Results Of The Otolith Decodes Performed On Sockeye Smolts Leaving Lake Washington In 2007

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<u>Synopsis Of Results</u>

1) In 2007, Dave Seiler and WDFW staff collected 810 out-migrating sockeye smolts from Lake Union. A purse seine was used and sampling occurred on May 8, 15, 22, and 29.
2) On each sampling date approximately 43% of the sampled smolts originated from hatchery-origin fry.
3) One hundred percent of the hatchery-origin and 97.8% of the natural-origin smolts were one-year-old fish. The remaining natural origin smolts were either zero or two-year-old fish.
4) Seventeen groups of hatchery fish were released in 2006 and were responsible for the hatchery-origin smolts collected in 2007. Hatchery fish were released in the Cedar River at three locations, at Landsburg where the hatchery is located (RK 36.0), at a site referred to as the Trestle located at RK 21.7, and at a location near the mouth of the Cedar River, referred to as the Airport site (RK 0.2). Two types of fry were released at each location, those that had been artificially fed for several weeks and those that were liberated without any supplemental rearing. Releases were categorized as early (February 6 – February 23), middle (February 28 – March 6) or late (March 13 – April 12) depending upon when the fish were planted into the Cedar River. A series of Chi-Square tests were performed that compared the survival of the various hatchery release groups from the time they entered Lake Washington as fry to the smolt stage. Fry-to-smolt survival of the hatchery groups were also compared to that achieved by naturally produced sockeye fry.
    a) The effect of release time on the fry-to-smolt survival of hatchery fry was examined in a hierarchal fashion. First, survival of fed and unfed hatchery fry released at the same time was evaluated. In general, within, early, middle, and late releases, fed fry survived to the smolt stage at higher rates than unfed hatchery fry. Therefore the effect of release time was evaluated separately in fed and unfed fry. These analyses showed that time of release did not appear to have a consistent effect on the fry-to-smolt survival rates for either fed or unfed fry released in 2006.
    b) Additionally, where fed and unfed hatchery fry were released did not consistently affect their fry-to-smolt survival rates.
    c) Smolt origin did however affect fry-to smolt survival rates; fed hatchery fry achieved the highest fry-to-smolt survival rates while NOR fry had the lowest fry-to-smolt survival rates.
5) When smolts were sampled, i.e. capture date, did not affect mean fork lengths in hatchery or NOR sockeye smolts. Therefore smolt size remained fairly constant during the out –migration period
6) Fed and unfed hatchery fish released during the same time period (e.g. early, middle, and late) had similar fork lengths at smolting.
7) Time of release, however, did affect size at smolting. Hatchery fish released during the early and middle periods were larger than NOR smolts. Hatchery fish released during the early period were also larger than hatchery origin fish released during the late period.

Introduction

The majority of sockeye smolts produced from the Lake Washington Basin originate from the Cedar River (Cedar River population), a southern tributary to Lake Washington, or from fish that spawn in streams emptying into the northern part of the lake (Northern Tributary populations). A few may also originate from sockeye that used spawning beaches scattered around the lake (Beach Spawning populations). Smolts originating 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 population can be either NORs or derived from a hatchery located at Landsburg (RK 36). Most hatchery sockeye are released into the Cedar River as unfed fry. However, in broodyears 2001, 2002, 2003, and 2005 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 they were planted and if they had experienced a rearing period prior to being released.

Beginning in 2004 and continuing through 2008 samples of smolting sockeye from the Lake Washington Basin have been collected in Lake Union just prior to their entry into seawater. Data collected from these fish are being used to compare the fry-to-smolt survival rates of hatchery and NOR sockeye. Additionally, data collected on these samples provides information on:

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

The origin (NOR and hatchery release type) of each sampled smolt was determined by examining its otoliths for thermal mark patterns. Results of similar otolith decodes made on sockeye smolts collected in the Lake Washington Basin have been provided to Seattle Public Utilities and the Anadromous Fish Committee. This report presents similar information on the decode data collected on smolts captured in the spring of 2007.

Origin And Age Of The Sockeye Smolts Collected In 2007

Lake Washington sockeye smolts were sampled once per week using a purse seine just before they entered seawater from May 8 – May 29, 2007. A total of 810 smolts were collected. Sampled fish were stored over ice and delivered to WDFW's Otolith Laboratory for processing. Upon arrival the fish were frozen and held until they could be processed. Fork lengths to the nearest mm were taken after the fish had been allowed to thaw and scale samples and otoliths were also obtained from each fish.

The numbers and percentage of hatchery and wild fish captured per sampling date in 2007 are shown in Table 1. The occurrence of hatchery-origin smolts was fairly consistent from one sampling date to the next and averaged 43%. Similar trends occurred in smolts sampled in 2004, 05, and 06 (Figure 1). In combination these data suggest that hatchery and NOR sockeye smolts tend to out-migrate from the Lake Washington basin at similar times.

Table 1. The number and percentage of hatchery and NOR sockeye smolts sampled in the Lake Washington Basin in May 2007.

2007 Sampling Dates	No. Of Smolts Collected	No. Of Hatchery Smolts	No. Of NOR Smolts	% Hatchery Smolts	± 95% C.I.s For Hatchery Smolts	% NOR Smolts
08-May	320	144	176	45.00%	5.45%	55.00%
15-May	218	92	126	42.20%	6.56%	57.80%
22-May	264	106	158	40.15%	5.91%	59.85%
29-May	8	3	5	37.50%	33.55%	62.50%
Totals	810	345	465	42.59%	3.41%	57.41%

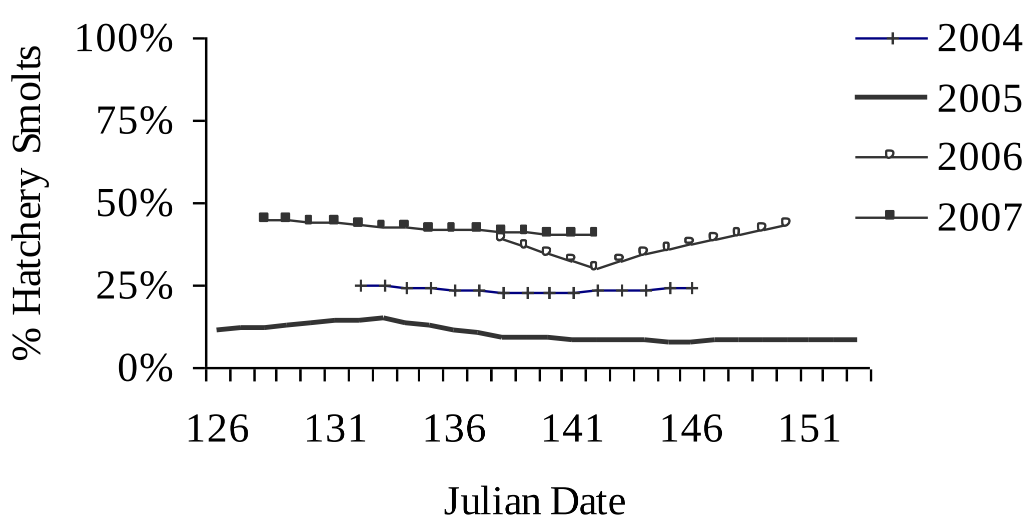

Figure 1. The percentage of hatchery and NOR sockeye smolts present in samples collected in Lake Washington from 2004 through 2007.

Over ninety-seven percent of the NOR smolts and one hundred percent of the hatchery-origin smolts sampled in 2007 were 1 year old fish. Nine or 1.9% of the NOR smolts sampled were two-year olds and for the first time a single age zero fish was identified. No three-year-old NORs were seen (Table 2).

Table 2. The age distribution of NOR and hatchery-origin sockeye smolts collected in the Lake Washington Basin in 2007.

2007 Sampling Dates	Smolt Origin	No.	No. Of 0-Yr-Olds	No. Of 1-Yr-Olds	No. Of 2-Yr-Olds	Other
08-May	NOR	176	0	172	3	1
15-May	NOR	126	0	120	6	0
22-May	NOR	157	1	157	0	0
29-May	NOR	5	0	5	0	0
Sub Total		465	1	454	9	1
08-May	Hatch	144	0	144	0	0
15-May	Hatch	92	0	92	0	0
22-May	Hatch	106	0	106	0	0
29-May	Hatch	3	0	3	0	0
Sub Total		345	0	345	0	0

95% Confidence Intervals Around The Smolt Age Estimates For 2007

Smolt Age	Smolt Origin	% Of Sample	± 95% Confidence Intervals
1-Yr-Old	Hatchery	100%	-
1-Yr-Old	NOR	97.84%	96.52% - 99.17%
2-Yr-Old	NOR	1.94%	1.30% - 2.58%

The age composition of the smolts collected in 2007 is very similar to what has been observed in our past collections. During the four-year period that smolts have been sampled in Lake Washington, ninety-five percent or more of them have been one-year old fish. In all four years, one hundred percent of the sampled hatchery origin fish smolted at age one. Two-year old smolts were observed but they were relatively rare, as their incidence in NORs ranged from 0.14% in 2006 to 4.12% in 2005. Two other age classes have also been observed in NORs, age zero and age 3 smolts. Both are very uncommon. For example, the only time we observed 3-yr-old smolts was in 2005. In that year, just three of them were detected out of 729 NORs that were sampled and as mentioned above, 2007 was the first year that we detected an age zero smolt. Even though age at smolting in NORs appears to be a little more diverse than it is in hatchery fish the vast majority of NOR and Hatchery-origin sockeye smolt at age one (Figure 2).

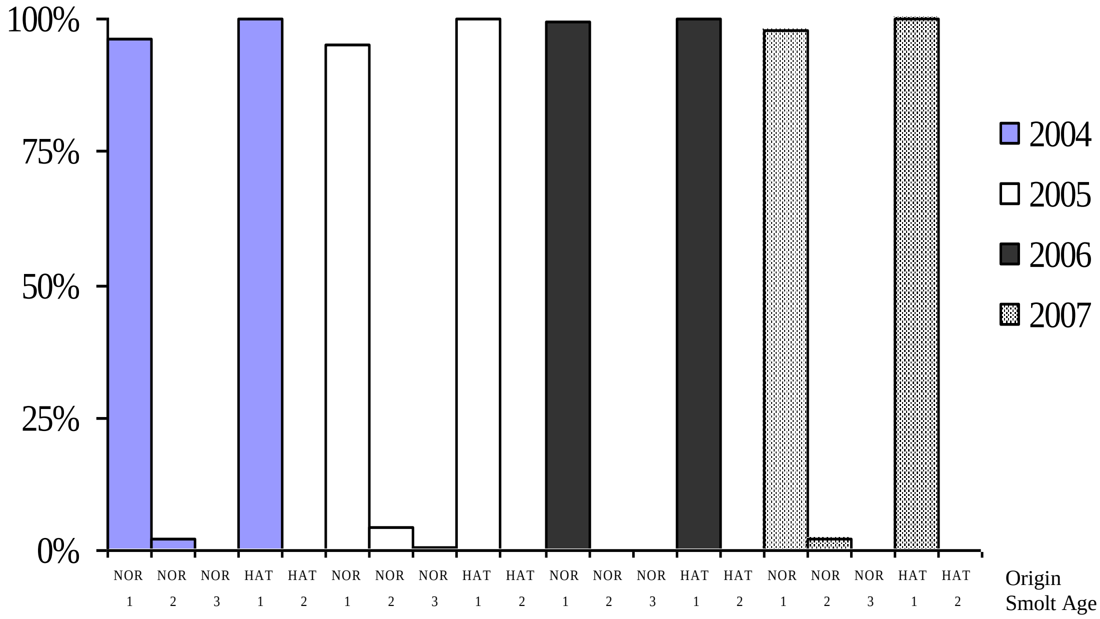

Figure 2. The age composition of NOR and hatchery-origin sockeye smolts sampled in the Lake Washington Basin from 2004 through 2007. NORs are natural origin smolts while HATs are smolts produced by the hatchery program. The number directly below the NOR or HAT designation represents smolt age.

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

One of the objectives of the smolt collection work has been to compare fry-to-smolt survival rates of hatchery origin fish originating from different release strategies. Another, has been to compare survival of fish originating from different hatchery treatments to NOR smolts. Two types of survival comparisons are possible, one uses the estimated 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. We used the first method, thus the results of the tests presented below compare the relative abundance of hatchery and NOR sockeye at the time they entered the lake to their relative abundance at the smolt stage.

Seventeen groups of hatchery fish were produced from the adults that were artificially spawned in 2005. Their offspring were released in 2006 and at the time they were sampled in 2007 they were one-year-old fish. As indicated above, almost all sockeye smolts leaving Lake Washington are one-year-olds. Consequently, all the fry-to-smolt survival comparisons shown below are based on the number of one-year-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. They were released into the Cedar River from the 6th through the 23rd of February 2006. Hatchery fry released from February 28th through the 6th of March were placed into a middle group, while the last third, or late group, was released from March 13th through the 12th of April. Hatchery fish were also categorized by where they were released. Three release locations were used in 2006. One was located at the hatchery (RK 36), another at a place referred to as the Trestle, which was located at RK 22 and the third spot was located at RK 0.16 and was referred to as the Airport Site. Two types of fry were released at each location, those that had been reared for up to 2 weeks and those that were released as unfed fry. During the rearing period fed fry gained approximately 30 to 50 mg, which represented a 20 to 30% gain in body weight and increased their fork lengths by 1 to 2 mm.

Estimates of the in-river survival of hatchery fry that were released into the Cedar River are presented in Table 3A which was taken from Kiyohara and Volkhardt (2007). No survival estimates were made for fry released at the Airport (RK 0.16). It was assumed

Table 3A. Estimates of in-river survival of fry released from the Landsburg Hatchery in 2006. Data are from Kiyohara and Volkhardt (2007).

Release Type	No. Released	Estimated No. Entering Lake Washington	% Survival
Early Releases	165,000	171,888	104.17%
6 Feb - 23 Feb 2006	566,000	340,620	60.18%
	289,000	148,042	51.23%
	692,000	345,039	49.86%
	819,000	103,908	12.69%
Sub Total	2,531,000	1,109,497	43.84%
Middle Releases	491,000	75,912	15.46%
27 Feb - 6 Mar	542,000	387,730	71.54%
	555,000	414,025	74.60%
	210,000	78,005	37.15%
	238,000	153,761	64.61%
Sub Total	2,036,000	1,109,433	54.49%
Late Releases			
13 Mar - 12 Apr	544,000	544,000	-
	700,000	700,000	-
	446,000	446,000	-
	206,000	206,000	-
	92,000	92,000	-
	38,000	38,000	-
Sub Total	2,026,000	2,026,000	

all the fry released at this location entered Lake Washington. In Table 3B a summary of the hatchery fry releases made in 2006 is shown and in Table 3C the estimated number of NOR fry entering Lake Washington is presented. Estimates of NOR abundance were also obtained from Kiyohara and Volkhardt (2007).

Table 3B. The number of hatchery sockeye fry released into the Cedar River in 2006. Data are from the hatchery out-planting records.

Time Period	Release Site	Date	No. Of Unfed Fry Released	No. Of Fed Fry Released
Early	Landsburg (RK 36.0)	06-Feb	0	165,000
		14-Feb	0	566,000
		21-Feb	0	289,000
	Landsburg Sub Total		0	1,020,000
	Trestle (RK 21.7)	22-Feb	692,000	
		23-Feb		819,000
	Trestle Sub Total		692,000	819,000
	Early Total		692,000	1,839,000
Middle	Landsburg (RK 36.0)	28-Feb	530,000	12,000
		05-Mar		210,000
	Landsburg Sub Total		530,000	222,000
	Trestle (RK 21.7)	27-Feb	491,000	
		02-Mar		555,000
		06-Mar		238,000
	Trestle Sub Total		491,000	793,000
	Middle Total		1,021,000	1,015,000
Late	Airport (RK 0.16)	13-Mar	544,000	
		16-Mar		700,000
		21-Mar		446,000
		29-Mar		206,000
		12-Apr	38,000	92,000
	Air Port Sub Total		582,000	1,444,000
	Late Total		582,000	1,444,000
			Total Number of Early Sockeye Fry Released	2,531,000
			Total Number of Middle Sockeye Fry Released	2,036,000
			Total Number of Late Sockeye Fry Released	2,026,000
			Grand Total Of All hatchery Fry Released in 2006	6,593,000

Table 3C. Estimated number of natural origin recruit (NOR) sockeye fry entering Lake Washington during the winter and spring of 2006. Data are from Kiyohara and Volkhardt (2007).

Location	Population Estimate	95% Confidence Interval
Cedar River	10,868,135	± 430,002
Northern Tributary Populations	548,604	± 42,066
Grand Total	11,416,739	± 472,068

A series of Chi-Square tests were performed to compare the fry-to-smolt survival rates of hatchery and NOR sockeye. The data presented in Table 3, parts A.B, and C along with that shown in Table 4, which summarizes the types and number of one-year-old hatchery smolts that were recovered in 2007, were used in these analyses.

Table 4. The number and type of hatchery-origin sockeye smolts recovered from each release location. The fish were sampled from Lake Union on May 8, 15, 22, and 29, 2007.

	Release Location								
	Airport (RK 0.16)		Trestle (RK 21.7)		Landsburg (RK 36.0)		Totals		
Release Time	Unfed	Fed	Unfed	Fed	Unfed	Fed	Unfed	Fed	Total Recovered
Early	0	0	25	46	0	47	25	93	118
Middle	0	0	14	48	6	9	20	57	77
Late	31	119	0	0	0	0	31	119	150
Totals	31	119	39	94	6	56	76	269	345

Three general sets of Chi-square analyses were performed. In the first set, the fry-to-smolt survival of fed and unfed hatchery fry that had been released during the same time period and location were contrasted. Five comparisons were made, one in the early release period and two each in the middle and late release periods. In four cases significant differences in survival were seen. In three of these, fed fry achieved higher survivals than unfed fry, and in one instance, unfed fry had higher survivals than fed individuals (Table 5A). Because the survival rates of fed and unfed fry differed from one another the effects of time and area of release on survival were evaluated separately for

Table 5. Fry-to-smolt survival comparisons among the groups of fry entering Lake Washington in 2006

A) Comparing The Fry-to-Smolt Survival Of Fed and Unfed Hatchery Origin Sockeye Released During The Same Time Period

Group	Otolith Code Designation	Release Location	No. Entering Lk Wa	% of Total	Obs. No. Recovered In Smolt Sample	Expected No.	Chi Square With Yates Correction	P value	Conclusion
Early Fed	EF2	Trestle	103,908	23.14%	46	16.43	51.42		
Early Unfed	EC2	Trestle	345,039	76.86%	25	54.57	16.57		Early Feds survived at a higher rate
Sub Total			448,947	100.00%	71	71.00	67.98	<0.001	than expected under Ho
Middle Fed	MF2	Trestle	567,786	88.21%	48	54.69	0.94		
Middle Unfed	MC2	Trestle	75,912	11.79%	14	7.31	5.24		Middle Unfeds survived at a higher
Sub Total			643,698	100.00%	62	62.00	6.18	0.013	rate than expected under Ho
Middle Fed2	MF1 + EF1	Landsburg	86,589	18.59%	9	2.79	11.70		
Middle Unfed2	MC1	Landsburg	379,146	81.41%	6	12.21	3.69		Middle Feds survived at a higher
Sub Total			465,735	100.00%	15	15.00	15.38	<0.001	rate than expected under Ho
Late Fed	LF4	Airport	1,146,000	67.81%	102	90.19	1.42		
Late Unfed	LC4	Airport	544,000	32.19%	31	42.81	3.54		Late Feds survived at a higher rate
Sub Total			1,690,000	100.00%	133	133.00	4.96	0.026	than expected under Ho
Late Late Fed	LLF4	Airport	298,000	88.69%	17	15.08	0.13		Failed to reject the null hypothesis
Late Late Unfed	LLC4	Airport	38,000	11.31%	0	1.92	3.05		that fed and unfed fry released at this
Sub Total			336,000	100.00%	17		3.19	0.074	time period had similar survival rates

Table 5. Fry-to-smolt survival comparisons among the groups of fry entering Lake Washington in 2006 continued. . .

B) Comparing The Survival Of Fed Hatchery Sockeye Fry Released At Different Times

Group	Otolith Code Designation	Release Location	No. Entering Lk Wa	% of Total	Obs. No. Recovered In Smolt Sample	Expected No.	Chi-Square Value	P value	Conclusion
Early Early Fed	EF1	Landsburg	660,550	23.07%	47	62.07	3.66		
Early Fed	EF2	Trestle	103,908	3.63%	46	9.76	134.49		Early Feds (EF2) survived at a higher rate than expected
Middle Fed	MF2	Trestle	567,786	19.83%	48	53.35	0.54		
Middle Fed2	MF1 + EF1	Landsburg	86,589	3.02%	9	8.14	0.09		
Late Fed	LF4	Airport	1,146,000	40.03%	102	107.68	0.30		
Late Late Fed	LLF4	Airport	298,000	10.41%	17	28.00	4.32		
Sub Total			2,862,833	100.00%	269	269.00	143.40	<0.001	
Early Early Fed	EF1	Landsburg	660,550	23.94%	47	53.39	0.77		
Middle Fed	MF2	Trestle	567,786	20.58%	48	45.89	0.10		
Middle Fed2	MF1 + EF1	Landsburg	86,589	3.14%	9	7.00	0.57		Failed to reject the Ho that the fed groups had similar fry to smolt survivals
Late Fed	LF4	Airport	1,146,000	41.54%	102	92.63	0.95		
Late Late Fed	LLF4	Airport	298,000	10.80%	17	24.09	2.09		
Sub Total			2,758,925	100.00%	223	223.00	4.47	0.346	

Table 5. Fry-to-smolt survival comparisons among the groups of fry entering Lake Washington in 2006 continued. . .

C) Comparing The Survival Of UnFed Hatchery Sockeye Fry Released At Different Times

Group	Otolith Code Designation	Release Location	No. Entering Lk Wa	% of Total	Obs. No. Recovered In Smolt Sample	Expected No.	Chi-Square Value	P value	Conclusion
Early Unfed	EC2	Trestle	345,039	24.96%	25	18.97	1.91		
Middle Unfed	MC2	Trestle	75,912	5.49%	14	4.17	23.13		
Middle Unfed2	MC1	Landsburg	379,146	27.43%	6	20.85	10.58		
Late Unfed	LC4	Airport	544,000	39.36%	31	29.91	0.04		Middle unfeds released from the
Late Late Unfed	LLC4	Airport	38,000	2.75%	0	2.09	2.09		Trestle had fry-to-smolt survival.
Sub Total			1,382,097	100.00%	76	76	37.75	<0.001	rates higher than expected
Early Unfed	EC2	Trestle	345,039	26.42%	25	16.37779	4.54		
Middle Unfed2	MC1	Landsburg	379,146	29.03%	6	17.99672	8.00		
Late Unfed	LC4	Airport	544,000	41.65%	31	25.82176	1.04		Middle unfeds (MC1) released
Late Late Unfed	LLC4	Airport	38,000	2.91%	0	1.803726	1.80		at Landsburg had fry-to-smolt
Sub Total			1,306,185	100.00%	62		15.38	0.004	survival rates lower than expected.
Early Unfed	EC2	Trestle	345,039	37.22%	25	20.8429	0.83		
Late Unfed	LC4	Airport	544,000	58.68%	31	32.86162	0.11		Failed to reject the null hypothesis that
Late Late Unfed	LLC4	Airport	38,000	4.10%	0	2.295481	2.30		fry-to-smolt survival was comparable
Sub Total			927,039	100.00%	56	56	3.23	0.199	in these groups

Table 5. Fry-to-smolt survival comparisons among the groups of fry entering Lake Washington in 2006 continued. . .

D) Comparing The Fry-to-Smolt Survival Of NOR and Hatchery-Origin Sockeye Fry

Group	Otolith Code Designation	No. Entering Lk Wa	% of Total	Obs. No. Recovered In Smolt Sample	Expected No.	Chi-Square Value	P value	Conclusion
NORs	-	11,416,739	75.59%	465	562.42	16.87		
Unfed	(EC2, LC4, LLC4)	927,039	6.14%	56	45.67	2.34		
Fed	(All but EF2)	2,758,925	18.27%	223	135.91	55.80		Fed fry had higher fry-to-smolt survival
		15,102,703	100.00%	744	744.00	75.01	<0.001	rates than unfed hatchery and NOR fry
NORs	-	11,416,739	92.49%	465	481.87	0.63		
Unfed	(EC2, LC4, LLC4)	927,039	7.51%	56	39.13	6.85		Unfed hatchery fry had higher fry-to-smolt
		12,343,778	100.00%	521		7.48	0.006	survival rates than NOR sockeye fry

fed and unfed hatchery fry. Time and area of release did not appear to have a strong affect on survival in fed fry. Only one group, fed fry released at the Trestle in the early period had a higher fry-to-smolt rate than the other five groups of fed fry (Table 5B). Similar tests were performed on the groups of unfed hatchery fry. In this case, two groups, both from the middle release period, had different fry-to-smolt survival rates than unfed fry releases occurring in the early and late release periods. In one instance, unfed fry released from the Trestle during the middle release period had higher survivals than expected. Conversely, unfed fry released from Landsburg in the middle period had a lower survival rate than expected (Table 5C). Consequently, time of release did not appear to have a consistent effect on fry to smolt survival for fed or unfed fry released in 2006.

Additionally, where hatchery fry were released did not appear to have a uniform effect on their survival. For example, fed fry released at Landsburg, the Trestle, and Airport had comparable fry-to-smolt survival rates (Table 5C). Additionally, unfed fry released at the Trestle and Airport had comparable fry-to-smolt survival rates yet unfed fry released at Landsburg during the early period had the lowest survival of any the groups of unfed fry.

The final set of Chi-Square tests compared the survival of NOR, fed- and unfed-hatchery origin fry (Table 5D). In these analyses, different release groups of fed and unfed hatchery fry were pooled if we had not previously rejected the hypothesis that they had achieved similar fry-to-smolt survival rates. Therefore, data from all the fed groups, except those released at the Trestle during the early period, were pooled. Similarly, data from three of the unfed groups (those released during the early and late periods) were pooled. Fed fry had the highest survival rates, followed by unfed hatchery fry. Fish with the lowest fry-to-smolt survival rate were the NORs.

Because four years of smolt samples have been analyzed it is now possible to put the 2007 results into context by comparing our current results to what was previously found. First, in three sampling years (2004, 2005, and 2007) it was possible to compare the survival of fed and unfed hatchery fry. In 2004 and 2005 fed fry achieved higher fry-to-smolt survivals than unfed fry ($P = 0.04$, 2004; $P = 0.01$, 2005). In 2007 this was also generally true as fed fry had better or equal survival rates to unfed individuals in four out of five releases. Thus, a relatively small increase in body weight and length appears to enhance the early survival of hatchery fry.

Second, in two (2004 and 2005) out of our four sampling years fry-to-smolt survival rates of unfed hatchery fry released during the late period were higher than those achieved by fish released at earlier dates. This tendency was not as strong in the smolts collected in 2006 and was not evident in fish collected in 2007. Hence, what is likely driving the survival of hatchery fry are the conditions the fish encounter once they enter Lake Washington. Retrospective analyses that examine the potential effects of a variety of limnological factors (e.g. water temperature, clarity, phytoplankton and zooplankton attributes such as abundance, size, and diversity, and the relative abundance of potential competitors and predators) may provide insights into what factors are largely responsible for early mortality in sockeye fry. From a management perspective such information could be used to delay or accelerate release times of cultured fish in order to maximize their potential survival.

Third, the consequences of release location on fry-to-smolt survival have been examined in all four years. In 2004 and 2005 release location had no apparent effect on fry-to-smolt survival. In 2006, unfed fry released at Landsburg did achieve a higher fry-to-smolt survival rate than individuals released at the Airport during the middle time period. The 2007 analyses, however, showed that unfed fry released at Landsburg had survived to the smolt stage at a lower rate than unfed fry released at the Trestle and Airport. Therefore, no consistent trend linking location to survival has manifested itself in the data we have so far examined. Thus, it does not appear that release location affects the ability of fry to survive to the smolt stage once they have entered Lake Washington. Instead as suggested above, their survival to the smolt stage is likely affected by the conditions they encounter soon after entering the lake.

Finally, one of the objectives of the Landsburg sockeye program has been to produce fry that are comparable to NORs. In 2004 and 2005, NOR fry had superior fry-to-smolt survival rates when compared to unfed hatchery fry. However, in 2006 and 2007, unfed hatchery fry had higher fry-to-smolt survivals than NORs. Hatchery fry typically enter Lake Washington at earlier dates than do NORs (Fresh et al. 2003). Two factors, the reliance on early maturing fish for broodstock and the relatively warm incubation temperatures at the hatchery likely cause this timing difference. Recall, in 2004 and 2005, hatchery fish released during the late period had superior survival rates to those released in the early and middle periods. One possible explanation for the superiority of NOR fry over unfed hatchery fry in 2004 and 2005 is that they entered Lake Washington when conditions were more favorable for fry survival. The opposite may have occurred in 2006 and 2007 when unfed hatchery fry had higher fry-to-smolt survival rates than NORs. In these years, early entrance in Lake Washington may have been beneficial. For example, the highest surviving group of unfed hatchery fry released in 2006 entered the lake in late February. Conversely, fifty percent of the Cedar River NORs did not enter the lake until April 11, some 43 days later (Kiyohara and Volkhardt 2007). What this suggests is that fry quality may be comparable between NORs and unfed hatchery fish as their subsequent survival to the smolt stage appears to be affected more by when most of them enter Lake Washington rather than their origin.

Unlike unfed hatchery fry, fed fry released in 2003 and 2004 (sampled as smolts in 2004 and 2005) realized similar fry-to-smolt survivals to NORs. In these two years, being reared for a short period of time apparently compensated for their early release date. Fed fry released in 2006 (sampled as smolts in 2007) survived to the smolt stage at a higher rate than NORs. In this case, feeding for short period apparently also provided the fish with a survival benefit. Although we have just a few sampling points, these data and the survival comparisons between fed and unfed hatchery fry, all suggest that a short rearing period does provide some positive survival benefits to hatchery-origin sockeye.

Comparing The Fork Lengths Of Hatchery-Origin and NOR Smolts

The importance of date of collection and smolt origin (NOR and fed and unfed fry released during the early, middle, and late periods) on smolt fork length was examined by using ANOVA. First, three, Two-Way ANOVAs were used to determine if fed and unfed hatchery fish released during the same time period (early, middle, and late) had different mean fork lengths. These analyses simultaneously tested whether the rearing treatment a fish received (fed vs. unfed) and the date (8^{th}, 15^{th}, and 22^{nd} May) it was collected as a smolt affected mean fork length. Additionally, each test evaluated whether there was an interaction between collection date, rearing history, and fork length. In all three analyses, the null hypothesis that fed and unfed fry released from the hatchery during the same time period produced smolts with similar fork lengths could not be rejected. Moreover, when a fish was sampled did not affect its fork length and no significant interactions between sampling date and rearing history on smolt length were seen. Second, a One-Way ANOVA was used to assess whether collection date affected fork length in NOR smolts. Like hatchery-origin fry, when a fish was collected did not appear to influence its fork length (Table 6).

Table 6. Results of the ANOVAs used to evaluate the importance of rearing history and collection date on the mean size of sockeye smolts originating from NOR and hatchery-origin fry.

Smolt Type	Null Hypothesis Tested	DF	*P* value
Early-Hatchery	Date of capture had no affect on smolt fork length	2	0.843
	Fed and unfed fry produce smolts with similar fork lengths	1	0.559
	There is no interaction between collection date and smolt fork length	2	0.534
	Error degrees of Freedom	112	
Middle-Hatchery	Date of capture had no affect on smolt fork length	2	0.324
	Fed and unfed fry produce smolts with similar fork lengths	1	0.981
	There is no interaction between collection date and smolt fork length	2	0.085
	Error degrees of Freedom	71	
Late-Hatchery	Date of capture had no affect on smolt fork length	2	0.390
	Fed and unfed fry produce smolts with similar fork lengths	1	0.877
	There is no interaction between collection date and smolt fork length	2	0.823
	Error degrees of Freedom	144	
NOR	Date of capture had no affect on smolt fork length	2	0.095
	Error degrees of Freedom	446	

These results allowed us to pool all the fork length data from each type of smolt and run a final One-Way ANOVA, which evaluated whether the mean fork lengths of early-, middle-, late-release hatchery and NOR origin smolts differed from one another. As in previous years, smolts produced from hatchery fry released during the early period were larger than those produced by NOR ($P \leq 0.001$) and late release hatchery fry ($P \leq 0.001$). Fry released during the middle period also produced larger smolts than NORs ($P = 0.002$) but no difference was detected between their mean fork lengths at smolting and those obtained from late-release hatchery fry ($P = 0.116$). The larger size of smolts produced from early- and middle-release hatchery fish probably reflects their longer rearing period in Lake Washington. A summary of all the smolt length information for hatchery and NOR smolts collected in 2007 is shown in Table 7.

Table 7. The mean fork lengths of one-year old hatchery and NOR sockeye smolts collected from Lake Washington on May 8, 15, 22, and 29, 2007.

Sampling Date	Smolt Origin	Type	N	Mean Fork Length	Standard Deviation
08-May	Early	Fed	51	123.2	8.6
		Unfed	13	120.7	6.4
	Middle	Fed	22	120.1	10.1
		Unfed	8	126.1	12.1
	Late	Fed	40	119.0	7.8
		Unfed	10	118.2	6.6
	NOR	-	172	118.1	10.0
15-May	Early	Fed	24	121.4	10.9
		Unfed	6	123.7	7.0
	Middle	Fed	17	122.4	9.6
		Unfed	5	114.4	10.5
	Late	Fed	32	119.5	8.6
		Unfed	8	121.3	11.3
	NOR	-	120	117.7	8.6
22-May	Early	Fed	18	125.2	8.0
		Unfed	6	121.7	9.9
	Middle	Fed	18	120.4	8.1
		Unfed	7	122.3	6.4
	Late	Fed	44	117.5	12.0
		Unfed	13	116.8	7.8
	NOR	-	157	116.0	8.3

Table 7. Continued. . .

Sampling Date	Smolt Origin	Type	N	Mean Fork Length	Standard Deviation
29-May	Early	Fed	0	-	-
		Unfed	0	-	-
	Middle	Fed	0	-	-
		Unfed	0	-	-
	Late	Fed	3	125.7	4.0
		Unfed		-	-
	NOR	-	5	120.6	6.8

Mean size of Lake Washington sockeye smolts has varied during the four years that we have made collections. So far the largest smolts were produced in 2004 when their mean size was approximately 135 mm. In 2005, 2006 and 2007 smolt size has ranged from 125 to 120 mm or 10 to 15 mm smaller (Figure 3). If the smolt collection program can be

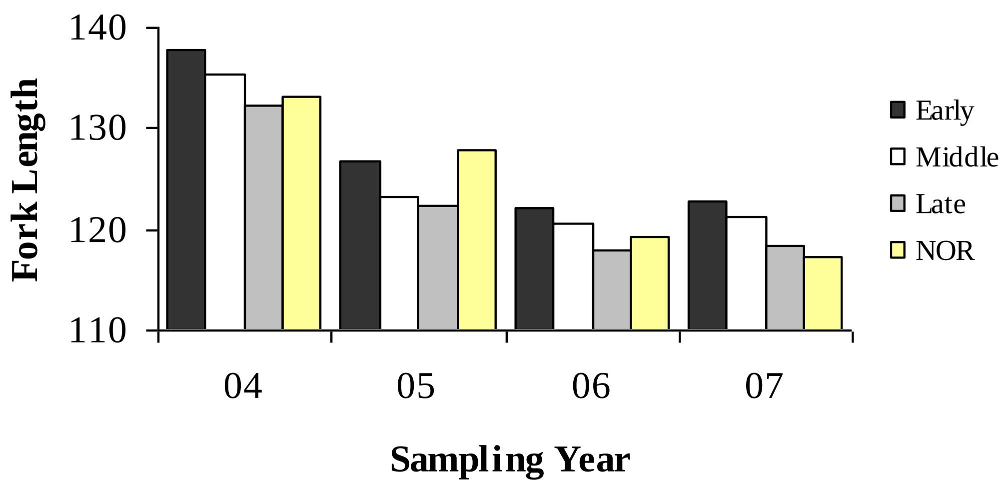

Figure 3. Mean fork lengths of NOR and hatchery origin sockeye smolts released during the early, middle, and late time periods by sampling year.

continued into the future, insights into factors that affect mean smolt size and the potential influence of smolt size on smolt-to-adult survival will become possible. For example, one potential factor that may affect smolt size would be the number of sockeye fry entering Lake Washington during the previous spring. This value would represent a measure of intra-specific competition for food resources in the lake. If food were limiting the expectation would be that smolt size would decrease as fry abundance rose. The relationship between mean fork lengths in NOR smolts and sockeye fry abundance for

Lake Washington sockeye is shown in Figure 4. Obviously we have just a few data points, however, no relationship between these two variables appears to exist in the data we have collected to date.

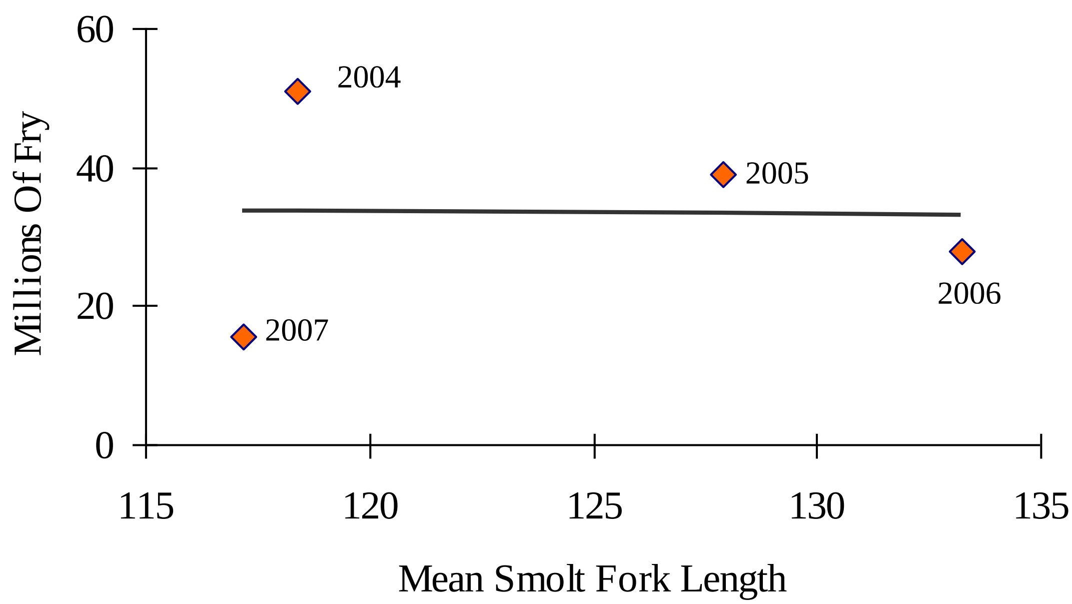

Figure 4. Relationship between the number of sockeye fry entering Lake Washington and mean size of sockeye smolts migrating from the lake one year later. The year the smolts were sampled is adjacent to the data point.

Some Final Considerations

As in previous years, the above results depend upon the assumption that the smolts collected and analyzed in 2007 were representative of the entire population. We believe our estimates of the relative abundance of hatchery and NOR sockeye smolts and their body size at smolting are unbiased because: 1) the fish were sampled in a non-selective manner by using a purse seine and 2) the percentage of hatchery and NOR smolts present was relatively constant from one sampling date to the next. Samples of sockeye smolts were also collected in 2008 and data from these fish are currently being generated. We hope that similar collections can be made in the future as this will make it possible for us to examine relationships between environmental factors and the growth and survival of both hatchery and NOR smolts. They will also allow us to continue to examine the effects of various rearing and release treatments on the relative survival of hatchery produced sockeye.

Literature Cited

Fresh, K., S. Schroder, E. Volk, J. Grimm, and M. Mizell. 2003. Evaluation of the Cedar River sockeye salmon hatchery: Analyses of adult otolith recoveries. Washington Department of Fish and Wildlife, Fish Program, Science Division. Report FPL 03-01. 42pp.

Kiyohara, K. and G. Volkhardt. 2008. Evaluation of downstream migrant salmon Production in 2007 from the Cedar River and Bear Creek. Washington Department of Fish and Wildlife, Fish Program, Science Division, Wild Salmon Production/Evaluation Report FPA 07-10. 62 pp.