Results Of The Otolith Decodes Performed On Sockeye Smolts Leaving Lake Washington In 2006

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2006 Lake Washington Sockeye Smolt Sample Analyses

Synopsis of Results

1) In 2006, Dave Seiler and WDFW staff collected 1,136 out-migrating sockeye smolts from Lake Union. Sampling occurred on May 18, 22, 25, and 30.
2) On each sampling date approximately 37% of the smolts originated from hatchery-origin fry.
3) One hundred percent of the hatchery origin fish and 99.9% of the natural origin smolts were one-year-old fish.
4) Thirty-one groups of hatchery fry were released in 2005. Seven releases occurred 36 kilometers above the mouth of the Cedar River at Landsburg where the hatchery is located. The remaining 24 releases occurred at the Airport, a site that is 0.16 K above the mouth of the river. Unlike previous years, no hatchery fish were reared in 2005 and thus all were released as unfed fry. Fry releases were categorized as early (24 Jan – Feb 17, 2005), middle (18 Feb – Mar 4, 2005) or late (3 Mar – Apr 4, 2005). A series of Chi-Square tests were performed that compared the fry-to-smolt survival of the various release groups. Fry-to-smolt survival of hatchery- and natural origin fry was also compared.
    a) Hatchery fry originating from early, middle, and late release groups had similar fry-to-smolt survival rates
    b) Fry liberated from the hatchery and the Airport site during the early release period had comparable fry-to-smolt survivals. However, fry liberated from the hatchery during the middle release period had higher fry-to-smolt survivals than fry released at the Airport.
    c) In 2005, 76% of the sockeye fry entering Lake Washington were NORs. One year later, 66% of the smolts leaving the lake were NORs. A Chi-square that compared hatchery and NOR fry-to-smolt survival indicated that hatchery fry had survived to the smolt stage at a higher rate than their NOR counterparts
5) The mean fork lengths of NOR and hatchery-origin smolts did not change over the sampling period
6) Smolts derived from the early hatchery release group had a longer mean fork length than NORs and hatchery smolts originating from the late release group. NOR smolts and those originating from the middle and late release groups had comparable mean fork lengths.
7) A regular program of sampling sockeye smolts just before they exit the Lake Washington Basin was started in 2004. The above results represent findings from the third collection of smolts that took place in 2006. Smolts were also collected in 2007 and are currently undergoing analysis.

Otolith Decode Information From The Sockeye Smolts Collected In May 2006 From Lake Union

Most 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 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 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. None of the hatchery fry produced from the 2004 brood year, however, were reared. This is the brood year that produced all the hatchery sockeye smolts that were sampled in 2006. All the fry incubated at the hatchery receive thermal marks in their otoliths making it possible to identify when and where a hatchery fish was planted and if they had experienced a rearing period prior to release.

Beginning in 2004, and continuing in 2005, 2006, and 2007 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 is to compare the fry-to-smolt survival rates of hatchery- and NOR sockeye. In addition, data collected on the smolts provides 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 their survival and size at the smolt stage, and
4) Inter-annual effects on smolt size, age at smolting, and survival

The results of otolith decodes made on smolts collected in 2004 and 2005 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 2006.

Origin and Age Of The Sockeye Smolts Collected In 2006

Over a 13-day period starting on May 18 and ending on May 30, 2006, Lake Washington sockeye smolts were sampled using a purse seine just before they entered seawater. A total of 1,136 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. In 2006 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. We found that fork lengths decreased by 3% and body weight decreased by 11% 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 was used again in 2006 and will be continued into the future because of 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 samples collected in 2005 and 2006.

The numbers and percentage of hatchery and wild fish captured per sampling date in 2006 are presented in Table 1. The table shows the occurrence of hatchery-origin smolts was fairly consistent from one sampling date to the next and averaged around 37%. A similar trend occurred in the smolt samples collected in 2004 and 2005. In combination these years suggest that the out-migration timing of hatchery and NOR smolts is comparable.

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

2006 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
18 May	538	208	330	38.7	4.1	61.3
22 May	90	27	63	30.0	9.5	70.0
25 May	427	155	272	36.3	4.6	63.7
30 May	78	34	44	43.6	11.0	56.4
Totals	1133	424	709	37.4	2.8	62.6

Over Ninety-nine percent of the NOR and one hundred percent of the hatchery-origin smolts sampled in 2006 were 1 year-old fish. Just one of the 709 NOR smolts sampled was a two- year old and no age zero or three-year old NORs were seen (Table 2). The age distribution of smolts sampled in 2004 and 2005 was similar to that seen in 2006. As in 2006, there were no two-year old hatchery smolts and two-year old NOR smolts were rare (2.2% in 2004 and 4.1% in 2005). No three-year NOR smolts were observed in 2006, they were rare in 2005 (0.4%) and none were observed in 2004. Consequently, during the three years that we have sampled sockeye smolts, one hundred percent of the hatchery-origin smolts and over ninety-seven percent of the NOR smolts have been one-year old fish. Two- and three-year old NOR smolts were rare, averaging 2.2% for two-year-olds and just 0.13% for three-year olds.

Table 2. The occurrence of one- and two-old sockeye smolts in NOR and hatchery origin fish collected in the Lake Washington Basin in 2006.

2006 Sampling Dates	Type Of Smolt	No.	No. Of 1-yr-olds	No. Of 2-yr-olds	Other
18 May	NOR	330	329	1	0
22 May	NOR	63	63	0	0
25 May	NOR	272	271	0	1
30 May	NOR	44	44	0	0
Sub Total		709	707	1	1
18 May	Hatch	208	208	0	0
22 May	Hatch	27	27	0	0
25 May	Hatch	155	155	0	0
30 May	Hatch	34	34	0	0
Sub Total		424	424	0	0

95% Confidence Intervals Around The Smolt Age Estimates For 2006			
Smolt Age	Type Of Smolt	% Of Sample	± 95% Confidence Intervals
1-yr-old	Hatchery	100%	-
1-yr-old	NOR	99.86%	99.58 – 100%
2-yr-old	NOR	0.14%	0 – 0.42%

<u>Comparing Fry-to-Smolt-Survival Rates In Hatchery and NOR Sockeye</u>

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. In the analyses described below the first method is used. Thus, the tests compared the relative abundance of hatchery and NOR sockeye at the time they entered the lake to their relative abundance at the smolt stage.

Altogether, thirty-one groups of hatchery sockeye were produced from the adults artificially spawned in 2004. Their offspring were released in 2005 and at the time smolts were sampled in 2006 they were 1-yr-old fish. As indicated above, almost all the sockeye smolts leaving Lake Washington are 1 yr-old fish. Consequently, all 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 2005, 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. Estimates of the in-river survival of fry that were released at the hatchery are presented in Table 3A which was taken from Volkhardt et al. (2006). In Table 3B a summary of the hatchery fry releases made in 2005 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 Volkhardt et al. (2006).

Table 3A. Estimates of in-river survival of fry released from the Cedar River Hatchery in 2005 (Data from Volkhardt et al. 2006).

Release Type	# Released	# Estimated Entering Lake Washington	% Survival
Early Releases Jan 24 – Feb 17, 2005	90,000	87,801	97.6
	256,000	236,746	92.5
	371,000	264,130	71.2
	574,000	366,356	63.8
	464,000	224,473	48.4
Sub Total	1,755,000	1,179,506	67.2
Middle Releases Feb 18 – Mar 4, 2005	551,000	253,684	46.0
	1,331,000	596,597	44.8
Sub Total	1,882,000	850,281	45.2
Late Releases Mar 7 – Apr 4, 2005	0	-	-
		-	-
Sub Total	0	-	-
Overall Total	3,637,000	2,029,787	55.8

Table 3B. The number of sockeye fry released by the hatchery at various times and locations during the 2005 out-migration period. Data are from hatchery out-planting records.

Time	Release Site	Date (Day-Month	No. Of Unfed Fry Released
Early	Airport (RK 0.16)	3 Feb	409,000
		7 Feb	374,000
		10 Feb	593,000
		11 Feb	584,000
		14 Feb	630,000
		15 Feb	624,000
		16 Feb	272,000
		17 Feb	575,000
	Airport Sub Total		**4,061,000**
	Hatchery (RK 36.0)	24 Jan	90,000
		25 Jan	256,000
		28 Jan	371,000
		1 Feb	574,000
		3 Feb	464,000
	Hatchery Sub Total		**1,755,000**
Middle	Airport (RK 0.16)	22 Feb	266,000
		23 Feb	640,000
		24 Feb	645,000
		25 Feb	587,000
		28 Feb	586,000
		1 Mar	243,000
		3 Mar	596,000
		4 Mar	584,000
	Airport Sub Total		**4,147,000**
	Hatchery (RK 36.0)	18 Feb	551,000
		22 Feb	1,331,000
	Hatchery Sub Total		**1,882,000**
Late	Airport (RK 0.16)	7 Mar	596,000
		8 Mar	430,000
		11 Mar	646,000
		16 Mar	527,000
		21 Mar	646,000
		23 Mar	269,000
		28 Mar	205,000
		4 Apr	91,000
	Airport Sub Total		**3,410,000**
Total Number Of Early Sockeye Fry Released			5,816,000
Total Number Of Middle Sockeye Fry Released			6,029,000
Total Number Of Late Sockeye Fry Released			3,410,000
Grand Total Of All Hatchery Fry Released In 2005			**15,255,000**

Table 3C. Estimated number of natural origin recruit (NOR) sockeye fry entering Lake Washington during the winter and spring of 2005 (Data are from Volkhardt et al. 2006).

Location	Population Estimate
Cedar River	37,027,961
Northern Tributary Populations	202,815
Grand Total	37,230,776

The data 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 18, 22, 25, and 30, 2006 in the Lake Washington Basin.

Release Time	Release Location		Total Number Recovered
	Airport (RK 0.16)	Hatchery (RK 36.0)	
Early	113	21	134
Middle	124	41	165
Late	125	-	125
TOTALS	362	62	424

Two series of Chi-Square tests were performed. One set examined whether time of release or release location affected fry-to-smolt survival of hatchery fry. The other compared fry-to-smolt survival values of hatchery fry to NORs. As mentioned previously, 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. In this analysis only the fry-to-smolt survival of fish released from the Airport location was compared as no fry were released from the hatchery during the late period. The null hypothesis that release time did not affect fry-to-smolt survival could not be rejected ($P = 0.08$; Table 5). In previous years, fry released during the late period have survived to the smolt stage at higher rates than those originating from the middle and early groups. Although not statistically significant, more smolts originating from the late release group did show up in our sample than expected. Moreover, fewer smolts from the early release period than expected were present in the 2006 sample. This plus the marginally non-significant *P*-value suggests that release timing probably did have an affect on fry-to-smolt survival, but not as strongly as it had in previous years. Another 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 and middle periods) in two different locations, the hatchery at Landsburg and the Airport. For the early period, release location had no apparent affect on fry-to-smolt survival (*P* = 0.06; Table 5). However, during the middle period, fry released from Landsburg achieved a significantly higher fry-to-smolt survival rate than those released from the Airport (*P* = 0.007; Table 5). One possible explanation for these results is that there is an inverse relationship between in-river survival and fry-to-smolt survival. As Table 3A shows, unfed fry released from the hatchery in the middle period experienced a 55% mortality rate as they emigrated down the Cedar River. Fry liberated from the hatchery during the early period, however, experienced an average mortality rate of 33%. A Chi Square Test was performed that compared the fry-to-smolt survival rates of hatchery fry originating from hatchery releases made during the early and middle periods. Fry from the middle release period had higher fry-to-smolt survival rates than those from the early releases (*P* = .0001). Clearly two factors could have influenced this outcome, time of entry into the lake and in-river mortality. Since time of release did not strongly affect the survival of fry released from the Airport site it may have had a similar low effect on these fish. At this point, however, we need more information to formally test the hypothesis that fish surviving a high in-river mortality rate have a better chance of surviving to the smolt stage than those that have not gone through a similar mortality episode. Currently we are examining our smolt otolith decode database (2004, 2005, & 2006) to see if we can extract information that we can use to explore this relationship in more detail.

Finally a single Chi-Square Test compared fry-to-smolt survival between NORs and unfed hatchery fish released from the Airport location. All the Airport fry were pooled into one group since the Chi-Square Test that evaluated the effects of release time on their ability to produce smolts was non-significant. Initially 76% of the sockeye fry entering Lake Washington in 2005 were of NOR origin. The percentage of NOR smolts in our 2006 sample was 66% and the Chi-Square test indicated that hatchery-origin fry survived to the smolt stage at a significantly higher rate than their NOR counterparts (*P* = <0.001; Table 5)

<u>Comparing The Fork Lengths Of Hatchery And NOR Smolts</u>

The importance of date of collection and smolt origin (hatchery early, middle, and late release groups and NORs) on the fork length of sampled smolts was examined using One-way ANOVAs. When a fish was sampled did not appear to affect its mean fork length. For example, the fork lengths of smolts originating from early-release fry had comparable fork lengths regardless of when they were sampled (*P* = 0. 744). Similar results were obtained for hatchery smolts produced from the middle (*P* = 0.806) and (*P* = 0.357) late release groups. Sampling date also did not affect the mean fork lengths of NORs. Thus it was possible to pool all the lengths from each type of smolt and perform a One-Way ANOVA to see if the origin of a smolt had affected its fork length. This analysis (P = <0.001) and a subsequent multiple comparison test showed that smolts produced from the early hatchery release group were significantly larger than NORs and late release group fish. NOR smolts and those originating from the middle and late release groups had comparable fork lengths. The larger size of the early release smolts probably reflected their longer rearing period in Lake Washington.

Table 5. Fry-to-smolt survival comparisons among the different hatchery groups of fry released in 2005 from the 2004 brood year.

Comparison	Null Hypothesis	Results Of The Chi-Square Tests		
		df	Chi-Square	Conclusion
Effect of release timing on the fry-to-smolt survival of hatchery fry released from the Airport (RK 0.16) Early vs. Middle vs. Late	Time of release has no impact on fry-to-smolt survival of unfed hatchery fish released at the Airport	2	4.97	Fail to reject the null hypothesis *P* = 0.08
Effect of release location on fry-to-smolt survival of early and middle release groups of hatchery fry Early Group: Hatchery release site vs. Airport release site	Where a fry is released has no affect on the fry-to-smolt survival rate of early group fish	1	3.59	Fail to reject the null hypothesis *P* = 0.06
Middle Group: Hatchery release site vs. Airport release site.	Where a fry is released has no affect on the fry-to-smolt survival of rate of middle group fish	1	7.17	Reject the null hypothesis. Fry released from the hatchery achieved a higher fry-to-smolt rate *P* = 0.007
Effect of release timing on the fry-to smolt survival of fry released from the hatchery (RK 36.0) Early Hatchery vs. Middle Hatchery	Time of release from the hatchery does not influence fry-to smolt survival	1	14.96	Fry released from the hatchery during the middle period achieved higher fry-to-smolt survivals than those released during the early period P = 0.0001
Effect of origin on fry-to-smolt survival NOR vs. hatchery fry-to-smolt survival	NOR and hatchery-origin fry have similar fry-to-smolt survivals	1	59.91	Hatchery-origin fry achieved higher fry-to smolt survival rates P = <0.0001

A summary of all the smolt length information for hatchery and NOR smolts is shown in Table 6.

Table 6. The mean fork lengths of one-year old hatchery and NOR sockeye smolts collected from Lake Washington on May 18, 22, 25, and 30, 2006.

Sampling Date	Smolt Origin	N	Mean Fork Length	Standard Deviation
18 May	Early Release	64	122.9	8.7
	Middle Release	85	120.4	8.8
	Late Release	59	117.2	8.7
	NOR	329	118.8	9.0
22 May	Early Release	10	119.9	7.5
	Middle Release	13	118.6	10.1
	Late Release	4	119.8	10.3
	NOR	63	117.4	11.9
25 May	Early Release	49	121.7	8.7
	Middle Release	54	121.0	7.6
	Late Release	52	119.1	7.7
	NOR	271	120.5	9.3
30 May	Early Release	11	121.8	10.4
	Middle Release	13	121.4	9.1
	Late Release	10	114.8	5.7
	NOR	44	117.8	11.4

Some Final Considerations

As in previous years the above results depend upon the assumption that the smolts collected and analyzed are representative of the entire population. Two factors in 2006 tend to support this assumption. The first is that fish were sampled in non-size selective manner by using a purse seine. Second, the proportion of hatchery origin fish appeared to be fairly constant from one collection date to the next. This consistency suggests that hatchery and NOR smolts emigrate from Lake Washington at similar times. If this is true, our estimates of relative abundance of NORs and hatchery fish were not biased because of when the fish were sampled.

Samples of sockeye smolts were also collected in 2007 and data from those samples are currently being generated. We hope that similar collections can be made in future years so that it will be possible to examine the effects of hatchery culture on sockeye smolts across multiple years.

Literature Cited

Volkhardt, G., D. Seiler, L. Fleischer, and K. Kiyohara. 2006. Evaluation of Downstream salmon production in 2005 from the Cedar River and Bear Creek. Washington Department of Fish and Wildlife, Fish Program, Science Division, Wild Salmon Production/Evaluation Report FPA 06-02. 63 pp.