Results Of The Otolith Decodes Performed On Sockeye Smolts Leaving Lake Washington In 2008

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Synopsis Of Results

1) In 2008, Dave Seiler and WDFW staff collected 1,110 out-migrating sockeye smolts from Lake Union. A purse seine was used and sampling occurred on May 6, 13, 20, and 27.
2) On each sampling date approximately 31% (range 25 to 33%) of the sampled smolts originated from hatchery-origin fry
3) One hundred percent of the hatchery-origin and 99.9% of the natural-origin smolts were one-year-old fish.
4) Twenty-four groups of hatchery fry were released in 2007 and were responsible for the hatchery-origin smolts collected in 2008. Hatchery fish were released into the Cedar River at three locations: Landsburg (RK 36.0) where the hatchery is located; a site referred to as the Trestle (RK 21.7); and at a location near the mouth of the Cedar River designated as the Airport (RK 0.2). Two types of fry were released, those that had been fed for approximately two weeks and those that were released without any supplemental feeding. Fed and unfed fry were released from the Airport site. Only unfed fry were released from the Trestle location while all the fish released at the Landsburg site were fed individuals. Releases were categorized as early (January 31 – 13 February), middle (15 – 21 February) or late (26 February – 19 March). 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 was also compared to that achieved by naturally produced sockeye fry or NORs (natural origin recruits).
    a. The effect of release period (early, middle, or late) on fry-to-smolt survival was examined in a hierarchal fashion. First, the survival of fed and unfed fish released at the same time and location were compared. In general fed fry survived to the smolt stage at higher rates than unfed hatchery fry. Consequently, the effect of release period and location were evaluated separately in fed and unfed fry. Neither factor consistently effected fry-to-smolt survival rates in fed or unfed fry.
    b. Fry origin did effect fry-to-smolt survival. Fed fry from three release groups had the highest fry to smolt survival rates. NOR fry had the second highest rate, having a greater fry to smolt survival rate than nine of the fourteen hatchery release groups.
5) When smolts were captured, i.e. their capture date, did not affect mean fork lengths in hatchery origin fry. NOR origin smolts sampled on May 27, however, were on average 3 mm shorter than those sampled on the 6th, 13th, and 20th of May.
6) Fork lengths of hatchery origin smolts were not affected by when they were released or whether they had been released as fed or unfed fry. Hatchery origin smolts sampled on all dates and NORs sampled on May 6, 13, and 20 had an average fork length of 124 mm while NORs sampled on May 27 averaged 120 mm.

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, 2005 and 2006 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 2009 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 fry-to-smolt survival rates of hatchery and NOR sockeye. Additionally, data collected on these samples provide information on:

1) The percentage of sampled smolts originating from the hatchery program
2) The age composition of both NOR and hatchery origin 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 2008.

Origin And Age Of The Sockeye Smolts Collected In 2008

Lake Washington sockeye smolts were sampled once per week using a purse seine just before they entered seawater from May 6 – May 27, 2007. A total of 1,110 smolts were collected. Sampled fish were stored over ice and delivered to WDFW’s Otolith Laboratory. 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 2008 are shown in Table 1. The occurrence of hatchery-origin smolts was fairly consistent from one sampling date to the next and averaged 31%. Similar trends occurred in smolts sampled in 2004, 05, 06, and 07 (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 2008.

2008 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
6-May	311	103	208	33.12%	5.23%	66.88%
13-May	368	128	240	34.78%	4.87%	65.22%
20-May	260	66	194	25.38%	5.29%	74.62%
27-May	171	48	123	28.07%	6.73%	71.93%
Totals	1110	345	765	31.08%	2.72%	68.92%

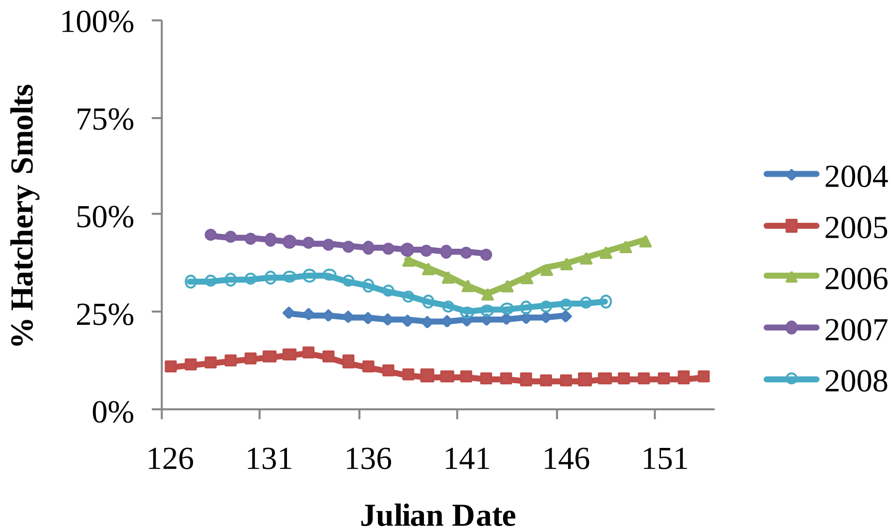

Figure 1. The percentage of hatchery and NOR sockeye smolts present in samples collected in the Lake Washington Basin from 2004 through 2008.

Over ninety-nine percent of the NOR smolts and one hundred percent of the hatchery-origin smolts sampled in 2008 were 1 year old fish. Just one of the NOR smolts sampled was a two-year, no age zero or 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 2008.

2008 Sampling Dates	Smolt Origin	No.	No. Of 0-Yr-Olds	No. Of 1-Yr-Olds	No. Of 2-Yr-Olds	Other
6-May	NOR	208	0	207	1	0
13-May	NOR	240	0	240	0	0
20-May	NOR	194	0	194	0	0
27-May	NOR	123	0	123	0	0
Sub Total		765	0	764	1	0
6-May	Hatchery	103	0	103	0	0
13-May	Hatchery	128	0	128	0	0
20-May	Hatchery	66	0	66	0	0
27-May	Hatchery	48	0	48	0	0
Sub Total		345	0	345	0	0

95% Confidence Intervals Around The 2008 Smolt Age Estimates

Smolt Age	Smolt Origin	% Of Sample	± 95% Confidence Intervals
1-Yr-Old	Hatchery	100%	-
1-Yr-Old	NOR	99.87%	0.26%
2-Yr-Old	NOR	0.13%	0.009%

The age composition of the smolts collected in 2008 is very similar to what has been observed in our past collections. During the five-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 five years, one hundred percent of the sampled hatchery origin fish smolted at age one. Two-year old smolts have been observed, however, they were relatively rare, as their incidence in NORs ranged from 0.13% in 2008 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 in 2007 an age zero smolt was found in our sample. 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 (Table 3).

Table 3. The age composition of NOR and hatchery-origin sockeye sampled in the Lake Washington Basin from 2004 through 2008.

Sampling Year	Smolt Origin	Number	% Age 0	% Age 1	% Age 2	% Age 3
2004	NOR	818	0.0%	96.4%	2.2%	0.0%
	Hatchery	256	0.0%	100.0%	0.0%	0.0%
2005	NOR	729	0.0%	94.9%	4.1%	0.4%
	Hatchery	85	0.0%	100.0%	0.0%	0.0%
2006	NOR	709	0.0%	99.7%	0.1%	0.0%
	Hatchery	424	0.0%	100.0%	0.0%	0.0%
2007	NOR	465	0.2%	97.8%	1.9%	0.0%
	Hatchery	345	0.0%	100.0%	0.0%	0.0%
2008	NOR	765	0.0%	99.9%	0.1%	0.0%
	Hatchery	345	0.0%	100.0%	0.0%	0.0%

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. Therefore 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.

Fourteen groups of hatchery fish were produced from the adults that were artificially spawned in 2006. Their offspring were released in 2007 and at the time they were sampled in 2008 they were one-year-old fish. As indicated in Table 3, almost all sockeye smolts leaving Lake Washington are one-year-olds. Consequently, all the fry-to-smolt survival comparisons presented 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 31st of January through the 13th of February 2007. Hatchery fry released from February 15th through the 21st of February were placed into a middle group, while the last third, or late group, was released from February 26th through the 19th of March. Hatchery fish were also categorized by where they were released. Three release locations were used in 2007. 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, those that had been reared for up to 2 weeks and those that were released as unfed fry. Both fed and unfed fry were released from the Airport, only unfed fry were released from the Trestle location, and only fed fry were released from the Landsburg site. During the rearing period fed fry gained approximately 30 to 70 mg, which represented a 16 to 30% gain in body weight and increased their fork lengths by 0.4 to 1.4 mm.

Estimates of the in-river survival of hatchery fry that were released into the Cedar River are presented in Table 4A which was taken from Kiyohara and Volkhardt (2008). No survival estimates were made for fry released at the Airport (RK 0.16). It was assumed all fry released at this location entered Lake Washington. In Table 4B a summary of the hatchery fry releases made in 2007 is shown and in Table 4C the estimated number of NOR fry entering Lake Washington is presented. Estimates of NOR abundance were also obtained from Kiyohara and Volkhardt (2008). 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 4, parts A, B, and C along with that shown in Table 5, which summarizes the types and number of one-year-old hatchery smolts that were recovered in 2008, were used in these analyses.

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. Three such comparisons were made, two in the early release period and one in the middle release period. In each analysis significant differences in survival were seen. Fed fry achieved higher survivals than unfed fry in the two releases that were made during the early time period. Unfed fry had higher survivals than fed individuals in the one paired release made during the middle period (Table 6A). 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 fed and unfed hatchery fry.

Six groups of fed fry were released, four at the Airport and two at Landsburg. Three of the groups, an early and middle group released at Landsburg (groups EF3 & MF3) and an early group released from the Airport (group EF1) had comparable and higher survivals

Table 4A. Estimates of in-river survival of sockeye fry produced from the Landsburg Hatchery in 2007. Data are from Kiyohara and Volkhardt (2008).

Release Type	No. Released	Estimated No. Entering Lake Washington	% Survival
Early Releases	543,000	169,537	31.22%
(31 Jan - 13 Feb)	579,000	179,733	31.04%
	786,000	786,000	-
	1,023,000	1,023,000	-
	1,038,000	1,038,000	-
	1,021,000	1,021,000	-
Sub Total	4,990,000	4,217,270	
Middle Releases	508,000	508,000	-
(15 Feb - 21 Feb)	508,000	226,494	44.59%
	520,000	152,646	29.36%
	1,021,000	1,021,000	-
	1,055,000	1,055,000	-
Sub Total	3,612,000	2,963,140	
Late Releases	443,000	168,166	37.96%
(26 Feb - 19 Mar)	536,000	536,000	-
	513,000	513,000	-
	314,000	219,039	69.76%
	793,000	793,000	-
	823,000	831,960	101.09%
	70,000	70,000	-
Sub Total	3,492,000	3,131,165	
Grand Total	12,094,000	10,311,575	

Table 4B. The number of hatchery sockeye fry released into the Cedar River in 2007. Data are from hatchery out-planting records.

Time Period	Release Site	Date	No. Of Unfed Fry Released[A]	No. Of Fed Fry Released[A]
Early	Airport (RK 0.2)	31-Jan-07	516,000	270,000
		1-Feb-07	492,000	531,000
		12-Feb-07	520,000	518,000
		13-Feb-07	513,000	508,000
	Airport Sub Total		2,041,000	1,827,000
	Trestle (RK 21.7)	7-Feb-07	169,537	0
	Trestle Sub Total		169,537	0
	Landsburg (RK 36.0)	8-Feb-07	0	179,733
	Landsburg Sub Total		0	179,733
	Early Total		2,210,537	2,006,733
Middle	Airport (RK 0.2)	15-Feb-07	508,000	
		20-Feb-07	523,000	498,000
		21-Feb-07	539,000	516,000
	Airport Sub Total		1,570,000	1,014,000
	Trestle (RK 21.7)	16-Feb-07	226,494	0
	Trestle Sub Total		226,494	0
	Landsburg (RK 36.0)	20-Feb-07	0	152,646
	Landsburg Sub Total		0	152,646
	Middle Total		1,796,494	1,166,646
Late	Airport (RK 0.2)	27-Feb-07	536,000	0
		5-Mar-07	513,000	0
		7-Mar-07	0	793,000
		19-Mar-07	70,000	
	Airport Sub Total		1,119,000	793,000
	Trestle (RK 21.7)	26-Feb-07	168,166	0
		6-Mar-07	219,039	0
		12-Mar-07	831,960	0
	Trestle Sub Total		1,219,165	0
	Late Total		2,338,165	793,000
			Total Number Of Early Sockeye Fry Released	4,217,270
			Total Number Of Middle Sockeye Fry Released	2,963,140
			Total Number of Late Sockeye Fry Released	3,131,165
			Grand Total Of All Sockeye Fry Released In 2007	10,311,575

[A] Number estimated to have entered Lake Washington

Table 4C. Estimated number of natural origin recruit (NOR) sockeye fry entering Lake Washington during the winter and spring of 2007. Data are from Kiyohara and Volkhardt (2008).

Location	Population Estimate	95% Confidence Interval
Cedar River	9,246,243	± 708,005
Northern Tributary Populations	5,983,651	± 1,275,633
Grand Total	15,229,894	± 1,983,638

Table 5. The number and type of hatchery-origin sockeye smolts recovered from each release location (Part A). Recovery information for fish that originated from paired releases of fed and unfed fry made at the Airport site is shown in Part B.

A: Recovery Of Hatchery Origin Smolts By Release Time & Rearing History: 2008

	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
Early	48	90	10	-	-	19	58	109
Middle	53	18	4	-	-	13	57	31
Late	40	26	24	-	-	-	64	26
Totals	141	134	38	-	-	32	179	166

B: Recovery of Smolts Originating From Paired Releases Of Fed and Unfed Fry: 2008

			No. Of Smolts Recovered	
Group	Date Of Release	Release Location	Fed	Unfed
Early Release 1	31 Jan - 1 Feb 2007	Airport	49	26
Early Release 2	12 - 13 Feb 2007	Airport	41	22
Middle Release 1	20 - 21 Feb 2007	Airport	18	43
Totals			108	91

than the remaining three groups released from the Airport (Table 6B). Two of the remaining fed groups released from the Airport during the early (EF4) and late periods (LF3) had comparable, and greater fry-to-smolt survival rates, than the lowest surviving group (MF4) that had been released during the middle period. Consequently, time and area of release did not appear to have a consistent effect on survival to the smolt stage for fed fry released in 2007.

Similar tests were performed on the eight release groups of unfed hatchery fry. In this case, two of the groups, one from an early release (E2) and another from a middle release (MC4) had higher fry-to-smolt survival rates than the remaining six releases (Table 6C). The two highest surviving groups were released at different locations (at the Trestle and Airport) and during different time periods. The six groups of unfed fry that experienced similar but lower fry-to-smolt survival rates had been released during all three time periods and at the Trestle and Airport. Thus, as with fed fry, time and location of release did not appear to have a consistent effect on fry-to-smolt survival in the unfed fry groups.

In a final set of Chi-Square tests, the survival of NOR, fed- and unfed-hatchery origin fry was compared (Table 6D). 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. The fry-to-smolt survival of six groups was compared, three represented fed fry (Fed #1, Fry #2, and MF4) two others represented unfed hatchery fry, (Unfed #1 and Unfed #2) and the last group was NOR fry. Fry from release group Fed #1 (EF1, EF3, and MF3) had the highest fry to smolt survival rates. NORs and fry originating Unfed #1 (E2 and MC4) had the second highest fry-to-smolt survival rates. Fry from release Fed #2 (EF4 and LF3) did not survive as well to the smolt stage as NORs but did achieve higher survivals than fry in Unfed #2 (release groups EC1, EC4, M1, M2, L1, and L2) and the MF4 group of fed fry (Table 6D).

Because five years of smolt samples have been analyzed it is now possible to put the 2008 results into context by comparing our current results to what was previously found. First, in four sampling years (2004, 2005, 2007 and 2008) it was possible to compare the survival of fed and unfed hatchery fry. During these four years, ten comparisons between the relative survival of fed and unfed hatchery fry were made. In eight cases, fed fry achieved higher fry-to-smolt survivals than paired releases of unfed fry. In the 2007 sampling year, five such comparisons were made and in one instance no difference could be found between the fry-to-smolt survival of fed and unfed fry released during the late period in 2006. Additionally, one of the three fed fry groups released in 2007 (smolt sampling year 2008) had a lower survival than its unfed control. This fed group (MF4) achieved a fry-to-smolt survival rate that was comparable to six of the unfed groups but had a lower survival than NORs and two unfed groups including its control. Of the fed fry groups released in 2007, fish in MF4 were smaller than fry from the other two fed releases. For example, fry in EF1 and EF4 were on average 60 to 70 mg heavier and .6 to .7 mm longer than fry in their control groups. Conversely, MF4 fry were on average 30 mg and .4 mm longer than the unfed fry used in their control group. A one-way ANOVA was used to compare the body weights of fed fry released in 2007. Fry in the MF4 group were significantly smaller ($P < 0.001$ for EF1, $P = 0.001$for EF4) than fish in the other two fed groups. How important this small but significant difference in size among the fed fry groups might have been on their relative survival is unknown. The above result does suggest that some minimal gain in size via artificial rearing may have to occur before a survival benefit is realized. Our data set will allow us to explore this

Table 6. Fry-to-smolt survival comparisons among groups of sockeye fry entering Lake Washington in 2007.

A) Comparing The Fry-to-Smolt Survival Of Paired Releases of Fed and Unfed Hatchery Origin Fry

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 Fed	EF1	Airport	801,000	44.28%	49	33.21	7.99		
Early Unfed	EC1	Airport	1,008,000	55.72%	26	41.79	5.59		
Sub Total			1,809,000	100.00%	75	75	13.59	<0.001	Reject H_o: Feds > Unfeds
Early Fed	EF4	Airport	1,026,000	49.83%	41	31.39	3.25		
Early Unfed	EC4	Airport	1,033,000	50.17%	22	31.61	2.62		
Sub Total			2,059,000	100.00%	63	63	5.88	0.015	Reject H_o: Feds > Unfeds
Middle Fed	MF4	Airport	1,014,000	48.84%	18	29.79	4.28		
Middle Unfed	MC4	Airport	1,062,000	51.16%	43	31.21	4.84		
			2,076,000	100.00%	61	61.00	9.13	0.003	Reject H_o: Unfeds > Feds

B) Comparing The Survival Of Fed Hatchery Sockeye 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	EF1	Airport	801,000	20.19%	49	33.52	7.15		
Early	EF3	Landsburg	179,733	4.53%	19	7.52	17.51		
Early	EF4	Airport	1,026,000	25.87%	41	42.94	0.09		
Middle	MF3	Landsburg	152,646	3.85%	13	6.39	6.84		
Middle	MF4	Airport	1,014,000	25.56%	18	42.44	14.07		
Late	LF3	Airport	793,000	19.99%	26	33.19	1.56		Early Fed (EF3) survived at
			3,966,379	100.00%	166	166.00	47.22	<0.001	a higher rate than expected
Early	EF1	Airport	801,000	21.15%	49	31.10	10.31		
Early	EF4	Airport	1,026,000	27.10%	41	39.83	0.03		
Middle	MF3	Landsburg	152,646	4.03%	13	5.93	8.45		
Middle	MF4	Airport	1,014,000	26.78%	18	39.36	11.59		
Late	LF3	Airport	793,000	20.94%	26	30.78	0.74		Middle Fed (MF4) survived
			3,786,646		147	147.00	31.13	<0.001	at a lower rate than expected
Early	EF1	Airport	801,000	28.89%	49	37.27	3.69		
Early	EF4	Airport	1,026,000	37.00%	41	47.74	0.95		
Middle	MF3	Landsburg	152,646	5.51%	13	7.10	4.90		
Late	LF3	Airport	793,000	28.60%	26	36.90	3.22		Middle Fed (MF3) survived
			2,772,646	100.00%	129	129.00	12.76	0.005	at a higher rate than expected
Early	EF1	Airport	801,000	30.57%	49	35.46	5.17		
Early	EF4	Airport	1,026,000	39.16%	41	45.43	0.43		
Late	LF3	Airport	793,000	30.27%	26	35.11	2.36		Early Fed (EF1) survived
			2,620,000		116	116.00	7.96	0.019	at a higher rate than expected
Early	EF4	Airport	1,026,000	56.40%	41	37.79	0.36		
Late	LF3	Airport	793,000	43.60%	26	29.21	0.25		
			1,819,000	100.00%	67	67	0.62	0.433	Fail to Reject H_o

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	EC1	Airport	1,008,000	15.89%	26	28.44	0.21		
Early	E2	Trestle	169,537	2.67%	10	4.78	5.69		
Early	EC4	Airport	1,033,000	16.28%	22	29.14	1.75		
Middle	M1	Airport	508,000	8.01%	10	14.33	1.31		
Middle	M2	Trestle	226,494	3.57%	4	6.39	0.89		
Middle	MC4	Airport	1,062,000	16.74%	43	29.96	5.68		
Late	L1	Trestle	1,219,165	19.21%	24	34.39	3.14		
Late	L2	Airport	1,119,000	17.64%	40	31.57	2.25		Early Unfed (E2) survived
			6,345,196	100.00%	179	179.00	20.92	0.004	at a higher rate than expected
Early	EC1	Airport	1,008,000	16.32%	26	27.58	0.09		
Early	EC4	Airport	1,033,000	16.73%	22	28.27	1.39		
Middle	M1	Airport	508,000	8.23%	10	13.90	1.10		
Middle	M2	Trestle	226,494	3.67%	4	6.20	0.78		
Middle	MC4	Airport	1,062,000	17.20%	43	29.06	6.68		
Late	L1	Trestle	1,219,165	19.74%	24	33.36	2.63		
Late	L2	Airport	1,119,000	18.12%	40	30.62	2.87		Middle Unfed (MC4) survived
			6,175,659	100.00%	169	169.00	15.54	0.016	at a higher rate than expected
Early	EC1	Airport	1,008,000	19.71%	26	24.8370101	0.05		
Early	EC4	Airport	1,033,000	20.20%	22	25.4530073	0.47		
Middle	M1	Airport	508,000	9.93%	10	12.5170646	0.51		
Middle	M2	Trestle	226,494	4.43%	4	5.58078746	0.45		
Late	L1	Trestle	1,219,165	23.84%	24	30.0400926	1.21		
Late	L2	Airport	1,119,000	21.88%	40	27.5720379	5.60		
			5,113,659	100.00%	126		8.29	0.141	Fail to Reject H_o

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	-	15,229,894	59.63%	765	661.87	16.07		
Fed #1	EF1, EF3,& MF3	1,133,379	4.44%	81	49.26	20.46		
Fed #2	EF4 & LF3	1,819,000	7.12%	67	79.05	1.84		
Middle Fed	MF4	1,014,000	3.97%	18	44.07	15.42		
Unfed #1	E2 & MC4	1,231,537	4.82%	53	53.52	0.01		
Unfed #2	EC1, EC4, M1, M2, L1, & L2	5,113,659	20.02%	126	222.23	41.67		Unfed # 2 survived at a
		25,541,469	100.00%	1110	1110	95.46	<0.001	rate lower than expected
NORs	-	15,229,894	74.55%	765	733.618322	1.34		
Fed #1	EF1, EF3,& MF3	1,133,379	5.55%	81	54.5944443	12.77		
Fed #2	EF4 & LF3	1,819,000	8.90%	67	87.6205526	4.85		
Middle Fed	MF4	1,014,000	4.96%	18	48.8440024	19.48		
Unfed #1	E2 & MC4	1,231,537	6.03%	53	59.3226786	0.67		Middle Fed survived at a
		20,427,810	100.00%	984	984	39.12	<0.001	rate lower than expected
NORs	-	15,229,894	78.45%	765	757.815061	0.07		
Fed #1	EF1, EF3,& MF3	1,133,379	5.84%	81	56.3951184	10.73		
Fed #2	EF4 & LF3	1,819,000	9.37%	67	90.510518	6.11		
Unfed #1	E2 & MC4	1,231,537	6.34%	53	61.2793028	1.12		Fed #1 survived at a rate
		19,413,810	100.00%	966	966	18.03	<0.001	higher than expected
NORs	-	15,229,894	83.31%	765	737.316105	1.04		
Fed #2	EF4 & LF3	1,819,000	9.95%	67	88.0622016	5.04		
Unfed #1	E2 & MC4	1,231,537	6.74%	53	59.621693	0.74		Fed #2 survived at a rate
		18,280,431	100.00%	885	885	6.81	0.033	lower than expected
NORs	-	15,229,894	92.52%	765	756.80257	0.10		
Unfed #1	E2 & MC4	1,231,537	7.48%	53	61.1974297	0.97		
		16,461,431	100.00%	818		1.07	0.301	Fail to Reject H_o

possibility. In the meantime, the ten comparisons made between fed and unfed groups of hatchery indicate that relatively short rearing periods (~ 2 wks) producing small increases in body weight (~ 60 or more mg) and length (~.6 or more mm) appear to enhance the survival of hatchery fry making their fry-to-smolt survival rates comparable or superior to NORs.

Second, in two (2004 and 2005) out of our five 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 and 2008. 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 five years. In 2004, 2005, and 2008 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. In 2008, two groups of unfed fry and NORs had comparable survival rates while six groups of unfed fish had poorer fry-to-smolt survival rates 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 a short period apparently also provided the fish with a survival benefit. The groups of fed fry released in 2007 and sampled as smolts in 2008 either had fry-to-smolt survivals that were greater than NORs (e.g. fed group #1) or they survived at a lower rate (fed group #2 and MF4). Although we have just a few sampling points, these data and the survival comparisons between fed and unfed hatchery fry, suggest that a short rearing period does provide some positive survival benefits to hatchery-origin sockeye fry.

Comparing The Fork Lengths Of Hatchery-Origin and NOR Smolts

The importance of date of collection and smolt origin (NOR, 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 (6^{th}, 13^{th}, 20^{th}, and 27^{th} of 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 in the ANOVAs performed on fish released during the early and late periods. A significant interaction between sampling date and fish size was found in the two-way ANOVA performed on data collected from fish released during the middle period. It was likely caused by the small number of fed fish recovered (n = 4) on the 20^{th} of May. These fish had a mean fork length of 113 mm, some 13 mm smaller than the mean fork lengths of the remaining middle fed smolts.

Second, a One-Way ANOVA was used to assess whether collection date affected fork length in NOR smolts. NOR smolts recovered on the first three sampling dates (May 6^{th}, 13^{th}, and 20^{th}) had similar and larger mean fork lengths than those sampled on the 27^{th} (123.6 mm vs. 120.1 mm). A final one-way ANOVA was performed that compared the fork lengths of early, middle, late hatchery smolts and NORs sampled on the 6^{th}, 13^{th}, and 20^{th} of May, and NORs sampled on the 27^{th} of May. This analyses showed that hatchery and NOR smolts had similar and longer fork lengths than NORs sampled on the 27^{th} of May (Table 7). A summary of all the smolt length information for hatchery and NOR smolts collected in 2008 is shown in Table 8.

Table 7. 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
	Sampling date had no affect on smolt fork length	3	0.834
Early Hatchery	Fed and unfed fry produce smolts with similar fork lengths	1	0.572
	There is no interaction between sampling date and smolt fork length	3	0.859
	Error degrees of freedom	159	
	Sampling date had no affect on smolt fork length	3	0.199
Middle Hatchery	Fed and unfed fry produce smolts with similar fork lengths	1	0.572
	There is no interaction between sampling date and smolt fork length	3	0.038
	Error degrees of freedom	80	
	Sampling date had no affect on smolt fork length	3	0.189
Late Hatchery	Fed and unfed fry produce smolts with similar fork lengths	1	0.548
	There is no interaction between sampling date and smolt fork length	3	0.698
	Error degrees of freedom	82	
NORs	Sampling date had no affect on smolt fork length	3	0.001
	Error degrees of freedom	761	
All	Smolt origin did not affect fork length	4	0.001
	Error degrees of freedom	1105	

Table 8. The mean fork lengths of one-year old hatchery and NOR sockeye smolts collected from Lake Washington on May 6, 13, 20, and 27, 2008.

Sampling Date	Smolt Orgin	Type	N	Mean Fork Length	Standard Deviation
6-May	Early	Fed	40	124.3	6.9
		Unfed	13	125.0	7.4
	Middle	Fed	7	123.9	8.8
		Unfed	17	123.2	6.8
	Late	Fed	6	125.7	8.7
		Unfed	20	121.8	5.7
	NOR	-	208	124.3	7.6
13-May	Early	Fed	40	124.5	6.6
		Unfed	26	123.2	6.5
	Middle	Fed	16	128.2	7.4
		Unfed	24	122.7	10.8
	Late	Fed	5	126.6	3.3
		Unfed	17	126.1	8.2
	NOR	-	240	123.0	8.6
20-May	Early	Fed	19	124.5	10.9
		Unfed	8	124.4	10.1
	Middle	Fed	4	113.0	7.0
		Unfed	9	125.0	7.5
	Late	Fed	9	124.3	5.5
		Unfed	17	126.1	6.5
	NOR	-	194	123.6	12.0
27-May	Early	Fed	10	126.9	8.3
		Unfed	11	124.3	11.2
	Middle	Fed	4	124.5	8.3
		Unfed	7	123.7	9.2
	Late	Fed	6	121.5	12.0
		Unfed	10	119.7	11.4
	NOR	-	123	120.1	9.7

Mean size of Lake Washington sockeye smolts has varied during the five 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, 2007, and 2008 smolt size has ranged from 125 to 120 mm or 10 to 15 mm smaller (Figure 2). If the smolt collection program can be continued into the

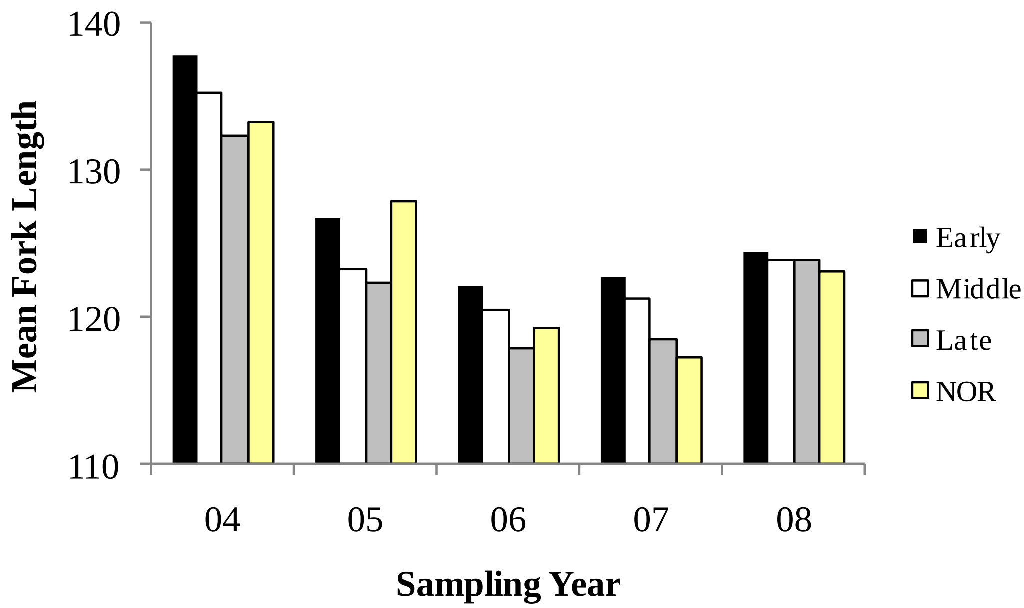

Figure 2. Mean fork lengths of one-year-old NOR and hatchery origin sockeye smolts released during the early, middle, and late time periods by sampling year.

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 was examined by using linear regression and is shown in Figure 3. Obviously we have just a few data points, however, no relationship between these two variables appears to exist ($r^2 < 0.001$, $P = 0.999$) in the data collected to date.

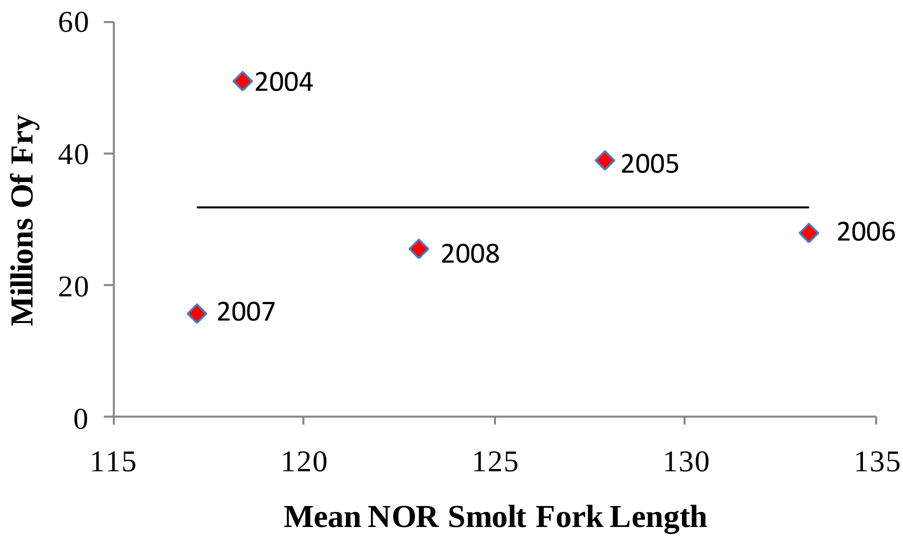

Figure 3. The number of sockeye fry entering Lake Washington and the mean size of sockeye smolts migrating from the lake one year later. The year the smolts were sampled is adjacent to each data point.

Some Final Considerations

As in previous years, the above results depend upon the assumption that the smolts collected and analyzed in 2008 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 May of 2009 and data from these fish will be generated later this fall. 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 fry. 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.

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