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MEMORANDUM

TO: Michele DeHart

FROM: FPC Staff

DATE: January 26, 2010

RE: Update of Sockeye Memos – Inclusion of 2009 data

In response to several inquiries regarding the high returns of sockeye adults in 2008, the FPC staff reviewed the adult return data for Mid-Columbia River and Snake River sockeye in 2008 and analyzed the in-river conditions and hatchery releases during recent out-migration years. These analyses were first posted on the FPC website on July 14, 2008 (http://www.fpc.org/documents/memos/109-08.pdf) and included survival data from migration years 1998 to 2007. Subsequently, FPC staff received several questions and review comments regarding this original analysis and posted memos in response to each of these questions on the web-site (July 21, 2008 - http://www.fpc.org/documents/memos/111-08.pdf and August 6, 2008 - http://www.fpc.org/documents/memos/121-08.pdf). Furthermore, NOAA issued a report about the increased sockeye returns in 2008, to which the FPC posted comments on February 18, 2009 (http://www.fpc.org/documents/memos/18-09.pdf). Finally, FPC staff updated the original analysis to include 2008 survival data and included this updated analysis in the 2008 Annual Report (http://www.fpc.org/documents/FPC_Annual_Reports.html). In response to your request, FPC staff have analyzed sockeye survival and in-river conditions for migration year 2009 and are updating the sockeye analysis to include this migration year. Below is a brief summary of our findings, followed by a more detailed discussion of the analyses.

- Sockeye adult returns to Bonneville Dam in 2009 were approximately 2.3 times the 10-year average. For the second year in a row, sockeye adult returns to Lower Granite Dam broke previous return records and were nearly 9.7 times the 10 year average.
- Approximately 93.9% of the Mid-Columbia PIT-tagged sockeye adults detected at Bonneville Dam out-migrated in 2007, while 5.5% out-migrated in 2008, and 0.6% out-

migrated in 2006. Of the PIT-tagged Snake River sockeye adults detected at BON in 2009, 87% out-migrated in 2007 and 13% out-migrated in 2008.

- PIT-tagged juvenile sockeye from the Mid-Columbia had a reach survival from Rock Island to John Day dam of approximately 0.59 in 2009, which was lower than more recent years (2006 and 2008) but still higher than years prior to 2006. Migration year 2009 also had a relatively short water transit time. Weighted regression analyses continue to reveal a significant relationship between water transit time and juvenile reach survival for Mid-Columbia sockeye. As water transit time decreases, reach survival increases.
- Hatchery releases of sockeye to the Mid-Columbia for migration year 2009 were still high, compared to releases prior to 2005. Releases in 2009 were comparable to the high hatchery output in this region since 2006, which is primarily due to the release of unclipped fry into Lake Skaha.
- PIT-tagged juvenile sockeye from the Snake River had a reach survival from Lower Granite to John Day dam of approximately 0.75 in 2009. This was the second highest survival among the years we have analyzed. Weighted regression analyses continue to show a strong relationship between both water transit time and fish travel time, and reach survival. As water transit or fish travel time decreases reach survival increases. These same regression analyses also continue to reveal a strong relationship between average percent spill and reach survival for Snake River sockeye indicating that survival increases as spill increases. Finally, the estimated proportion of juvenile fish transported was higher in 2009, compared to 2006 and 2007, but still lower than most years prior to 2006.
- The high returns of sockeye adults in 2008 and 2009 are likely due to a combination of conditions which occurred during the 2006-2008 juvenile out-migrations, including:
    - Higher flow and spill during 2006
    - Higher proportion of river flow spilled in the lower flow year of 2007
    - Improved spill operations at McNary Dam in 2006-2008; changing the operation from the previous night time spill only to 40% spill 24 hours per day.
    - Improved spring spill operations at John Day in 2006, 2008, and 2009. A T1 line outage in 2006 forced JDA to spill spill 40% of river flow for 24 hours per day. Tests were conducted in 2008 and 2009 that called for 24-hour spill of 30% versus 40% spill, which occurred in 2-day blocks.
    - Lower proportion of juvenile sockeye transported at Snake River projects.
    - Increased hatchery production in the upper Columbia River by Fisheries and Ocean , Canada
- At this time, there is no evidence of straying among PIT-tagged Mid-Columbia sockeye adults to the Snake River, based on detections of adults at Ice Harbor and/or Lower Granite dams.

2009 Sockeye Adult Returns

Sockeye adult returns to Bonneville Dam (BON) in 2009 totaled 177,823, which was about 2.3 times the 10-year average (1999-2008) but less than the 2008 total of 213,607 (Table 1). Based on counts at Priest Rapids Dam (PRD) and Ice Harbor Dam (IHR), the vast majority of the sockeye adults returning to BON were of Mid-Columbia origin. However, sockeye adult returns to Lower Granite Dam (LGR) in 2009 totaled 1,219, which was 9.67 times the 10-year average (1999-2008) and a new record high since counting at LGR began in 1975.

In 2009, 350 PIT-tagged adult sockeye were detected at Bonneville Dam (BON). Of these, 93% were released as juveniles on the Mid-Columbia River. Based on these PIT-tag detections, approximately 93.9% of the PIT-tagged Mid-Columbia sockeye adults detected at BON out-migrated in 2007, 5.5% out-migrated in 2008, and 0.6% out-migrated in 2006. Only 23 PIT-tagged Snake River sockeye adults were detected at BON in 2009. Of these, 87% out-migrated in 2007 and 13% out-migrated in 2008.

Table 1. Adult Sockeye counts at Bonneville, Priest Rapids, Ice Harbor, and Lower Granite Dam. Counts and 10-yr average (1999-2008) are based on historic count dates, beginning March 15th.

Project	2009 Total Count	2008 Total Count	10-yr Average
BON	177,823	213,607	78,590
PRD	153,466	196,835	74,878
IHR	867	539	90
LGR	1,219	909	126

Mid-Columbia Sockeye – Methods:

To update previous sockeye analyses, FPC staff analyzed in-river conditions in 2009 compared to past years (1998-2008). Specifically, FPC staff estimated juvenile reach survivals for Mid-Columbia sockeye based on releases of PIT-tagged individuals at Rock Island Dam (RIS). Due to limited sample sizes, only estimates of survival from RIS to John Day Dam (JDA) were possible for all years. These same PIT-tagged individuals were used to estimate median fish travel times from the point of release to McNary (MCN) and JDA. With these travel times, we estimated the water transit time (WTT), fish travel time (FTT), average flow, and average percent spill that these out-migrants would have experienced during their out-migration from RIS to JDA. The estimation of reliable environmental variables requires that the window of time is as small as possible. In order to minimize this window, we only analyzed PIT-tags released at RIS between April 15th and May 26th of each year. Survival estimates and estimates of each of the environmental variables listed above can be found in Table 2 below.

Table 2. Juvenile survival (RIS-JDA) and in-river conditions experienced by PIT-tagged sockeye juveniles released from RIS. Survival estimate to JDA was not possible in migration year 2000 due to small sample size. No juvenile sockeye were PIT-tagged at RIS in 2003.

Migration Year	Average Flow (Kcfs)	Fish Travel Time (days)	Water Transit Time (days)	Average Spill Percent	Juvenile Survival (RIS-JDA)	95% Confidence Interval	
						Lower Limit	Upper Limit
1998	222.1	16.2	8.9	32.8	0.55	0.40	0.71
1999	215.7	11.4	9.2	31.9	0.50	0.39	0.62
2000	208.6	11.6	9.9	32.8	N/A	N/A	N/A
2001	91.9	23.3	20.5	18.1	0.25	0.10	0.40
2002	191.2	10.9	10.6	31.3	0.33	0.20	0.46
2004	157.7	10.9	12.6	28.2	0.40	0.16	0.64
2005	160.3	11.0	12.3	27.7	0.42	0.05	0.78
2006	238.7	10.2	8.4	28.0	0.88	0.59	1.18
2007	204.1	10.1	10.2	20.3	0.56	0.40	0.72
2008	198.5	7.3	9.9	21.2	0.77	0.41	1.13
2009	189.8	12.3	10.2	20.7	0.59	0.39	0.80

Two types of weighted regression analyses were used to investigate what effects these environmental conditions may have on juvenile reach survival (RIS-JDA). The first of these analyses used actual survival estimates (i.e., untransformed). Weighting for these untransformed regressions was based on the inverse variance of the survival estimates. The second of these analyses used log-transformed survival estimates.

Logarithmic transformation is useful in analyses of survival data because the mean and variance estimates are often positively correlated. Logarithmic transformation will often reduce this heteroscedasticity (Burnham et al. 1987:211-212). By definition, using a log-transformation of survival assumes that survival is lognormally distributed. There is both empirical evidence and a theoretical basis for assuming that a lognormal distribution is a reasonable approximation for characterizing variability in survival rates (Peterman 1981, Hilborn and Walters 1992:264-266). Since our overall reach survival estimates are the product of shorter reach survival estimates, it is a good general practice to log-transform these overall reach survival estimates ($Ln(Surv_{RIS\text{-}JDA})$) prior to performing regressions of survival versus candidate covariates. In order to do this with weighted regression, it is necessary to calculate the variance of a log-transformed variable. For lognormally distributed random variables, the variance of log (x) is (Blumenfeld 2001):

$$Var[\log (x)] = \log (1+ [cv(x)]^2) \qquad (1)$$

In addition to these weighted regression analyses, FPC staff reviewed hatchery release data from 1998 to 2009. For this analysis, we tallied hatchery releases of sockeye in the Mid-Columbia region (MCN to Chief Joseph Dam) based on their expected year of out-migration. Due to recent changes in hatchery releases in this zone, we included releases of fry.

Mid-Columbia Sockeye – Results:

Juvenile survival (RIS-JDA) in migration year 2009 was 0.59, which is among the highest estimates of juvenile survival (Table 2). However, juvenile survival in 2009 was lower than what was seen in 2006 and 2008. Weighted regression analyses of the log-transformed survival estimates revealed a significant relationship between water travel time (WTT) and juvenile reach survival (R^2 = 0.40, p = 0.029, Table 3). Although fairly strong, this relationship was not significant for the untransformed weighted regression analyses (R^2 = 0.21, p = 0.104, Table 3). Regardless of significance, both the transformed and untransformed regressions indicate that water transit time appears to have an effect on juvenile reach survivals of Mid-Columbia River sockeye. Specifically, as water transit times decrease, juvenile reach survivals increase (Figure 1). The weighted regression analyses found no significant relationship between juvenile reach survival and fish travel time (FTT) or average percent spill for Mid-Columbia sockeye (Table 3).

Table 3. Results from weighted regression analyses for Mid-Columbia River sockeye. Each environmental variable was regressed against juvenile reach survival (RIS-JDA). Statistically significant variables are in bold (α = 0.05) and italics (α = 0.1).

Environmental Variable	Untransformed Data			Transformed Data		
	Adjusted R^2	F statistic (df = 1,8)	P value	Adjusted R^2	F statistic (df = 1,8)	P value
WTT	0.21	3.36	0.104	0.40	7.05	**0.029**
FTT	0.08	1.75	0.222	0.14	2.42	0.159
Avg. Percent Spill	0.00	0.21	0.659	0.00	0.07	0.803

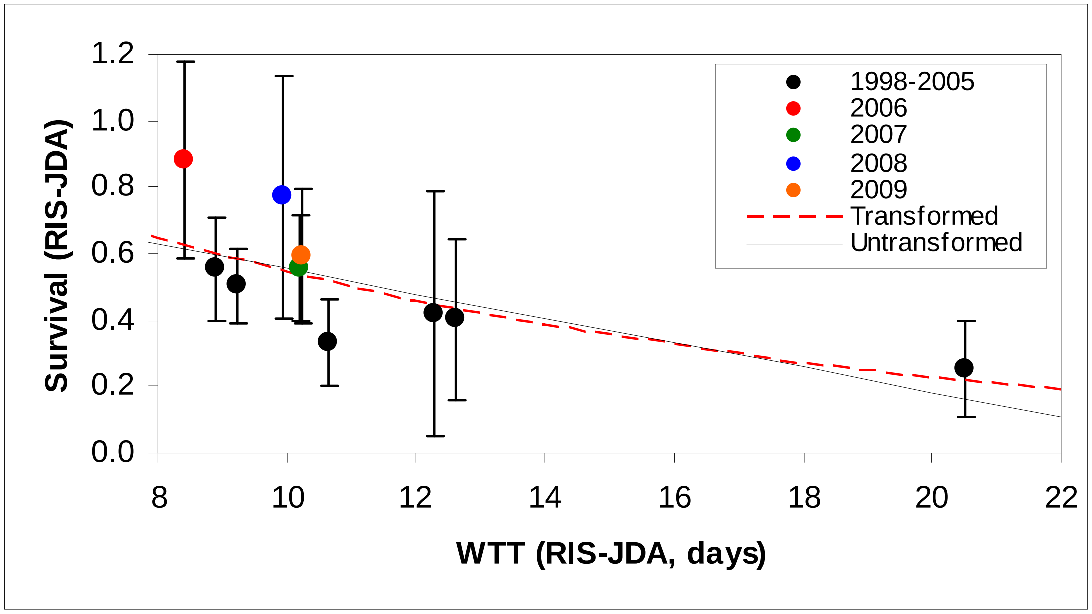

Figure 1. Weighted regressions of water transit time and juvenile reach survival (RIS-JDA) of PIT-tagged Mid-Columbia River sockeye juveniles released at RIS.

Over the years presented in this analysis, the average spill proportion for the Rock Island to John Day reach has had little variation, except in 2001 (Table 2). Because the average spill variable did not change much over the years analyzed, this variable did not affect the reach survival estimate. However, there have been substantial changes in the spill operations on a per project basis (Figure 2). For example, out-migrants prior to 2005 would have experienced 48% to 66% spill at PRD, whereas those out-migrating from 2006 to 2009 experienced only 27% to 12.9% spill. During this period of reductions in spill at PRD, spill levels at MCN and JDA in recent years have been higher than in historic years. For example, 2006 and 2008 out-migrants experienced the largest percent spill at MCN among the years analyzed, particularly when compared to 2001-2005. Beginning in 2006, spill at MCN was 40% of instantaneous flow for 24-hours. Prior to this time, spill at MCN was limited to night-time spill the gas cap. Spill percent at JDA in 2006 and 2008 were also the highest among the years analyzed. Spring operations at JDA in 2006, 2008, and 2009 were different from previous years. In previous years (and in 2007), spill at JDA was limited to 60% of instantaneous flow during night-time hours. However, due to a T1 line outage in 2006, the spill at JDA in 2006 was 24 hours, at approximately 40% of instantaneous flow. Testing in 2008 and 2009 allowed for 24-hour spring spill at JDA, which fluctuated between 30% of instantaneous flow and 40% of instantaneous flow, with each spill level lasting for about 2-days.

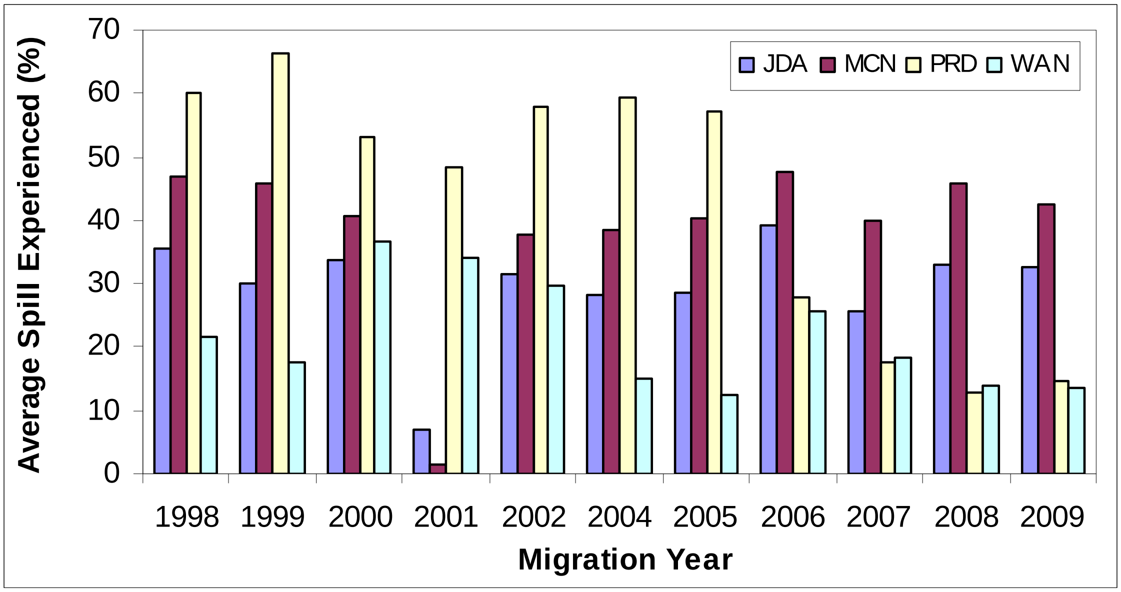

Figure 2. Average percent spill experienced by PIT-tagged sockeye juveniles at Wanapum, Priest Rapids, McNary, and John Day dams.

Beginning in migration year 2006, there has been a substantial increase in the number of hatchery sockeye released in the Mid-Columbia (Table 4). This is primarily due to releases of sockeye fry into Lake Skaha by Fisheries and Ocean Canada. These fry are released into Lake Skaha in the spring but do not out-migrate as smolts until the following spring. These fry releases first began in the spring of 2004, with 352,500 individuals released for out-migration in spring 2005. These fry releases have increased substantially since migration year 2005. Since these fry are so small when released, they are not marked or tagged with external marks or PIT-tags. It is worth noting that there is no estimate of survival from fry to smolt for these individuals so there is no way to know to what degree they contributed to the adult returns in 2008 and 2009. All other sockeye juveniles released in the Mid-Columbia are clipped (AD, LV, or RV).

Table 4. Hatchery releases (by migration year) of sockeye smolts and fry in the Mid-Columbia Zone.

Migration Year	Total Smolts Released	Total Fry Released	Total Juveniles Released	Percent Fry
1998	365,784	0	365,784	0
1999	210,591	0	210,591	0
2000	142,901	0	142,901	0
2001	241,216	0	241,216	0
2002	308,042	0	308,042	0
2003	208,986	0	208,986	0
2004	315,790	0	315,790	0
2005	240,459	352,500	592,959	59
2006	172,923	1,205,500	1,378,423	87
2007	140,542	1,384,000	1,524,542	91
2008	225,670	1,479,000	1,704,670	87
2009	252,133	900,000	1,152,133	78

Given these results, it is likely that the increased adult returns of Mid-Columbia sockeye in 2008 and 2009 are the combination of good in-river conditions in 2006 - 2008 (e.g., decreased water transit times, increased percent spill at MCN and JDA), increased juvenile reach survivals, and hatchery output in migration years 2006 – 2008.

Snake River Sockeye – Methods:

FPC staff also estimated juvenile reach survivals for PIT-tagged individuals from Lower Granite Dam (LGR) to McNary Dam (MCN) for migration year 2009. In order to increase sample sizes, individuals that passed LGR undetected but had first-time detections at Little Goose Dam (LGS) were used in this analysis. These same PIT-tagged individuals were used to estimate median fish travel times from the point of LGR detection to MCN. With these travel times, we estimated the water transit time (WTT), fish travel time (FTT), average flow, average temperature, and average percent spill that these out-migrants would have experienced during their out-migration from LGR to MCN. The estimation of reliable environmental variables requires that the window of time is as small as possible. In order to minimize this window, we only included PIT-tagged sockeye that were detected at LGR between May 8th and June 4th of each year. This window was extended down to LGS for those individuals that were first detected at LGS, based on the median travel time from LGR to LGS for each particular year. Survival estimates and estimates of each of the environmental variables listed above can be found in Table 5 below.

Table 5. Juvenile reach survival (LGR-MCN) and in-river conditions experienced by PIT-tagged sockeye juveniles with fist time detects at LGR or LGS. Survival estimate to MCN was not possible in migration year 2004 due to a large proportion of PIT-tagged individuals being transported in that year.

Migr. Year	Avg. Flow (Kcfs)	Fish Travel Time (days)	Water Transit Time (days)	Average Temp. (°C)	Average Spill Percent	Juvenile Survival (LGR-MCN)	95% Con. Int.	
							Lower Limit	Upper Limit
1998	196.6	10.3	6.3	13.8	43.2	0.60	0.22	0.98
1999	173.0	6.4	7.2	12.3	39.5	0.63	0.42	0.84
2000	117.0	7.5	10.9	13.9	46.1	0.64	0.37	0.91
2001	80.5	12.5	15.3	14.4	1.2	0.26	0.06	0.46
2002	147.0	8.6	8.9	12.3	36.7	0.50	0.35	0.66
2003	152.6	5.6	8.2	12.5	38.4	0.71	0.50	0.91
2004	129.0	6.8	9.7	13.2	27.4	N/A	N/A	N/A
2005	121.9	14.3	10.2	13.8	27.6	0.45	0.13	0.77
2006	189.9	6.8	6.6	13.6	40.0	0.86	0.47	1.25
2007	116.0	8.4	11.7	13.9	38.3	0.62	0.38	0.86
2008	195.8	6.9	6.5	11.6	44.4	0.67	0.43	0.90
2009	180.3	6.7	6.9	12.8	37.5	0.75	0.62	0.89

As with the Mid-Columbia sockeye, two types of weighted regression analyses were used to investigate what effects these environmental conditions may have on juvenile reach survival for Snake River sockeye (LGR-MCN). We used the same two types of weighted regression analyses: 1) untransformed survivals weighted by the inverse variance of the survival estimates and 2) log-transformed survivals. Weighting for the log-transformed weighted regression analyses was done in the same manner as was discussed for Mid-Columbia sockeye (Eq. 1 above).

In addition, we estimated the proportion of the Snake River sockeye juvenile population destined to be transported. This estimate was based on the detection probabilities at each of the collector projects. As with the Mid-Columbia sockeye, we reviewed hatchery release data for the last 12 years (MY 1998-2009). For this analysis, we tallied hatchery releases of sockeye in the Snake River Zone (above LGR) based on their expected year of out-migration. Due to recent changes in hatchery releases in this zone, we included releases of fry. However, there have been releases of sockeye eyed-eggs and adults to the Snake River in recent years. Our analyses of hatchery releases do not include these releases, since there is no way to determine their contribution to out-migrant numbers. Finally, to address the possibility of straying, we reviewed PIT-tag detections of Mid-Columbia sockeye adults at Ice Harbor and Lower Granite Dam in 2009.

Snake River Sockeye – Results:

Among the migration years analyzed, migration year 2009 resulted in the second highest estimate of juvenile survival (LGR-MCN), at 0.75 (Table 5). Only migration year 2006 had higher estimates of juvenile reach survival (Table 5). Both fish travel time (FTT) and water transit time (WTT) were found to have a significant effect on juvenile reach survival (LGR-MCN) for Snake River sockeye. These relationships were significant at the $\alpha = 0.05$ level, using either the untransformed or the log-transformed survival estimates (Table 6). Specifically, as FTT and WTT decrease, reach survival (LGR-MCN) increases (Figures 3 and 4).

Weighted regression analyses of the log-transformed survival estimates revealed a significant relationship between average percent spill and juvenile reach survival ($R^2 = 0.32$, $p = 0.040$, Table 6). Although fairly strong, this relationship was not significant for the untransformed weighted regression analyses ($R^2 = 0.18$, $p = 0.109$, Table 6). Regardless of significance, both the transformed and untransformed regressions indicate that average percent spill appears to have an effect on juvenile reach survivals of Snake River sockeye. Specifically, as average percent spill increases, juvenile reach survival increases (Figure 5). Finally, the weighted regression analyses found no significant relationship between juvenile reach survival (LGR-MCN) and average temperature (Table 6).

Table 6. Results from weighted regression analyse for Snake River sockeye. Each environmental variable was regressed against juvenile reach survival (LGR-MCN). Statistically significant variables are in bold ($\alpha = 0.05$) and italics ($\alpha = 0.1$).

Environmental Variable	Untransformed Data			Transformed Data		
	Adjusted R^2	**F statistic (df = 1,9)**	**P value**	**Adjusted R^2**	**F statistic (df = 1,9)**	**P value**
WTT	0.39	7.33	**0.024**	0.42	8.11	**0.019**
FTT	0.50	11.12	**0.009**	0.54	12.56	**0.006**
Avg. Percent Spill	0.18	3.16	0.109	0.32	5.77	**0.040**
Avg. Temp.	0.00	0.28	0.612	0.00	0.25	0.631

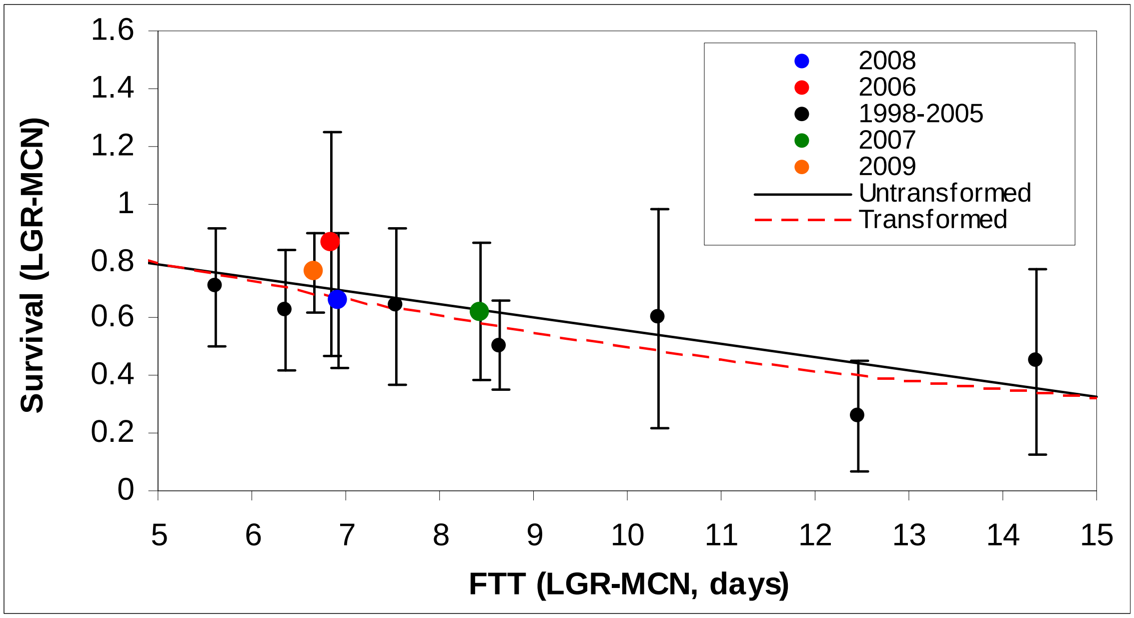

Figure 3. Weighted regression of fish travel time (FTT) and juvenile reach survival (LGR-MCN) of PIT-tagged Snake River sockeye juveniles released above Lower Granite Dam.

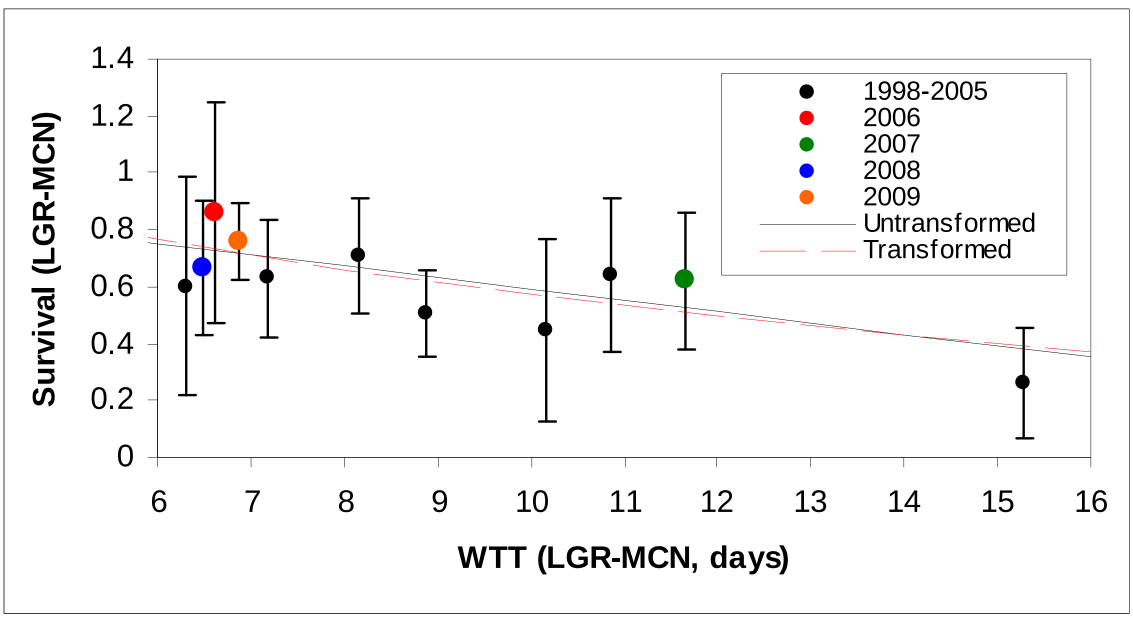

Figure 4. Weighted regression of water transit time (WTT) and juvenile reach survival (LGR-MCN) of PIT-tagged Snake River sockeye juveniles released above Lower Granite Dam.

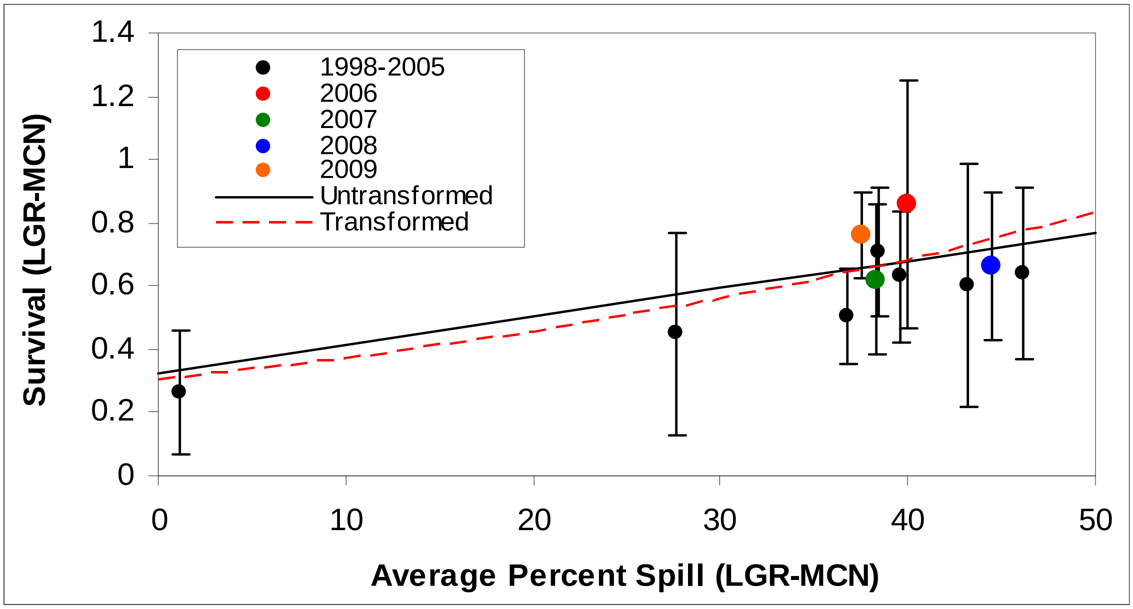

Figure 5. Weighted regression of average percent spill and juvenile reach survival (LGR-MCN) of PIT-tagged Snake River sockeye juveniles released above Lower Granite Dam.

As with the Mid-Columbia sockeye, the high flows and, thus, short water transit times in 2006, 2008, and 2009 likely contributed to the increased reach survival in these years. Weighted regression analyses showed a significant ($\alpha = 0.05$) negative relationship between water transit time and juvenile reach survival (LGR-MCN), where reach survival increases as water transit time decreases (Table 6, Figure 4). Furthermore, it is likely that average spill percent also contributed to the higher reach survivals in more recent migration years, as there was a significant ($\alpha = 0.05$) positive relationship between reach survival and average percent spill (Table 6, Figure 5).

According to our analysis, approximately 64.5% of all Snake River juvenile sockeye out-migrants in 2009 were "destined" for transport. This proportion is slightly higher than that for 2006 and 2007 but much lower than that for most of the migration years prior to 2006 (Table 7).

Table 7. Estimated proportion of Snake River sockeye juvenile population "destined" for transport.

Migration Year	Proportion Transported
1998	0.719
1999	0.753
2000	0.518
2001	0.950
2002	0.663
2003	0.758
2004	0.952
2005	0.859
2006	0.592
2007	0.532
2008	0.620
2009	0.654

Releases of hatchery sockeye to the Snake River have fluctuated over the past 11 years, ranging from 40,419 in 2000 to 335,803 in 1998 (Table 8). Since 2005, hatchery releases of sockeye in the Snake River zone have averaged about 207,000 per year. In recent years, there have been releases of eggs and mature sockeye adults to the Snake River. However, it is difficult to know to what degree these releases are contributing to the out-migrating populations and, thus, adult returns.

Table 8. Hatchery releases (by migration year) of sockeye smolts and pre-smolts in the Snake River Zone.

Migration Year	Number Released
1998	335,803
1999	151,899
2000	40,419
2001	86,029
2002	144,838
2003	140,410
2004	76,927
2005	209,046
2006	158,160
2007	208,968
2008	232,500
2009	257,060

There were no detections of PIT-tagged Mid-Columbia sockeye adults at Ice Harbor or Lower Granite dams in 2009. Therefore, based on PIT-tag detections, there is no evidence of straying of PIT-tagged adult Mid-Columbia sockeye to the Snake River. Similar analyses of 2008 returns also revealed no evidence of straying of PIT-tagged adult Mid-Columbia sockeye to the Snake River.

Therefore, it is likely that the increased adult returns of Snake River sockeye in 2008 and 2009 are likely the result of a combination of good in-river conditions (e.g., low water transit time in 2006 and high spill percent in 2006 and 2007), increased juvenile reach survivals in 2006, 2007, and 2008, and low transportation proportions in 2006 and 2007. Coincidently, prior to 2008, the last year when sockeye adult returns to LGR were above 200 was in 2000 and most of these adults would likely have out-migrated in 1998 and 1999. Of all the years analyzed, 1998 and 1999 had some of the shortest water travel times, highest average percent spill, and highest reach survivals.

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