of 2.0+ smolts. Only one year of data were available so this potential effect is not considered in these analyses.
8) A regular program of smolt and adult collection should occur on a yearly basis to allow comprehensive analyses on the effects of various hatchery treatments.

Otolith Decode Information From the Sockeye Smolts Collected in May of 2004 From Lake Union

One thousand and seventy sockeye salmon smolts were collected from Lake Union over three days in May of 2004. These juveniles were actively migrating toward the sea and had originally reared in Lake Washington. Sockeye smolts can originate from three main sources in the Lake Washington Basin, from the Cedar River (the Cedar River population), from fish spawning on beaches in Lake Washington (the Beach Spawning population), and from streams emptying into the northern end of the lake (Northern Tributary population). All the smolts originating from the Beach and Northern Tributary populations were NORs (natural origin recruits) while those from the Cedar River can be both NORs and Hatchery-origin smolts. The Cedar River Hatchery is located at Landsburg (RK 36) and is used to produce sockeye fry that are released into the Cedar River mainly as unfed fry. Although, beginning in Broodyear 2001 and continuing through Broodyear 2003 some groups of fry were fed for approximately two weeks prior to being liberated into the Cedar River. Water temperatures at the hatchery are purposively manipulated during the incubation period to induce recognizable codes or "T-marks" into the otoliths of every hatchery fish.

Sockeye smolts can migrate from Lake Washington at three different ages, 0.0, 1.0, and 2.0; however, 0.0's and 2.0's are rare. Consequently, almost all of the smolts captured had originated from the 2002 broodyear. Table 1 shows the dates that smolts were sampled, the number obtained, and the incidence of marked fish collected on each sampling date. As the table shows, the occurrence of hatchery or thermally marked fry was fairly consistent from one sampling date to the next and averaged around 24%. The fork length, age, and sex of each sampled smolt were also determined. Table 2 shows

Table 1. The number of sockeye smolts sampled from Lake Union in May 2004 and the incidence of thermal codes in the sampled fish.

Date Of Sampling	Number Of Smolts Collected	No. Of T-Marked Smolts	No. Of Non-marked Smolts	% Marked	% Non-Marked
11 May	376	94	282	25.00	75.00
18 May	354	80	274	22.60	77.40
25 May	340	82	258	24.12	75.88
TOTALS	1070	256	818	23.93	76.07

the number and age of smolts collected by type (NOR or hatchery) by sampling date.

The primary purpose of collecting the smolts was to compare the fry-to-smolt survival rates of hatchery- and NOR sockeye in Lake Washington. In addition, the data collected on the smolts allowed us to determine:

1) If NOR and Hatchery origin smolts were comparable in size, and
2) To access the relative survival rates of different hatchery release strategies. For, example, hatchery-origin fry are released into the Cedar at three different times

(early, middle, and late), and into three different areas (Landsburg RK 36, mid-river RK 22.4 and lower river ≤ RK 3.1). In addition, some of the fry released at lower river locations had been reared for several weeks and they were released simultaneously with unfed fry. Thus, it was possible to also test whether short-term rearing provided any survival advantages to the fry.

Table 2. The number and sex of 1.0 and 2.0 NOR and hatchery-origin sockeye smolts collected on each sampling date in 2004.

Date Smolts Were Sampled	Type Of Smolt	No.	# Of 1.0 Females	# Of 1.0 Males	# Of 2.0 Females	# Of 2.0 Males	Other
11 May	NOR	282	155	116	4	7	0
18 May	NOR	274	117	149	2	3	3
25 May	NOR	258	121	127	0	2	8
Totals		814	393	392	6	12	8
11 May	Hatchery	90	46	44	0	0	0
18 May	Hatchery	73	32	40	0	0	1
25 May	Hatchery	79	39	39	0	0	1
Totals		242	117	123	0	0	2
11 May	Unread Hatch	4	3	0	0	1	0
18 May	Unread Hatch	7	3	4	0	0	0
25 May	Unread Hatch	3	1	2	0	0	0
Totals		14	7	6	0	1	0

Comparing Fry-to-Smolt Survival Rates in Hatchery and NORs

Estimates of fry abundance have to be made in order to compare the fry-to-smolt survival of sockeye juveniles originating from different sources. Two basic types of comparisons are possible; one uses the abundance of hatchery and NOR fry at the time they enter Lake Washington. The other uses the abundance of hatchery fish at the time they were released into the Cedar River. In the first method, the mortality of hatchery fry as they emigrate down the Cedar River is not included while in the second it is. Altogether, seventeen groups of hatchery sockeye fry were produced from the adults artificially spawned in 2002. Their offspring were released in 2003 from the Landsburg Hatchery and at the time we sampled smolts in 2004 they were 1.0+ in age. Data in Table 2 show that over 98% of the smolts sampled in 2004 were 1.0+ fish and that there was an even higher prevalence of these fish in the hatchery-origin smolts (99.6% were 1.0+'s). Consequently, survival comparisons among the various types of sockeye juveniles are predominately based on the number of fry in each group produced from the 2002 Broodyear.

Hatchery fry can be pooled into three types based on the time they were released from the hatchery. The first third of the hatchery released were placed into an "Early" group, those that came from the middle third of the hatchery run were referred to as the "Middle" group, while the last third of the run were called the "Late" group. Hatchery fish were also categorized by where they were released. In 2003, hatchery fry were released in four different areas, at RK 0.16 (Airport), RK 3.1 (Riviera), mid-river (RK 22.4), and at the hatchery which is located at RK 36. In addition, paired groups of fed and unfed sockeye fry were released at RK 0.16 during the early, middle, and late portions of the hatchery fry out-migration period. In Table 3, the abundance of hatchery fry released at various times and locations is shown along with estimates of the number of wild fry that were produced from the Cedar River and northern tributaries.

Table 3 Part A. The number of sockeye fry released by the hatchery at various times and locations during the 2003 out-migration period. Data are from two sources, Seiler et al. 2004 (draft) and from current hatchery records.

# OF FRY RELEASED FROM THE HATCHERY (Source: Hatchery Database)					
	Release Location (RK)				
Time Period	Airport (RK 0.16)	Riviera (RK 3.1)	Middle (RK 22.4)	Landsburg (RK 36)	Total
Early	2,395,000	1,470,000	986,000	1,391,000	6,242,000
Middle	871,000	908,000	1,102,000	1,950,000	4,831,000
Late	1,165,000	901,000	1,274,000	1,564,000	4,904,000
Totals	4,431,000	3,279,000	3,362,000	4,905,000	15,977,000
# OF HATCHERY FRY ENTERING LK WASH. IN 2003 (Source: Seiler et al. 2004)					
	Release Location (RK)				
Time Period	Airport (RK 0.16)	Riviera (RK 3.1)	Middle (RK 22.4)	Landsburg (RK 36)	Total
Early	2,395,000	1,540,053	802,268	1,652,555	6,389,876
Middle	871,000	908,000	1,142,930	1,287,143	4,209,073
Late	1,165,000	997,861	738,521	914,441	3,815,823
Totals	4,431,000	3,445,914	2,683,719	3,854,139	14,414,772
# Of Fed and UnFed Sockeye Fry Released At The Airport in 2003					
Time Period	# Of Unfed Fry (controls)		# Of Fed Fry (treatment)		Totals
Early	1,246,000		1,149,000		2,395,000
Middle	574,000		297,000		871,000
Late	647,000		518,000		1,165,000
Totals	2,467,000		1,964,000		4,431,000

A number of hatchery groups were destroyed 2003 because of IHN and these losses account for the differences between Seiler et al.'s (2004) numbers and those reported by the hatchery. For example, a middle group of 296,000 fed-fry that was supposed to be

released at the Airport was destroyed. The loss of this group reduced the total number of fry released from the Airport by 296 K as well as reducing the total number of fry released during the middle part of the hatchery fry run. Nine hundred and forty-two thousand fry falling into various release groups were lost or destroyed in 2003 and hence were not released. At the time Seiler et al. produced their report these losses had not been accounted for. Consequently, the second set of numbers in Table 3 will represent the number of fry released from each area by the hatchery. Table 3 Part B provides estimates of the number of NOR fry entering Lake Washington during the winter and spring of 2003. These values were obtained from Seiler et al. 2004.

Table 3 Part B. Estimates of NORs entering Lake Washington during the spring of 2003. Data are from Seiler et al. 2004.

Estimated Number of NOR sockeye fry entering Lake Washington in 2003			
Location	Population Estimate	High Value	Low Value
Cedar River	27,859,466	34,776,202	20,942,730
Northern Tribs	2,216,993	2,512,790	1,912,197

The values shown in Table 3, parts A and B are the "gold standard" values that were used in a series of Chi Square tests performed to compare the fry-to-smolt survival rates of hatchery- and NOR sockeye. Table 4 summarizes the types of 1.0+ hatchery juveniles that were recovered. These numbers were also considered "gold standard" values for the Chi Square Tests.

Table 4. The number of thermally marked sockeye smolts observed in the fish sampled in Lake Union on May 11, 18, and 25, 2004.

	Release Location				
Time	Airport[1]	Riviera	Middle	Landsburg	Totals
Early	42	19	18	24	103
Middle	14	13	20	14	61
Late	36	17	8	17	78
Totals	92	49	46	55	242
1 Smolts originating from fed and non-fed fry are included in the Airport total					

The number of recovered smolts originating from "fed" and "unfed" fry released at the Airport location			
Time	# Unfeds Recovered	# Feds Recovered	Totals
Early	23	19	42
Middle	5	9	14
Late	13	23	36
Totals	41	51	92

Two general types of Chi-Square tests were performed (Table 5 and 6). One series compared the fry-to-smolt survival of hatchery-origin sockeye that had been released into

Table 5. Results of Chi-Square tests that compared the fry-to-smolt survival rates of NOR and hatchery origin fish that were either released in different areas of the Cedar River or that had been reared for a short period

Test #	Type of Sockeye Fry	Number Of Fry	Percentage Of Population	Total Recovered	Expected Number	Observed Number	Chi-Sq Value	Result	Conclusion
Fry Numbers Equal Those Entering Lake Washington									
1	Fed	1964000	0.4432	92	40.78	51	2.318	Chi Square 0.05	Fed sockeye fry
	Unfed	2467000	0.5568	92	51.22	41	1.845	df 1 = 3.841	survived at a higher rate
		4431000	1.0000				4.163	Reject H_O	than unfed cohorts
Fry Numbers Equal Those Released From The Hatchery									
2	Airport Unfed	2467000	0.1761	191	33.63	41	1.617		
	Riviera	3279000	0.2340	191	44.69	49	0.415		Failed to reject the H_O
	Middle	3362000	0.2399	191	45.82	46	0.001	Chi Square 0.05	that no difference
	Landsburg	4905000	0.3500	191	66.86	55	2.103	3 df = 7.815	occurred in the survival
		14013000	1.0000		191.00		4.135	Fail to Reject H_O	of non fed sockeye
Fry Numbers Equal Those Entering Lake Washington									
3	Airport Unfed	2462700	0.1933	191	36.93	41	0.450		Failed to reject the H_O
	Riviera	3445914	0.2705	191	51.67	49	0.138		that no difference
	Middle	2683719	0.2107	191	40.24	46	0.825	Chi Square 0.05	occurred in the survival
	Landsburg	3854139	0.3026	191	57.79	55	0.135	3 df = 7.815	of non fed sockeye
		12446472	0.9771		186.62		1.547	Fail to Reject H_O	from different releases
Fry Numbers Equal Those Entering Lake Washington									
4	Wild NORs	30076459	0.7072	997	705.11	793	10.832	Chi Square 0.05	NOR sockeye fry
	Hatch Unfeds	12450772	0.2928	997	291.89	204	26.166	df 1 = 3.841	survived at a higher rate
		42527231			997.00		36.998	Reject H_O	than unfed hatchery fry
Fry Numbers Equal Those Entering Lake Washington									
5	Wild NORs	30076459	0.9387	844	792.26	793	0.000	Chi Square 0.05	Failed to reject the H_O
	Fed Hatch	1964000	0.0613	844	51.74	51	0.001	df 1 = 3.841	that NORs and Fed fry
		32040459			844.00		0.001	Fail to Reject H_O	survive at similar rates

Table 6. Results of Chi-Square tests that compared fry-to-smolt survival rates in fed and unfed hatchery origin sockeye that were released at different times into the Cedar River

Test #	Type of Sockeye Fry	Number Of Fry	Percentage Of Population	Total Recovered	Expected Number	Observed Number	Chi-Sq Value	Result	Conclusion
Fry Numbers Equal Those Released From The Hatchery									
1	Early unfed	5093000	0.3425	223	76.37	84	0.762	Chi Square 0.05	Failed to reject the H_O
	Middle unfed	4534000	0.3049	223	67.99	61	0.719	df 2 = 5.991	unfed fry released at
	Late unfed	4386000	0.2949	223	65.77	78	2.274	Fail to Reject H_O	different times had
		14013000	0.9423		210.13	223	3.754		similar survival rates
Fry Numbers Equal Those Entering Lake Washington									
2	Early unfed	5240876	0.4209	223	93.87	84	1.037	Chi Square 0.05	Unfed Late fry survived
	Middle unfed	3912073	0.3142	223	70.07	61	1.173	df 2 = 5.991	at a higher rate than Early
	Late unfed	3297823	0.2649	223	59.07	78	6.070	Reject H_O	& Middle unfed fry who
		12450772			223.00		8.280		had equal survival rates
Fry Numbers Equal Those Entering Lake Washington (Airport Releases Only)									
3	Early Fed	1149000	0.5850	51	29.84	19	3.936		Late Fed fry survived at
	Middle Fed	297000	0.1512	51	7.71	9	0.215	Chi Square 0.05	a higher rate than Early
	Late Fed	518000	0.2637	51	13.45	23	6.779	df 2 = 5.991	and Middles. See Chi
		1964000	1.0000		51.00	51	10.930	Reject H_O	#4 for continuation
4	Early Fed	1149000	0.7946	28	22.25	19	0.340	Chi Square 0.05	Fail to reject H_O that fed
	Middle Fed	297000	0.2054	28	5.75	9	1.314	df 1 = 3.841	fry released early and
		1446000			28.00	28	1.654	Fail to Reject H_O	middle have similar survival rates.
Fry Numbers Equal Those Entering Lake Washington (Airport Releases Only)									
5	Early Unfed	1246000	0.5051	41	20.71	23	0.254	Chi Square 0.05	Failed to reject the H_O
	Middle Unfed	574000	0.2327	41	9.54	5	2.160	df 2 = 5.991	that time of release had
	Late Unfed	647000	0.2623	41	10.75	13	0.470	Fail to Reject H_O	no affect on the survival
		2467000			41.00	41	2.884		on unfed fry released at different times

different areas of the Cedar River. Moreover, the fry-to-smolt survival of fed and unfed sockeye released at the Airport were compared, and comparisons between fry-to-smolt survival in NOR and fed and unfed hatchery fish were conducted. As Table 5 shows, fed fry achieved a greater fry-to-smolt survival rate than unfed fry. Wild or NOR fry survived at a higher rate than unfed hatchery fry, yet no difference in the fry-to-smolt survival rates of NOR and fed hatchery fry were found. In addition, no difference in fry-to-smolt survival rates were found in unfed hatchery fish that had been released into different parts of the Cedar River, i.e. fry released at Landsburg had similar fry-to-smolt survivals as those liberated at Riviera.

In Table 6 the effects of release time on fry-to-smolt survival in hatchery-origin fry are presented. The results of the first test (that uses numbers of fry released from the hatchery) indicate that time of release does not affect fry-to-smolt survival. However, the second test (that uses the numbers of fry from each release time that were estimated to enter Lake Washington) shows that unfed fry released during the last third of the hatchery run did achieve higher fry-to-smolt survival rates than those liberated during the first two thirds of the run. A subsequent Chi-Square test using Yates correction factor disclosed fry released in the early and middle periods had similar fry-to-smolt survival rates. The next three tests examine the consequence of time of release on fed and unfed fry released at the Airport site. As tests 3 and 4 indicate, fed fry released during the late part of the run had greater fry-to-smolt survival rates than those liberated during the first two-thirds of the run. Time of release, however, had no affect on fry-to-smolt survival in unfed fry released at the Airport location.

Comparing The Body Sizes Of Hatchery and NOR smolts

Three t-tests were performed on NOR 1.0+ smolts to determine if the sex of a smolt affected its fork length at the time of capture. All of these tests were non-significant suggesting that sex does not influence body size at out-migration (Table 7). A One-Way ANOVA was then performed that compared the mean fork lengths of NORs and hatchery fish released at different times (Early, Middle, and Late). The test indicated that Early Hatchery smolts were larger than smolts originating from NORs and from Late Hatchery releases. Smolts produced from Middle Hatchery fry, Late Hatchery fry and NORs were all comparable in size. As Table 8 shows the mean size of smolts from each of these groups were similar to one another, ranging from 138 mm (Early Hatchery smolts) to 132 mm (Late Hatchery smolts).

Table 7. Results of t-tests that compared the mean length of female and male NOR 1.0+ smolts captured on three sampling days in 2004.

Date Collected	Sex	Number	Mean Fork Length (mm)	t-value	Conclusion
11 May	Female	155	136.1	0.248	Fail to reject H_O that male and female smolts are the same size
	Male	116	136.4		
18 May	Female	117	128.6	1.251	Fail to reject H_O that male and female smolts are the same size
	Male	149	130.1		
25 May	Female	121	134.9	0.698	Fail to reject H_O that male and female smolts are the same size
	Male	127	133.7		

Table 8. The mean size of 1.0+ NOR and hatchery-origin sockeye smolts sampled in 2004 from Lake Union.

Origin of Smolt	Number	Mean Size
Early Hatchery Release	83	137.78
Middle Hatchery Release	52	135.29
NOR	793	133.25
Late Hatchery Release	54	132.35

Three additional One-Way ANOVAs were performed to see if body size within smolts produced by the same type of fry changed because of sampling date. A significant result was obtained in one of these analyses. Smolts captured on the 18th of May produced from hatchery fry released during the middle of the run were smaller than those obtained from this group on the 11th and 25th of May. However, it appears that smolt size within a group tended to remain constant over the sampling dates used in 2004 (Table 9).

Table 9. The mean fork lengths of sockeye smolts captured in Lake Union that originated from the same type of fry.

Origin of Smolts	Sampling Date	N	F value	Mean FL (mm)	Conclusion
	11 May	24		140.6	
	18 May	17		138.5	
Early Hatchery	25 May	19	0.397	138.5	Fail to Reject H_O
	11 May	20		139.9	Reject H_o smolts collected on 18 May were smaller than those obtained on the 11th and 25th.
	18 May	14		127.9	
Mid Hatchery	25 May	13	9.019	137.2	
Late Hatchery	11 May	18	2.836	137.9	
	18 May	13		137.2	
	25 May	18		131.6	Fail to Reject H_O

Some Final Thoughts

These results should not be generalized across multiple brood years. Recall, that most of the smolts sampled originated from the 2002 brood year. Survival estimates could change even for this brood year if we find that some of the treatments produce significant numbers of 2.0+ smolts. Moreover, specific yearly interactions may occur between treatments and the conditions present in Lake Washington. Consequently, the effects of different hatchery release sites, time of release, and rearing programs may change over time.

Because of the inherent incompleteness of the data we have gathered it is important that we begin a regular program of obtaining representative samples of out-migrating smolts from Lake Washington.

Moreover, a similar effort should be carried out on adult sockeye as they enter freshwater. Only by conducting such sampling on a consistent basis will we be able to legitimately decipher the biological effects of the hatchery strategies that are being implemented.