2005 Lake Washington Sockeye Smolt Sample Analyses

Synopsis of Results

1) From May 6th through June 2nd 2005, WDFW (Dave Seiler and his staff) collected 814 out-migrating sockeye smolts from Lake Union.
2) On each sampling date approximately 10% of the smolts originated from hatchery-origin fry
3) One hundred percent of the hatchery-origin and 95% of the natural origin (NORs) smolts were 1-yr-old smolts. The remaining NOR smolts were either 2- (4.5%) or 3-yr-olds (0.4%).
4) Fourteen groups of hatchery fish were released in 2004 and were responsible for the hatchery-origin smolts collected in 2005. The fish were released at two locations, at Landsburg and at a site close to the mouth of the river. Fry releases were categorized as early (20 Jan – Feb 21, 2004), middle (Feb 23 – Mar 4, 2004) or late (Mar 12 – Apr 6, 2004). A series of Chi-Square tests were performed that compared the fry-to-smolt survival of the various hatchery release groups. Fry-to-smolt survival of hatchery- and NOR fry was also compared.
    a) Release timing affected the survival of unfed hatchery fry. Individuals released in the late period had the highest survivals, those released during the middle were next while those released in the early period had the poorest survival.
    b) Release location had no affect on fry-to-smolt survival of unfed fry once they had entered Lake Washington.
    c) Release timing did not affect the survival of fed fry.
    d) Fed fry survived at higher rates than unfed fry.
    e) NOR fry survived at a higher rate than unfed hatchery fry released during the early and middle periods. However, NORs and hatchery fry released in the late period appeared to have equivalent fry-to-smolt survivals
    f) NOR and fed hatchery fry had similar fry-to-smolt survivals
5) The mean size of NOR smolts increased in size over the sampling period. A similar trend was seen in hatchery-origin smolts.
6) Smolts originating from fed and unfed hatchery fry released during the early period had comparable fork lengths. However, fed fry released during the middle period were larger at the smolt stage than the smolts produced from unfed fry released at the same time.
7) Smolts derived from NORs were smaller than hatchery origin smolts in the May 6th sample but hatchery origin and NOR smolts were comparable in size in the May 13 and May 18 samples. Size comparisons between NOR and hatchery-origin fry for the May 25 and Jun 2 samples were not made because of the small number of hatchery origin fish present in these samples.
8) A regular program of sampling sockeye smolts just before they exit out of the Lake Washington Basin was started in 2004. The above results represent findings from the second collection of smolts. Smolts were also collected in 2006 and are currently undergoing analysis.

Otolith Decode Information From The Sockeye Smolts Collected In May and June Of 2005 From Lake Union

Most of the sockeye smolts produced from the Lake Washington Basin originate from the Cedar River, a southern tributary to the lake (Cedar River population), or from fish that spawn in streams emptying into the northern part of the lake (Northern Tributary populations). A few may also be from sockeye that use spawning areas scattered around the lake shoreline (Beach Spawning populations). Smolts produced from the Northern Tributary and Beach Spawning populations are produced by naturally spawning adults and are thus natural origin recruits or NORs. Those from the Cedar River can be either NORs or derived from a hatchery that is located at Landsburg (RK 36). Generally, hatchery sockeye are released into the Cedar River as unfed fry. However, beginning in brood year 2001 and continuing through brood year 2003, some groups of fry were fed for approximately two weeks prior to being released into the Cedar River. All the fry incubated at the hatchery receive thermal marks in their otoliths making it possible to identify when and where the fish were planted and if they had been reared prior to release.

Beginning in 2004, and continuing in 2005 and 2006 representative samples of sockeye smolts have been collected in lakes Washington and Union just prior to their entry into seawater. The primary goal of these collections was to compare the fry-to-smolt survival rates of hatchery- and NOR sockeye. In addition, data collected on the smolts provided information on:

1) The percentage of smolts originating from the hatchery program
2) The age and size composition of both NOR and hatchery-origin smolts
3) The effect of different hatchery release locations, times, and rearing strategies on the size and fry-to-smolt survival of hatchery sockeye
4) Inter-annual effects on smolt size, age at smolting, and survival

The results of the otolith decodes made on the smolts collected in 2004 were provided to Seattle Public Utilities and the Anadromous Fish Committee in July of 2005. This report presents similar information on the decode data collected on the smolts captured in the spring of 2005.

Origin and Age Of The Sockeye Smolts Collected In 2005

Over a five-week period starting on May 6 and ending on June 2, 2005 Lake Washington sockeye smolts were sampled via a purse seine just before they entered seawater. A total of 814 smolts were collected. Sampled fish were stored over ice and delivered to WDFW's Otolith Laboratory for processing. The samples were typically delivered to the lab in the early evening and consequently they were frozen so that they could be processed at a later time. Fork lengths to the nearest mm, scale samples and otoliths were extracted from each fish. We evaluated the affect of freezing and thawing on fork length and body weight values by weighing and measuring the same fish in a fresh state and after it had been frozen and thawed. A total of 60 smolts were processed in this manner and data collected from them were used in paired t-tests to see if freezing and thawing had an affect on their length and weight values. These tests disclosed that fork lengths decreased on average by 3% ($t = 16.5$; $p < 0.001$) and body weight decreased on average by 11% ($t = 5.2$; $p < 0.001$) after a fish had been frozen and thawed. Desiccation caused by freezing apparently was responsible for the observed reduction in size. All of the size measurements we used in our 2004 and 2005 analyses were taken on fish that had been frozen and thawed. This approach will be continued into the future because of the effects of freezing and thawing on smolt size and the need to use a consistent method for data collection. In 2004 the sex of each smolt was determined by dissection. However, no differences in size or age were found between male and female smolts so fish gender was not ascertained in the 2005 samples.

The numbers and percentage of hatchery and wild fish captured per sampling date in 2005 are presented in Table 1. On average about 10% of the smolts collected on each sampling date were of hatchery origin. Ninety-five percent confidence intervals (95% CI's) around the percentage of hatchery fish recovered on each sampling date are shown in the table. A correlation analysis between collection date (Julian Date) and percentage of hatchery origin smolts in each sample was performed to see if the abundance of hatchery fish increased or decreased over time. Prior to performing the analysis, the percentage values were normalized by using the arc sin square root transformation. The analysis was non-significant ($p = 0.221$) suggesting that the proportion of hatchery smolts was similar on each sampling date. A similar result occurred in 2004 where almost equal numbers of smolts were sampled throughout the sampling period (May 11, 18, and 25, 2004) and comparable percentages of hatchery smolts (~24%) were collected on each date. At least for these two collections of smolts the percentage of hatchery and wild fish remained relatively constant throughout the sampling period.

Table 1. The number and percentage of hatchery and NOR sockeye smolts sampled in the Lake Washington Basin in May and early June, 2005.

2005 Sampling Dates	No. Of Smolts Collected	No. Of Hatchery Smolts[a]	No. Of NOR Smolts	% Hatchery Smolts	95% CI's For % Hatchery Smolts	% NOR Smolts
6 May	192	21	171	10.94	6.5 –15.4	89.06
13 May	170	25	145	14.71	9.4 – 20.0	85.29
18 May	347	31	316	8.93	5.9 – 11.9	91.07
25 May	93	7	86	7.53	2.2 – 12.9	92.47
2 Jun	12	1	11	8.33	0 – 23.9	91.67
Totals	814	85	729	10.44	8.3 – 12.5	89.56
[a] identified by the presence of a thermal code in their otoliths						

Ninety-six percent of the NOR and one hundred percent of the hatchery-origin smolts sampled in 2005 were 1 year-old fish. Approximately 4% of the NOR smolts were 2 year olds and 0.4% were aged as 3 year olds (Table 2). The age distribution of the 2004 smolts was very similar to that seen in 2005. As in 2005, there were no 2 year old hatchery fish and relatively few (~2%) of the NOR smolts were two year olds. Three year-old smolts were rare in 2005 and none were observed in 2004. Consequently, in 2005 and in 2004 over 94% of the sockeye smolts leaving the Lake Washington basin were 1 year-old fish.

Table 2. The occurrence of one-, two-, and three-year-old sockeye smolts in NOR and hatchery origin fish collected in the Lake Washington Basin in 2005.

2005 Sampling Dates	Type Of Smolt	No.	No. Of 1-yr-olds	No. Of 2-yr-olds	No. Of 3-yr-olds	Unreadable	Other
6 May	NOR	171	168	3	0	0	0
13 May	NOR	145	128	16	1	0	0
18 May	NOR	316	299	11	2	0	4
25 May	NOR	86	86	0	0	0	0
2 Jun	NOR	11	11	0	0	0	0
Sub Total		729	692	30	3	0	4
6 May	Hatch	21	21	0	0	0	0
13 May	Hatch	25	25	0	0	0	0
18 May	Hatch	31	31	0	0	0	0
25 May	Hatch	7	7	0	0	0	0
2 Jun	Hatch	1	1	0	0	0	0
Sub Total		85	85	0	0	0	0

Confidence Intervals Around The Smolt Age Estimates For 2005			
Smolt Age	Smolt Type	% Of Sample	± 95% Confidence Intervals
1-yr-old	NOR	94.9	93.3% – 96.5%
	Hatchery	100.0	
2-yr-old	NOR	4.1	2.67 % - 5.6%
3-yr-old	NOR	0.4	0.0% - 0.9%

Comparing Fry-to-Smolt-Survival Rates In Hatchery and NOR Sockeye

Estimates of fry abundance have to be made before it is possible to compare the fry-to-smolt survival rates of sockeye smolts that have originated 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 of their release into the Cedar River. In the first method, the mortality of hatchery fry as they migrate down the Cedar River is accounted for while in the second it is not. Altogether, fourteen groups of hatchery sockeye were produced from the adults artificially spawned in 2003. Their offspring were released in 2004 and at the time smolts were sampled in 2005 they were 1-yr-old fish. As indicated above, almost all the sockeye smolts leaving Lake Washington are 1 yr-old fish. Consequently, the fry-to-smolt survival comparisons among the various types of sockeye are based on the number of 1 yr-old smolts each group produced.

Hatchery fry were pooled into three types based on the time they were released. The first third of the fry released from the hatchery were placed into an "early" group. Those that originated from the middle third were referred to as the "middle" group, while the last third of the released fish were called the "late" group. Hatchery fish were also categorized by where they were released. In 2004, hatchery fry were released from two locations, at the hatchery (RK 36) and at a site close to the mouth of the Cedar River (RK 0.16, referred to as the Airport). In addition, paired groups of fed and unfed fry were released at the lower river site during the early and middle portions of the hatchery fry out-migration period. In Table 3A estimates of the in-river survival of fry that were released at the hatchery are presented. These estimates were calculated by Seiler et al. (2005). In Table 3B a summary of the hatchery fry releases made in 2004 is shown and in Table 3C the estimated number of NOR fry entering Lake Washington is presented. The estimates of NOR abundance were also obtained from Seiler et al. (2005).

Table 3A. Estimates of in-river survival of fry released from the Cedar River Hatchery in 2004 (Data from Seiler et al. 2005).

Release Type	# Released	# Estimated Entering Lake Washington	% Survival
Early Releases Jan 20 – Feb 21, 2004	205,000	117,145	57.14%
	389,000	360,780	92.75%
	310,000	296,613	95.68%
	240,000	140,357	58.48%
Sub Total	1,144,000	914,895	79.97%
Middle Releases Feb 23 – Mar 4, 2004	570,000	466,516	81.84%
	82,000	62,652	76.40%
	351,000	267,695	76.27%
Sub Total	1,003,000	796,863	79.45%
Late Releases Mar 12 – Apr 6, 2004	266,000	147,543	55.47%
	198,000	106,219	53.65%
	95,000	51,476	54.19%
	11,000	5,647	51.34%
Sub Total	570,000	310,885	54.54%
Overall Total	2,717,000	2,022,643	74.44%

Table 3B. The number of sockeye fry released by the hatchery at various times and locations during the 2004 our-migration period. Data are from hatchery out-planting records.

Unfed Sockeye Fry Releases From The Landsburg Hatchery: 2004					
	Release Locations				
Time Period	Release Code	RK 0.16 (Airport)	Release Code	RK 36 (Landsburg)	Total
Early	E3	1,181,000	E1	1,144,000	2,325,000
Middle	M3	1,104,000	M1	1,003,000	2,107,000
Late	L3	379,000	L1	570,000	949,000
Totals		2,664,000		2,717,000	5,381,000

Releases of Fed and Unfed Control Fry At The Airport Site (RK 0.16): 2004					
Time Period	Release Code	Unfed Controls	Release Code	Fed Fry	Total
Early	EC1	648,000	EF1	204,000	852,000
Early	EC2	606,000	EF2	577,000	1,183,000
Sub Total		1,254,000	Sub Total	781,000	2,035,000
Middle	MC3	574,000	EF3	660,000	1,234,000
Middle	MC4	555,000	EF4	459,000	1,014,000
Sub Total		1,129,000	Sub Total	1,119,000	2,248,000
Overall Total		2,383,000		1,900,000	4,283,000

Summary Of Types of Fry Released At The Airport and Landsburg Locations: 2004			
Release Location			
Airport Releases Including Controls		Landsburg Releases	
Total Early Unfeds	2,435,000	Total Early Unfeds	1,144,000
Total Middle Unfeds	2,233,000	Total Middle Unfeds	1,003,000
Total Late Unfeds	379,000	Total Late Unfeds	570,000
Grand Total All Unfeds	5,047,000	Grand Total All Unfeds	2,717,000
Season Total For All Unfed Fry Released			7,764,000
Season Total For All Fed Fry Released			1,900,000
Total Number of Fed and Unfed Fry Released			9,664,000

Table 3C. Estimated number of natural origin recruit (NOR) sockeye fry entering Lake Washington during the winter and spring of 2004 (Data are from Seiler et al. 2005).

Location	Population Estimate
Cedar River	38,686,899
Northern Tributary Populations	177,801
Grand Total	38,864,700

The values shown in Table 3, parts A, B and C 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 yr-old hatchery smolts that were recovered. These numbers were also used as gold standard values in the Chi-Square tests.

Table 4. The number of hatchery origin sockeye smolts recovered from fish sampled on May 6, 13, 18, 25, and June 2, 2005 in the Lake Washington Basin.

Release Time	Release Location		Total Number Recovered
	Airport (RK 0.16)[a]	Landsburg	
Early	16	5	21
Middle	40	8	48
Late	9	7	16
Totals	65	20	85
Number of Smolts Originating From The Paired Fed and Unfed Fry Groups Released At The Airport Site			
Release Time	Recovered Unfeds	Recovered Feds	Total Number Recovered
Early	6	8	14
Middle	12	23	35
Totals	18	31	49
[a] The number of smolts originating from fed and unfed fry are included in the Airport total.			

Two series of Chi-Square tests were performed. One set examined whether time of release, release location, or feeding affected fry-to-smolt survival of hatchery fry. The other compared fry-to-smolt survival values of hatchery fry to NORs. In all of these analyses, the number of fry estimated to have entered Lake Washington from each group was used to calculate the proportion that treatment represented in the overall fry population. This percentage was used to determine the expected values in the Chi–Square analyses.

The first within hatchery treatment Chi-Square test evaluated the effect that release time (early, middle, and late) had on survival. The test showed that late fry survived at a higher rate than middle fry and that middle fry had higher survivals than those liberated during the early third of the fry release period. The second set of tests examined the importance of release location on survival. These tests compared fry-to-smolt survival values of fry released at the same time (early, middle, and late) in two different locations, Landsburg and the Airport. Release location within the same time period had no affect on fry-to-smolt survival. The last series of within hatchery treatment comparisons examined the importance of feeding on fry-to-smolt survival. These tests were restricted to the paired releases of fry made at the Airport release location. As Table 3B shows there were four sets of fed and unfed fry. Two of the groups were released during the early period and two were released during the middle of the fry release period. The first Chi-Square tests run evaluated whether fish representing the same rearing treatment (fed or unfed) released at different times had similar fry-to-adult survival rates. That proved to be the case, so these groups were then pooled, creating one population of fed fry and another of unfed fry. A final Chi-Square was then performed to compare the performance of fed and unfed fry and it revealed that fed fry achieved higher fry-to-smolt survival rates than unfed cohorts. All of these within hatchery comparison and their results are summarized in Table 5.

The second set of Chi-Squares compared fry-to-smolt survival between NORs and unfed and fed hatchery fish. Two sets of tests were conducted. In the first one, the survival of NOR fry was compared with that of unfed fry released during the early, middle and late periods. Unfed hatchery fry released in the early and middle periods had poorer fry-to-smolt survival values than NORs. No difference in fry-to-smolt survival was detected between NORs and unfed hatchery fish released during the late period. In the second part of this analysis, the fry-to-smolt survival rates of fed and NOR fry were compared. In this analysis the null hypothesis of equivalent survival could not be rejected. Consequently, two types of hatchery fry, those that were released relatively late, and those that had been reared for several weeks, had fry-to-smolt survival values that were comparable to NOR fry. The results of the tests used to compare hatchery and NOR fry are shown in Table 6.

Comparing The Body Sizes Of Hatchery And NOR Smolts

The importance of smolt origin (hatchery fed, unfed and NOR) and date of collection on length at capture was examined. Sampling date did affect size. A one-way ANOVA that compared the mean lengths of NOR smolts captured on different sampling dates showed that smolts captured on the first two sampling dates (May 6 and 13) were significantly smaller than those obtained on the last three dates (May 18 & 25, June 2). A similar trend occurred in hatchery origin smolts. In this case a regression analysis ($p < 0.001$) with a r^2 value of 0.18 showed that a slight increase in body size occurred from one sampling date to the next in the body sizes of hatchery-origin smolts. ANOVAs were also used to see if smolt size in hatchery fish was affected by whether they had been fed or not. For fed and unfed fry released during the early period no differences were seen ($p = 0.865$) however, in the middle release period, smolts originating from fed fry were significantly larger than those derived from unfed hatchery fry ($p = 0.004$).

The fork lengths of NOR and hatchery-origin smolts were compared using ANOVA methods. Separate ANOVAs were performed on the length data collected on each sampling date because smolt size in both NOR and hatchery-origin fish increased over time. A two-step procedure was used to run these tests. First, one-way ANOVAs were performed that compared the fork lengths of hatchery-origin smolts that were collected on the same sampling date. These were run to see if it would be possible to pool the lengths of hatchery smolts coming from different release strategies that had been collected on the same date. Altogether, three such ANOVAs were performed, one for the fish collected on the 6th, 13th, and 18th of May. Because so few hatchery-origin smolts were collected during the last two sampling dates they were not included in this analysis. The ANOVAs disclosed that the origin of a hatchery smolt did not affect its size at capture on May 13 and 18. However, on May 6, smolts derived from unfed fry released during the middle of the hatchery release period were significantly smaller than those originating from fed middle release hatchery smolts. These fish were removed from the

Table 5. Fry-to-smolt survival comparisons among the different hatchery fry release groups.

Comparison	Type Of Fry	Results Of Chi Square Tests		
		df	Chi-Square	Conclusions
Effect of release timing on the survival of unfed hatchery fry				
Early vs. Middle vs. Late	No. Entering Lake Washington	2	28.19	Reject H_o of equivalent survival
Early vs. Middle	No. Entering Lake Washington	1	4.39	Reject H_o of equivalent survival, Late > Middle> Early
Effect of release location on the survival of unfed hatchery fry				
Early Airport vs. Early Landsburg	No. Entering Lake Washington	1	0.01	Fail to reject H_o of equivalent survival
Middle Airport vs. Middle Landsburg	No. Entering Lake Washington	1	1.82	Fail to reject H_o of equivalent survival
Late Airport vs. Late Landsburg	No. Entering Lake Washington	1	0.02	Fail to reject H_o of equivalent survival
Effect of release timing on the survival of unfed fry used as controls in the paired fed and unfed fry survival study				
Early unfed vs. Middle Unfed	No. Entering Lake Washington	1	1.96	Fail to reject H_o of equivalent survival
Effect of release timing on the survival of fed fry used in the paired fed and unfed fry survival study				
Early fed vs. Middle fed	No. Entering Lake Washington	1	2.40	Fail to reject H_o of equivalent survival
Effect of feeding on the survival of hatchery fry				
Fed vs. Unfed	No. Entering Lake Washington	1	6.35	Reject H_o, Fed had higher survivals

Table 6. Fry-to-smolt survival comparisons among the NOR fry and hatchery fry release groups

Comparison	Type Of Fry	Results Of Chi Square Tests		
		df	Chi-Square	Conclusions
The fry-to-smolt survival rates of NORs vs. unfed hatchery fry released at three different times				
NORs vs. Early Unfeds	No. Entering Lake Washington	1	23.62	Reject H_o NOR > Early Unfeds
NORs vs. Middle Unfeds	No. Entering Lake Washington	1	14.44	Reject H_o NOR > Middle Unfeds
NORs vs. Late Unfeds	No. Entering Lake Washington	1	0.82	Fail to reject H_o of equivalent survival between Late Unfeds and NORs
The fry-to-smolt survival of NORs vs. Fed fry released from the Airport location				
NORs vs. Fed Fry	No. Entering Lake Washington	1	0.15	Fail to reject H_o of equivalent survival between Feds and NORs

pooled sample. The ANOVAs that compared the lengths of NOR and hatchery smolts indicated that the hatchery fish collected on May 6 were longer than the NORs collected on that date ($p < 0.001$). No difference in mean size was detected between the two types of smolts on the remaining two sampling dates, $p = 0.128$ for May 13 and $p = 0.750$ for May 18 (Table 7). A summary of the smolt length information for all the hatchery and NOR smolts is shown in Table 8.

Table 7. The mean size of NOR and pooled hatchery-origin sockeye smolts collected on May 6, 13, and 18, 2005 in the Lake Washington Basin.

Sampling Date	Smolt Origin	n	Mean Fork Length	Standard Deviation
May 6	NOR	166	114.2	7.27
	Hatchery	14	122.4	6.01
May 13	NOR	127	120.9	7.15
	Hatchery	24	123.5	7.42
May 18	NOR	296	126.2	8.31
	Hatchery	31	125.7	10.10

Some Final Considerations

The validity of the above results depends upon the assumption that the samples collected are representative of the entire sockeye smolt population leaving Lake Washington. Three factors tend to support this assumption. First, samples were taken over a fairly extensive period. Second the proportion of hatchery fish collected on each sampling date remained fairly constant, and third non size-selective gear (a purse seine) was used to obtain the samples.

If the samples are representative then it appears that rearing the fish for a short period of time does provide them with some survival advantage over unfed fry. This finding also occurred in the 2004 analysis. Another interesting finding was the apparent survival advantage enjoyed by unfed hatchery fry released during the late period.

Table 8. Mean fork lengths of NOR and hatchery-origin smolts by capture date.

Sampling Date	Smolt Origin	n	Mean Fork Length	Standard Deviation
May 6	Early Unfed	2	124.5	2.12
	Early Fed	1	118.0	-
	Middle Fed	9	123.2	6.59
	Middle Unfed	6	114.8	3.13
	Late	3	118.7	5.51
	NOR	167	114.2	7.26
May 13	Early Unfed	4	127.5	5.74
	Early Fed	2	121.0	8.49
	Middle Fed	7	126.0	8.04
	Middle Unfed	10	121.20	7.60
	Late	2	117.5	0.71
	NOR	128	121.1	7.28
May 18	Early Unfed	4	119.25	2.50
	Early Fed	3	128.0	8.66
	Middle Fed	5	134.4	6.31
	Middle Unfed	8	126.0	8.18
	Late	11	123.2	12.79
	NOR	298	126.5	9.86
May 25	Early Unfed	2	133.5	2.12
	Early Fed	2	129.0	4.24
	Middle Fed	2	141.0	9.90
	Middle Unfed	1	123.0	-
	Late	0	-	-
	NOR	86	126.7	8.54
Jun 2	Early Unfed	1	144.0	-
	Early Fed	0	-	-
	Middle Fed	0	-	-
	Middle Unfed	0	-	-
	Late	0	-	-
	NOR	11	127.7	10.21

Literature Cited

Seiler, D., G. Volkhardt, and L. Fleischer. 2005. Evaluation of downstream migrant salmon production in 2004 from the Cedar River and Bear Creek. Washington Department of Fish and Wildlife Technical Report FPA 05-05. 65 pp.