FISH PASSAGE CENTER

1827 NE 44th Ave., Suite 240, Portland, OR 97213
Phone: (503) 230-4099 Fax: (503) 230-7559
http://www.fpc.org/
e-mail us at fpcstaff@fpc.org

MEMORANDUM

TO: Ed Bowles
Oregon Department of Fish and Wildlife

FROM: Michele DeHart
Michele DeHart

DATE: August 27, 2009

RE: Steelhead Adult Returns in 2009

In response to your request, the FPC staff has reviewed the returns of adult steelhead to the Snake and Mid-Columbia Rivers in 2009 and analyzed the in-river conditions, PIT tag data, juvenile passage characteristics, and hatchery releases for outmigration years contributing to the 2009 adult return. We compared in-river migration conditions contributing to the 2009 return with outmigration conditions experienced by other recent return years. We conducted additional analyses in order to assess the relative importance of freshwater juvenile migration conditions relative to marine conditions. Adult returns of steelhead which out migrated in 2007 will not be complete until the end of 2009. Adult returns of steelhead which out migrated in 2008 will not be complete until the end of 2010. Estimation of smolt to adult return (SAR) rates for steelhead out migrating in 2007 will occur when the 2009 return is complete. Thus, our analysis must be considered preliminary. Our conclusions are summarized below, followed by detailed discussion of the analysis.

- As of August 26th, 2009, the total adult steelhead count at Bonneville Dam (BON) was 450,639 (Table 1). The count to date exceeds all other years on record, including the previous record count in 2001 through August 26th.
- The steelhead return in 2009 is primarily comprised of juvenile out migrants from 2007 and 2008. Passage conditions for steelhead in 2007 and 2008 differ significantly from previous years, mainly in the Snake River, as a result of the federal court ordered spill for fish passage operations plan. In particular, 2007, had a higher proportion of spill

provided for downstream migrants during lower flow conditions compared with previous years.

- Although marine environmental conditions undoubtedly affect mortality in the marine environment, several lines of evidence suggest that conditions experienced in the freshwater environment are partially manifest after exiting the hydrosystem.
- Juvenile in river reach survivals for the upper Columbia from Rock Island to McNary Dam averaged 0.697 for 2007 and 2008, compared to the average of 0.56 for 1998-2006. Juvenile steelhead out migrating in 2007 and 2008 experienced the shortest combined average water travel times of all years analyzed (1998 to 2008) in the Rock Island to McNary Dam reach.
- Juvenile steelhead migrating through the upper Columbia are likely benefiting from improved spill for passage at McNary Dam that was included in the court ordered federal operations plan that increased spill at McNary from night-time only (at the gas cap) to 24-hour spill (at 40% of instantaneous flow).
- Juvenile reach survival from Lower Granite to McNary Dam was relatively high for 2007 and 2008, averaging 0.68 compared to previous year's average of 0.55
- Consistent with past years data, based upon multi-year analysis, the most important variables explaining variability in reach survival for steelhead were spill proportion and water transit time (i.e., flow). Higher spill proportions, particularly for Snake River fish, and higher flow during outmigration years 2007 and 2008 (in the Columbia River) are likely the primary factors contributing to the higher juvenile survivals and faster juvenile travel times which occurred in 2007 and 2008. These results are consistent with historical findings (Schaller et al 2007) which concluded that water transit time (i.e., flow) and spill proportion were the most important variables in steelhead in-river juvenile survival and fish travel time.
- Operations in the Lower Columbia River in 2008 precluded the estimation of juvenile survival in that reach. Removal of turbine intake screens at Bonneville's second powerhouse could have increased passage mortality as well as reducing tag detection probability.
- The proportion of hatchery and wild steelhead (combined) transported from the Snake River in 2007 and 2008 was less than 50%, as the result of the court ordered spill program. This was a significant reduction from previous years.
- NOAA analysis has indicated that in-river juvenile steelhead survival appears to increase with increasing spill, as higher densities of in-river migrating steelhead reduce impacts of predation (i.e. predator swamping).
- Hatchery releases did not increase in 2007 and 2008 when compared to previous years, therefore the increase adult return seen in 2009 is not the result of increase hatchery releases.
- Model analysis of PIT tag data from 1998 through 2006 for in river migrants indicates that the primary factors affecting in-river juvenile steelhead survival are water travel time (i.e., flow), spill proportion, and Julian date.
- For in-river migrants, model averaged coefficients provide some indication of magnitude of change that could be expected for in-river migrants with changes in environmental conditions. At all water travel times, for each 5% increase in average percent spill, in-river survival is expected to show a 27% relative increase. At all spill levels, for each decrease of 2 days in water transit time, in-river survival is expected to show a 15% relative increase. At all ocean conditions, for each 5% increase in average

percent spill, Lower Granite to Lower Granite SARs are expected to show a 49% relative increase.

- Model analysis of PIT tag data from 1998 through 2006 for in-river migrants shows that factors that tend to increase freshwater survival (higher spill proportion and faster water transit time) will tend to increase ocean-adult survival and factors that tend to decrease freshwater survival will tend to decrease ocean-adult survival.
- Analyses of PIT tag data from, 1996 through 2006, for in-river migrants, on the variability of marine and freshwater mortality rates in conjunction with the positive correlation between freshwater and ocean-adult mortality rates indicates that improvements in freshwater survival are likely to translate into improvements in overall life-cycle survival (i.e. smolt-to-adult return).

Steelhead Adult Returns in 2009

As of August 26th, 2009, the total adult steelhead count at Bonneville Dam (BON) was 450,639. This adult steelhead count at BON was 1.99 times the 2008 count and 1.95 times the 10-year average. This 2009 total includes a new record daily count of 34,053 adult steelhead at Bonneville Dam, which was recorded on August 13th. Prior to this year, the previous record daily count for adult steelhead at Bonneville Dam was 14,432, which occurred on August 3, 2001. In fact, when compared to other year's counts up to Aug. 23rd, the total count of adult steelhead in 2009 exceeds all other years on record, including the previous record 2001 return year.

Juvenile Outmigration Conditions 2007 and 2008

The 2009 adult return is comprised of steelhead that out migrated as juveniles in 2007 and 2008. Juvenile passage conditions and analysis of juvenile passage characteristics show that reach survivals were higher and travel times were faster for in-river steelhead through the Lower Granite to McNary reach and from the Rock Island to McNary reach. Juvenile survival could not be estimated in 2008 for the McNary to Bonneville river reach due to removal of turbine intake bypass screens for most of the spring out-migration, which affected PIT tag recapture detections at Bonneville Dam and potentially increased passage mortality at the Bonneville Project. In general, historic survival estimates for steelhead from McNary to Bonneville have broader confidence limits because of low detection probabilities at downstream sites and lower numbers of marked steelhead.

Water Year 2007 was variable throughout Columbia Basin. At The Dalles Dam, the observed runoff volume recorded between January and July of 2007 was 95.7 Maf, which was 89% of the average runoff volume between 1971 and 2000. In general, the Snake River contained less than average water supply. The April through August runoff volume at Lower Granite Dam in 2007 was approximately 13.5 Maf, which was 59% of average (based on 1971-2000). Despite the low runoff volume in the Snake River, and subsequently low flows, voluntary spill was provided at all FCRPS projects in 2007 throughout the spring and summer. Given that flows were so low in the Snake River, spill proportions at Snake River projects were higher than usual, particularly for those projects that are set to spill a set volume (e.g., LGR, LMN, and IHR). Planned spill levels in 2007 were mostly met, except for days where flows were sufficiently low as to not meet powerhouse minimums and spill volumes, or total dissolved gas exceeded water quality standards. Planned spill levels for 2007 can be seen in Table 1 below.

Water Year 2008 was near or above average throughout Columbia Basin. At The Dalles Dam, the observed runoff volume recorded between January and July of 2008 was 99.2 Maf, which was 92% of the average runoff volume between 1971 and 2000. The Snake River saw above average runoff volumes in 2008. The April through August runoff volume at Lower Granite Dam in 2008 was approximately 24.3 Maf, which was 106% of average (based on 1971-2000). Voluntary spill was provided at all FCRPS projects in 2008 throughout the spring and summer. Through mid-May to late June, flows were generally in excess of hydraulic capacity. Therefore, most projects were forced to spill in excess of planned spill operations during this time. Planned spill levels for 2008 are displayed in Table 1 below.

Table 1. Planned spill operations at FCRPS projects in 2007 and 2008.

Season/Project	2007 FCRPS Operations Agreement Spill Levels	2008 FCRPS Operations Agreement Spill Levels
SPRING Snake River (Apr. 3-June 20), Lower Columbia (Apr. 10-June 30)		
Lower Granite	20 kcfs day/night	20 kcfs day/night
Little Goose	30% day/night	30% day/night
Lower Monumental	Gas Cap day/night	(Gas Cap)
Ice Harbor	30% day/night vs. 45 Kcfs day/gas cap night	30% day/night vs. 45 Kcfs day/gas cap night
McNary	40% day/night	40% day/night
John Day	0 day / 60% night	0 day / 60% night
The Dalles	40% day/night	40% day/night
Bonneville	100 kcfs day/night	100 kcfs day/night
SUMMER Snake River (June 21-August 31), Lower Columbia (July 1-August 31)		
Lower Granite	18 kcfs day/night	18 kcfs day/night
Little Goose	30% day/night	30% day/night
Lower Monumental	17 kcfs day/night	17 kcfs day/night
Ice Harbor	30% day/night vs. 45 Kcfs day/gas cap night	30% day/night vs. 45 Kcfs day/gas cap night
McNary	40% day/night vs. 60% day/night	40% day/night vs. 60% day/night
John Day	30% day/night	30% day/night
The Dalles	40% day/night	40% day/night
Bonneville	85 Kcfs day / gas cap night vs. 75 kcfs day / gas cap night	85 Kcfs day / gas cap night vs. 75 kcfs day / gas cap night

Figures 1and 2 illustrate the increase in spill proportions in recent years under the federal operations agreement. These increases are particularly notable in low flow years such as 2007 in the Snake River.

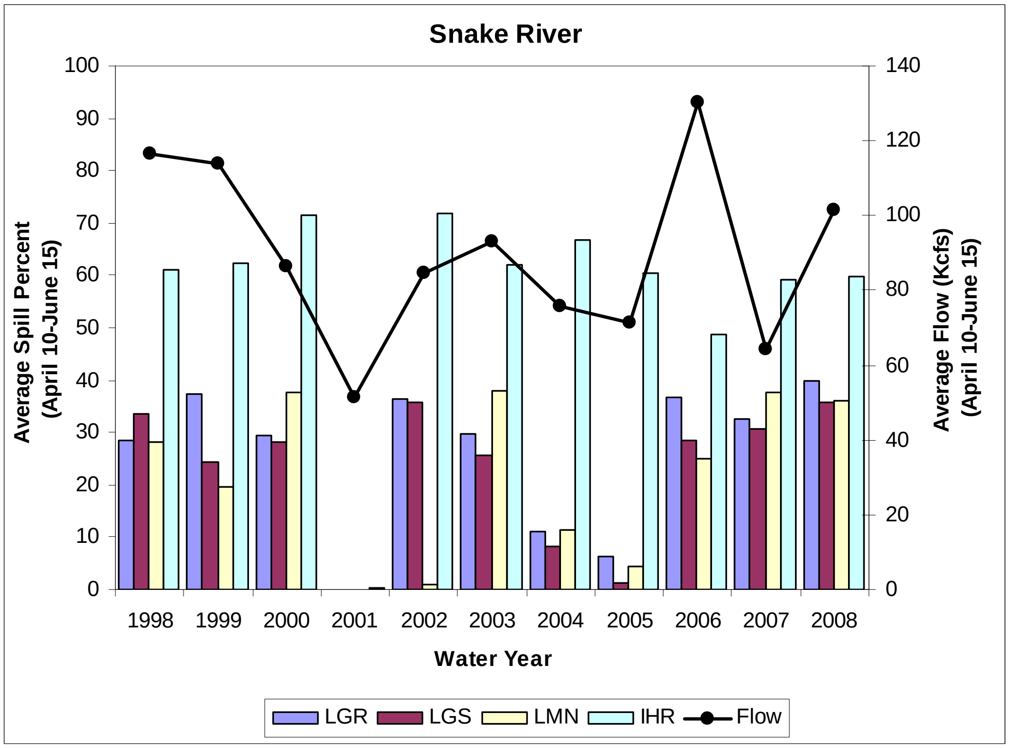

Figure 1. Spill proportion and flow at Snake River projects (1998-2008) Average flow is an average of the four Snake River projects from April 10-June 15 of each year.

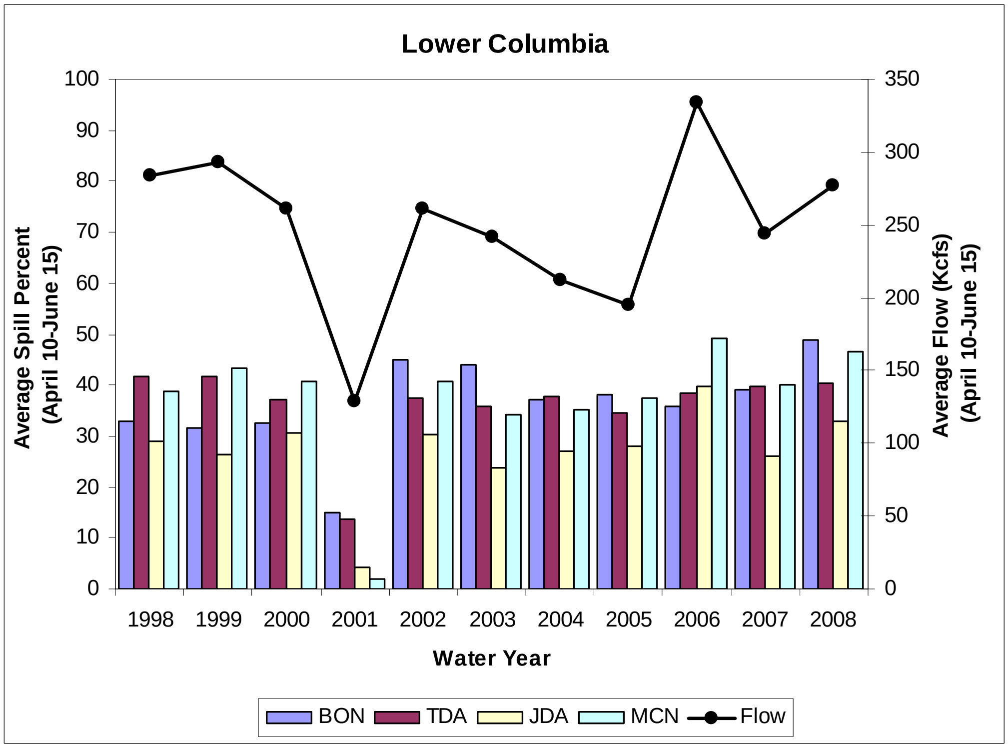

Figure 2. Spill proportion and flow at Lower Columbia River projects (1998-2008). Average flow is an average of the four Lower Columbia River projects from April 10-June 15 of each year.

Juvenile Survival Summary

PIT-tagged juvenile steelhead cohorts from the Mid-Columbia had reach survivals from Rock Island to McNary ranging from 0.54 to 0.83 and averaging 0.697 in 2007 and 2008. The average survival for the three cohorts in 2007 was 0.67 while in 2008 the average was 0.72. These survivals were well above the average for all other years of 0.57. Based on regression analysis, water transit time was found to significantly effect juvenile reach survival for Mid-Columbia steelhead, with shorter water transit times resulting in higher reach survivals (RIS-MCN). Hatchery steelhead releases in the Mid-Columbia have been relatively constant from 1998 to 2008, averaging 938,000 per year. Steelhead releases in 2007 and 2008 were near but below the average number released.

PIT-tagged juvenile steelhead cohorts from the Snake River had an average reach survival from Lower Granite to McNary Dam of approximately 0.72 in 2008, which was the second highest average annual survival among the years analyzed (1998-2008). The highest year was 1999 with average survival of 0.73, and that out-migration contributed to the record return of 2001. Multivariate regression showed that average spill proportion and water transit time were equally important in explaining reach survival for steelhead. Survival increased with increasing spill and also increased as water transit time decreased. Finally, the estimated proportion of juvenile steelhead transported in 2007 and 2008 was lowest of any of the years 1999 to 2008. As with Mid-Columbia river steelhead, Snake River steelhead hatchery releases in 2007 and 2008 were near but slightly below the average for the years analyzed. Therefore, the high returns of Snake River steelhead adults in 2009 is likely due to some extent to a combination of conditions which occurred during the 2007 and 2008 juvenile out-migrations, including: 1) higher flow and spill during 2008, 2) higher proportion of river flow spilled in the lower flow year of 2007, and 3) lower proportion of juvenile steelhead transported at Snake River projects in both years. It may be that ocean productivity also played a role, but given the inability to control those factors, we have are summarizing the data on the freshwater management actions that appear to be affecting adult returns.

Mid-Columbia Steelhead Juvenile Migration Analysis– Methods:

In order to determine how in-river conditions and juvenile population characteristics may have influenced the 2009 adult steelhead returns, the FPC staff analyzed in-river conditions in 2007, and 2008 compared to past years (1998-2006). Specifically, FPC staff estimated juvenile steelhead reach survivals for Mid-Columbia releases of PIT-tagged individuals at Rock Island Dam (RIS). Due to limited sample sizes, only estimates of survival from RIS to McNary Dam (MCN) were calculated for all years. Survival and travel time were estimated using PIT-tagged steelhead marked and released at Rock Island Dam in the years 1998 to 2008. Fish marked at Rock Island Dam bypass between April 21 and June 1 were included in three two-week release groups for subsequent analysis in the reach Rock Island Dam tailwater to McNary Dam tailwater.

Reach survival was then analyzed in relation to flow, spill, water temperature, and release dates during passage. Indices were used to characterize the river environment and timing of out-migration of each cohort during each year. Four indices were calculated for each cohort based on timing and fish travel time through the hydro-system. Water transit time (WTT) was calculated by summing the WTT's for each reservoir in the reach Rock Island Dam tailwater to McNary Dam tailwater. Average spill proportion was simply the average of spill proportion at all four dams in the reach as each cohort passed through. Date group was a number from 1 to 3 based on which two-week time period the cohort was released at Rock Island Dam. Average Temperature was the temperature, as measured at the tailwater of each dam, as the cohort passed through the downstream reservoir. The environmental indices; WTT, average spill proportion, and average water temperature were generated based on fish travel time through the reach. Fish travel time between dams was estimated for each group.

Since the Mid-Columbia dams do not have juvenile passage detections, travel time was calculated for the entire reach, Rock Island to McNary Dam. Travel time to dams between Rock Island and McNary dams was estimated based on the proportion of the total distance between dams that each dam represented. For example, in the reach Rock Island Dam to McNary Dam, for the earliest detection group in 1998 (marked from 4/21 to 5/4), travel time was estimated to be 7.9 days based on 22 detections. Travel time to Wanapum Dam, which is approximately 23% of the total distance from Rock Island to McNary, was calculated as the (total travel time * proportion of distance) or (7.9d * 0.23 = 1.8d). Based on this information, the environmental variables (flow and forebay elevation) at this site would have been averaged for the two week period April 23 to May 6. Once an average discharge and average forebay elevation at each dam were calculated, water transit times were then estimated. The overall reach water transit time variable was the sum of these calculated values for each project within the reach. Similarly, two-week average values were generated for average spill proportion and average temperature (degrees C) at all dams. The number of blocks per year and years analyzed was determined by the availability of PIT-tagged fish in those respective reaches and are summarized in Table 2. The criteria were to reject survival estimates if standard errors for any dam to dam segment within the reach exceeded 0.2. Estimates of each of the environmental variables mentioned above can be found in Table 3.

Table 2. Number of blocks and days for each reach estimates.

Reach	Species[a]	Years	Blocks per year	Days per Block	Total Blocks
LGR to MCN	ST H&W	1998 to 2008	6	7	61
RIS to MCN	ST H&W	1998 to 2008[b]	3	14	28

[a] H&W = Hatchery and Wild Combined

[b] No survivals were estimated in 2003 because no PIT-tagging was done at Rock Island Dam

Weighted regression analyses were used to investigate the effects environmental conditions may have had on juvenile reach survival (RIS-MCN). Logarithmic transformation was used because the mean and variance estimates were positively correlated. Log transformation reduces 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). Log-transform of reach survival estimates ($\mathrm{Ln}(\mathrm{Surv}_{\mathrm{RIS\text{-}JDA}})$) was done prior to regressing survival versus candidate covariates. For lognormally distributed random variables, the variance of log (x) is (Blumenfeld 2001):

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

Equation 1 was used to weight the survival estimates.

An information theory approach was used to examine the relative importance of environmental variables in explaining the variability in reach survival data (Burnham and Anderson 2002). Regression equations were fit to reach survival data and the Akaike's Information Criterion for small sample sizes (AICc) were calculated. The AICc scores were used to determine the relative likelihood of each equation being the best fitting equation, given the data set and the group of equations considered. Explanatory models were evaluated based on their resulting AICc scores. Lower values indicated a better fit to the data. AICc scores were examined for each variable singly. Based on those results, multivariate models were estimated using the highest rank variables identified from the bivariate AICc scores. Top ranked variables were combined in increasingly complex models to evaluate fit. Finally the fully saturated model (which included all explanatory variables) was fitted and the result added to the family of related models. Model weights were calculated using equation 2.

$$w_i = \frac{\exp(-1/2 \bullet \Delta_i)}{\sum_{r=1}^{R} \exp(-1/2 \bullet \Delta_r)} \qquad (2)$$

where Δ_i is the delta AICc, or difference between AICc for best fitting model (lowest AICc score) and each subsequent model. And R is the total number of models. The model weights were used to make inference regarding the best fitting models, and were also used to generate predictive models based on a model averaging approach. Weights express the relative likelihood of each model, relative to the other models examined, given the data (Burnham and Anderson 2002). Weights were also used to calculate the weight of evidence for the relative importance of each of the variables that were present in the set of models considered. Relative weight of evidence values were calculated as the sum of the weights of all the models in which the variables were present (Burnham and Anderson 2002). Weighted average coefficients were combined in models and used to predict in-river survival for the steelhead dataset.

Finally, FPC staff reviewed hatchery release data from 1998 to 2008. For this analysis, we tallied hatchery releases of steelhead in the Mid-Columbia region (above Priest Rapids Dam) based on their expected year of out-migration. We also estimated the proportion of the total release that was unclipped, in order to address whether increased returns of unclipped adult steelhead could be due to increased releases of unclipped hatchery steelhead.

Mid-Columbia Steelhead – Results

Juvenile Migration

Among the migration years analyzed 2007 and 2008 resulted in some of the highest estimates of juvenile reach survival (RIS-MCN), ranging from 0.54 to 0.83 (Table 3). The average survival for 2007 and 2008 combined was 0.67 which was higher than the average reach survival estimate for the years 1998 to 2006 (0.56). Furthermore, five of six reach survival estimates for the 2007 to 2008 cohorts were above the overall average for 1997-2006. By comparison, the years 1999 and 2000 also had relatively high survival, and those migration years contributed to the highest adult steelhead returns seen in 2001.

Table 3. Juvenile survival (RIS-MCN) and in-river conditions experienced by PIT-tagged steelhead juveniles released from RIS from 1998 to 2008. No juvenile steelhead were PIT-tagged at RIS in 2003.

Migration Year	Average Flow (Kcfs)	Fish Travel Time (days)	Water Transit Time (days)	Average Spill Percent	Average Temp (C)	Juvenile Survival (RIS-MCN)	95% Confidence Interval	
							Lower Limit	Upper Limit
1998	176.5	7.9	6.0	41.9	12.5	0.586	0.474	0.699
1998	212.5	5.7	5.1	42.3	11.2	0.600	0.480	0.720
1998	231.0	7.7	4.7	46.7	12.8	0.455	0.331	0.578
1999	204.6	6.2	5.3	47.9	9.2	0.670	0.563	0.777
1999	183.7	6.4	5.6	46.4	10.6	0.607	0.530	0.684
1999	210.6	7.4	5.1	48.6	12.4	0.681	0.515	0.846
2000	215.9	6.0	5.0	45.8	11.1	0.913	0.548	1.279
2000	193.6	5.8	5.5	45.1	12.9	0.657	0.465	0.849
2000	159.0	7.7	6.6	42.9	13.3	0.405	0.161	0.650
2001	81.3	19.0	11.3	33.9	11.2	0.247	0.186	0.307
2001	83.9	17.5	11.8	36.2	13.0	0.230	0.165	0.295
2001	101.0	17.5	10.2	36.1	14.4	0.178	0.101	0.255
2002	166.8	6.7	6.4	39.9	10.0	0.764	0.527	1.001
2002	165.3	7.7	6.3	39.1	10.9	0.676	0.549	0.803
2002	214.5	6.9	5.1	48.4	12.3	0.625	0.441	0.810
2004	152.8	8.9	6.8	38.4	11.6	0.506	0.212	0.801
2004	158.3	9.1	6.5	36.8	13.0	0.492	0.239	0.744
2005	138.4	8.1	7.5	39.9	10.3	0.622	0.430	0.813
2005	163.0	8.5	6.3	37.0	11.6	0.674	0.494	0.855
2006	210.5	7.2	5.0	34.0	9.3	0.730	0.466	0.995
2006	203.8	6.9	5.1	26.9	11.8	0.665	0.513	0.817
2006	250.4	5.4	4.3	37.8	12.8	0.547	0.449	0.646
2007	192.1	5.4	5.6	27.2	6.8	0.661	0.340	0.983
2007	198.2	5.8	5.4	23.1	8.4	0.827	0.513	1.141
2007	191.4	7.6	5.7	23.6	9.8	0.535	0.235	0.836
2008	141.1	7.6	7.1	19.4	6.4	0.613	0.235	0.991
2008	197.9	6.0	5.3	26.0	7.9	0.743	0.521	0.964
2008	269.4	4.6	4.1	41.9	8.8	0.801	0.548	1.053

The best fitting model based on AICc included variables for water transit time, release group and water temperature (Table 4). Relative variable weights showed that water transit time (WTT) had the highest weight of 1.0 (it was present in all models that received any weight), indicating it was the most important environmental variable in explaining reach survival. Release group had the second highest weight of 0.85 followed by average temperature with a weight of 0.67. With a weight of 0.15, average spill proportion was last. A weighted regression of WTT and log survival demonstrates the relatively strong relation between WTT and survival indicated by the relative weight. The regression of WTT to log survival had an R-squared 0.83 with $p = 0.0000$. Steelhead reach survival appears to increase with decreasing water transit time (i.e., increasing flows) (Figure 3). The relation depicted in Figure 3 of WTT versus survival is the relation from a predictive model based on weighted average coefficients. The predictive model shown in Figure 3 shows the relation between WTT and survival in the presence of all other predictive variables in a multivariate framework.

Table 4. Rank of Models based on AICc for **steelhead** in the **RIS to McN** reach.

Model	Variables	AICc	delta AICc	Weight
WTT+REL_GRP+AV_TEMPC	**3**	**132.9**	**0.0**	**0.438**
WTT+REL_GRP	**2**	**133.9**	**1.0**	**0.267**
AV_TEMPC+WTT	**2**	**135.1**	**2.2**	**0.144**
WTT+AV_TEMPC+REL_GRP+AVG_SPIL_PROP	**4**	**136.1**	**3.3**	**0.086**
REL_GRP+WTT+AVG_SPIL_PROP	**3**	**136.7**	**3.8**	**0.064**
WTT	**1**	**151.2**	**18.3**	**0.000**
WTT+AVG_SPIL_PROP	**2**	**153.8**	**21.0**	**0.000**
AVG_SPIL_PROP+REL_GRP+AV_TEMPC	**3**	**180.6**	**47.7**	**0.000**
AV_TEMPC+AVG_SPIL_PROP	**2**	**182.8**	**49.9**	**0.000**
AV_TEMPC	**1**	**189.0**	**56.2**	**0.000**
AVG_SPIL_PROP	**1**	**195.4**	**62.6**	**0.000**
REL_GRP+AVG_SPIL_PROP	**2**	**197.7**	**64.9**	**0.000**
REL_GRP	**1**	**201.4**	**68.5**	**0.000**

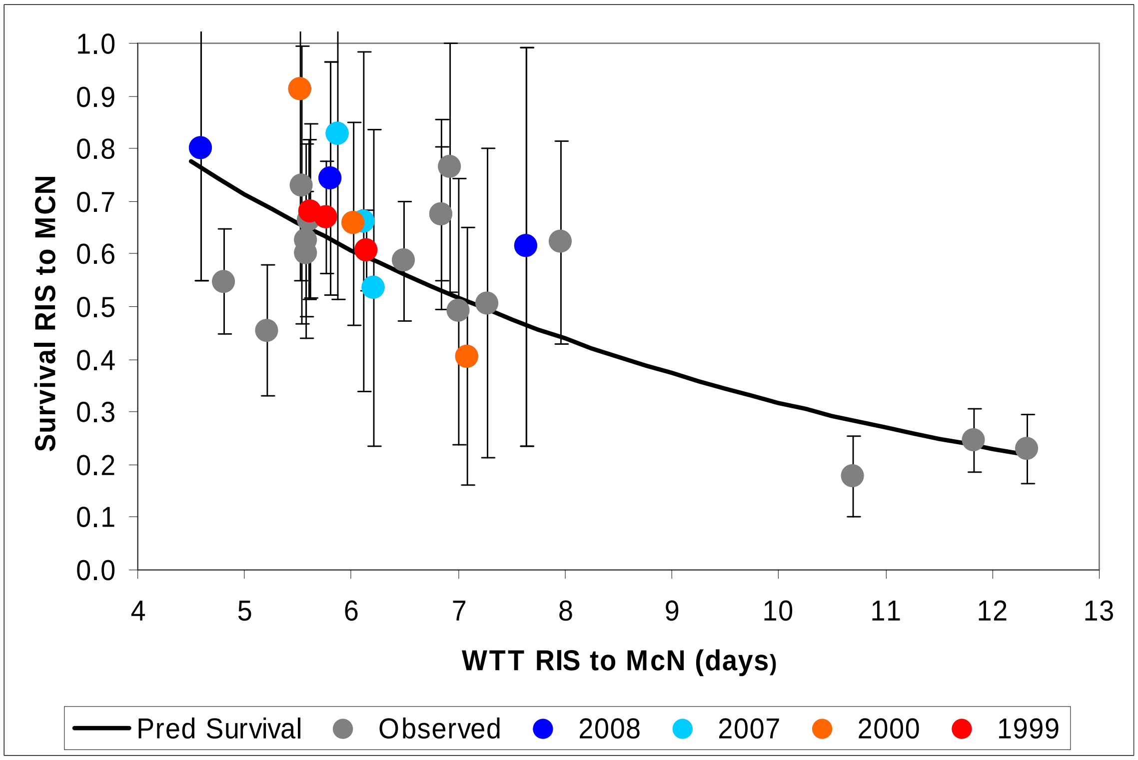

Figure 3. Predicted survival versus water transit time from the weighted average model plotted with reach survivals and 95% confidence intervals for PIT-tagged steelhead released at Rock Island Dam.

Over the years in this analysis, the average spill proportion for the Rock Island to McNary Dam reach has had little variation. Because the average spill variable did not change much over the years analyzed, this environmental variable did not explain much of the observed variability in reach survivals. However, there have been substantial changes in the spill operations on a per project basis (Figure 4). For example, out-migrants prior to 2006 would have experienced 56% to 76% spill at PRD, whereas those out-migrating from 2006 to 2008 experienced only 17% to 23% spill. During this period of reductions in spill at PRD, spill levels at MCN 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 to the gas cap.

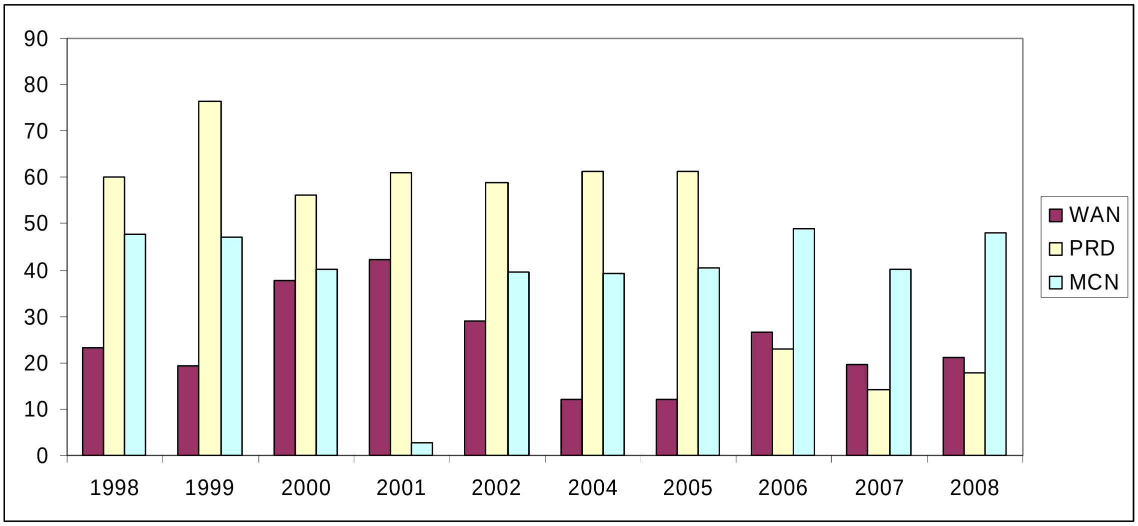

Figure 4. Average percent spill experienced by PIT-tagged steelhead juveniles at Wanapum, Priest Rapids, and McNary dams.

Mid-Columbia Hatchery Releases:

Releases of hatchery steelhead to the Mid-Columbia River (above Priest Rapids Dam, PRD) have remained consistent over the years analyzed (Table 5). Over the years we analyzed, the average release total for steelhead smolts above PRD is 938,099 juveniles. The release total in migration years 2007 and 2008 were slightly below this average total. The proportion of hatchery steelhead released above PRD that are unclipped has varied over the years. In migration years 2007 and 2008, the percent of hatchery steelhead released above PRD that were unclipped was 18.9% and 24.0%, respectively. When compared to what was released in previous years, these releases of unclipped hatchery steelhead in 2007 and 2008 were relatively low (Table 5).

Given these results, it is likely that the increased adult returns of Mid-Columbia steelhead in 2009 is the combination of good in-river conditions in 2007 and 2008 (e.g., decreased water transit times), increased juvenile reach survivals, hatchery output in migration years 2007 and 2008 and presumably good ocean productivity.

Table 5. Hatchery releases (by migration year) of steelhead smolts above Priest Rapids Dam.

Migration Year	Total Smolts Released	Percent Unclipped
1998	972,149	0.0
1999	1,245,090	18.0
2000	925,744	63.8
2001	838,581	60.9
2002	877,386	68.4
2003	882,558	46.2
2004	853,405	50.8
2005	883,134	24.7
2006	1,048,151	32.3
2007	901,549	18.9
2008	891,344	24.0

Snake River Steelhead – Methods:

In order to determine how environmental factors may have influenced the 2009 adult steelhead returns to the Columbia River at Bonneville Dam and presumably the Snake River as well, the FPC staff conducted a similar analysis as that for the Mid-Columbia steelhead. Specifically, FPC staff estimated juvenile reach survivals of PIT-tagged individuals from Lower Granite Dam (LGR) to McNary Dam (MCN). In order to increase sample sizes, individuals that passed LGR undetected but had first-time detections at Little Goose Dam (LGS) were also used in this analysis.

Reach survival was then analyzed in relation to flow, spill and water temperature during passage. Indices were used to characterize the river environment and timing of out-migration of each cohort during each year. Four indices were calculated for each cohort based on timing and fish travel time through the hydro-system. Water transit time (WTT) was calculated by summing the WTT's for each reservoir in the reach Lower Granite tailwater to McNary Dam. Average spill proportion was simply the average of spill proportion at all four dams in the reach as each cohort passed through. Date group was a number from 1 to 6 based on which one-week time period the cohort passed or was released at Lower Granite Dam. Average temperature was the temperature, as measured at the tailwater, of each dam as the cohort passed through the downstream reservoir. The environmental indices; WTT, average spill proportion, and average water temperature were generated based on fish travel time through the reach. Fish travel time between dams was estimated for each group. Conditions at downstream dams were averaged over one week and the travel time to the next dam was used to adjust the start date of the calculations. For example, travel time from Lower Granite to Little Goose Dam, for the earliest steelhead cohort in 1999 (passed LGR from 4/10 to 4/16), was estimated to be 4.5 days based on 627 detections at both Lower Granite and Little Goose dams during that one week period. Average spill proportion, average Lower Granite tailwater temperature, average total discharge, and average forebay elevation at Little Goose Dam over the time period April 15 to April 21 were then calculated and assigned for that reach. At each downstream site similar variables were calculated. Since no PIT-tag detection data were available until 2005 at Ice Harbor Dam, the travel time to Ice Harbor Dam was estimated as 43% of the total travel time from Lower Monumental Dam to McNary Dam. The overall reach environmental variables were the average of these calculated values for spill and water temperature, while for water transit time the values were summed for a reach water transit time.

As with the Mid-Columbia steelhead, weighted regression analyses were used to investigate what effects these environmental conditions may have had on juvenile reach survival (LGR-MCN). An information theoretic approach was used to examine the relative importance of environmental variables in explaining the variability in reach survival data (Burnham and Anderson 2002). Regression equations were fit to reach survival data and the Akaike's Information Criterion for small sample sizes (AICc) were calculated. The AICc scores were used to determine the relative likelihood of each equation being the best fitting equation, given the data set and the group of equations considered. Explanatory models were evaluated based on their resulting AICc scores. Model weights were calculated and the weights were used to make inference regarding the best fitting models, and were also used to generate predictive models based on a model averaging approach. Weights were also used to calculate the weight of evidence (or relative variable importance) for each of the variables that were present in the set of models considered.

In addition to reach survival analysis, the proportion transported was also computed for the years 1999 to 2008. The site-specific transport proportions P(J) are based on data from the run-at-large at each dam. These P1, P2, P3, and P4 proportions are computed using facility collection, and transport, for Lower Granite (J=1), Little Goose (J=2), Lower Monumental (J=3), and McNary (J=4) dams. Collection efficiency was estimated using the CSJ mark-recapture model on PIT tagged steelhead released from the Salmon, Snake, Grande Ronde and Imnaha River traps. In both 2007 and 2008 collection for transportation began May 1 at Lower Granite Dam, and was delayed at Little Goose until May 10, while at Lower Monumental Dam collection for transport began May 13. Because transportation was delayed in the Snake River, estimates of the fish timing at Lower Granite Dam were important for determining the overall probability of being transported. However for hatchery and wild steelhead there are likely differences in timing, but PIT-tags alone are not a good measure of overall wild population timing, and markings are not useful for separating hatchery from wild with certainty. Therefore, for transport estimations, a single seasonal timing was developed for combined rearing types. It was assumed for estimating overall seasonal transport probability that fish arriving at Lower Granite Dam prior to May 1 would not be transported, while those arriving on that date or later would be transported if collected at any of the transport dams.

Finally, FPC staff reviewed hatchery release data from 1998 to 2008. For this analysis, we tallied hatchery releases of steelhead in the Snake River region (above Lower Granite Dam, LGR) based on their expected year of out-migration.

Snake River Steelhead – Results

Juvenile Migration:

Figure 5 below provides an illustration of the overall average environmental variables experienced by steelhead juveniles in each of the years analyzed. Estimates of juvenile reach survivals and environmental variables for each of the cohorts in this analysis are listed in Table 6. Steelhead reach survivals from Lower Granite Dam to McNary Dam were high relative to other recent years (Table 6, Figure 6). In 2007 and 2008 reach survivals ranged between 0.52 and

0.76, with the average 0.68. These survivals were relatively high compared to the average for the reach estimates from the previous years in the analysis which was 0.55 (See Figure 6 for a plot of reach survivals from all years of multiyear analysis). All but one of the 12 estimates in 2007 and 2008 were higher than the 0.55 average of previous years (Table 6). The river conditions were relatively good in 2008, with water transit times relatively low at 9.0 days on average for the survival cohorts and spill proportions averaging 42% of total discharge through the reach, as high as any year analyzed. High flows and relatively high spill proportions in the reach were likely important in explaining the relatively high reach survivals (Figures 7 and 8). In 2007 WTT and average temperature were both higher than average, which might have negatively affected survival given these variables inverse relation with survival. However, spill proportion was higher than average and the overall result was higher than average survivals for the year (Figure 7).

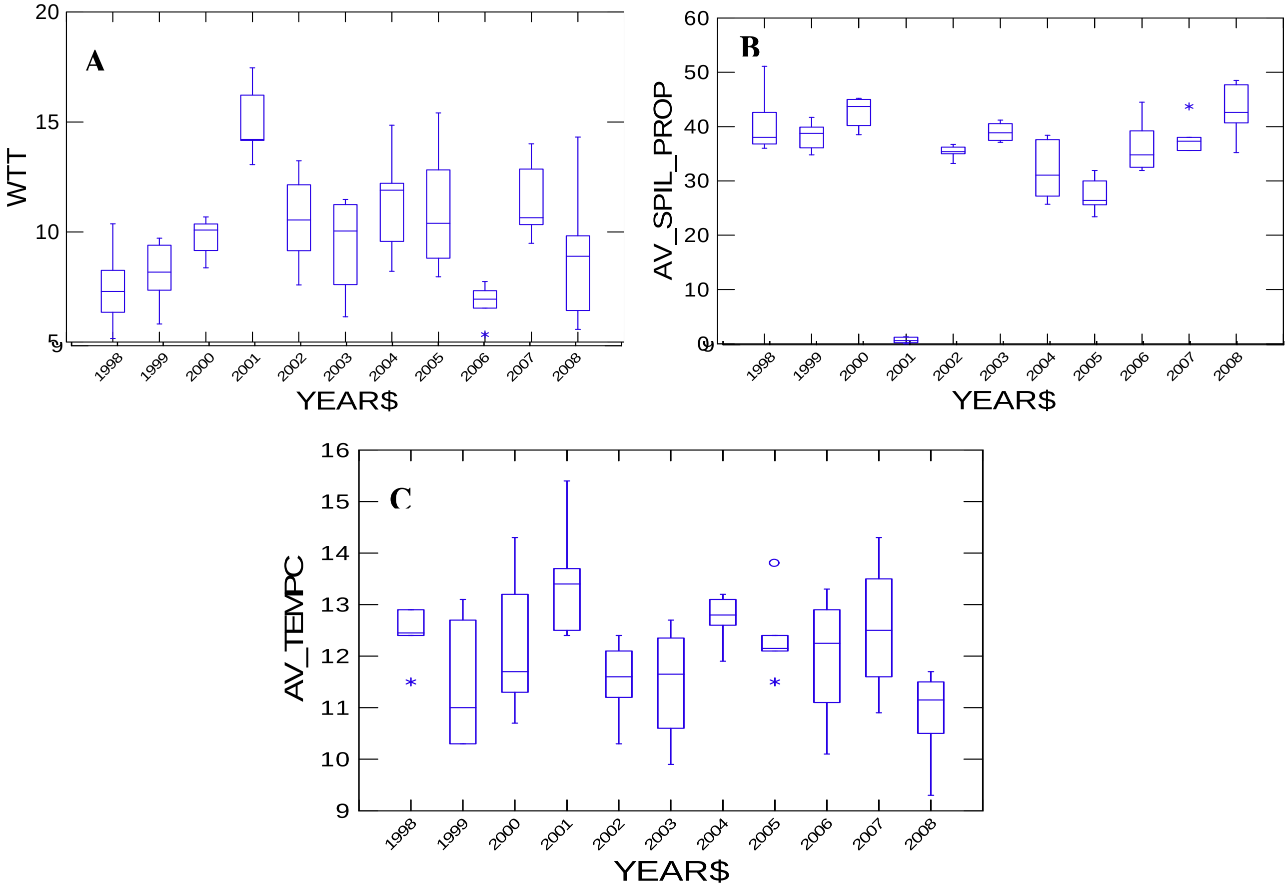

Figure 5. WTT (A), Average Spill Proportion (B), Average Temperature (C) (degrees C) variables summarized by year for the reach **LGR to McN** for **steelhead survival groups**. The upper and lower edges of the boxes show central 50% of observations (the inter-quartile range (IRQ), while the whiskers show extent of data points within 1.5*IRQ. Values outside 1.5*IRQ are shown as symbols.

Table 6. Juvenile survival (LGR-MCN) and in-river conditions experienced by PIT-tagged steelhead juveniles.

Migration Year	Average Flow (Kcfs)	Fish Travel Time (days)	Water Transit Time (days)	Average Spill Percent	Average Temp (C)	Juvenile Survival (RIS-MCN)	95% Confidence Interval	
							Lower Limit	Upper Limit
1998	123.5	10.8	10.4	38.3	11.5	0.622	0.335	0.909
1998	161.2	9.1	8.3	37.7	12.4	0.722	0.543	0.900
1998	174.8	8.7	7.2	36.8	12.9	0.703	0.575	0.831
1998	169.5	8.2	7.4	36.0	12.4	0.617	0.436	0.799
1998	196.1	7.3	6.4	42.6	12.9	0.723	0.401	1.046
1998	238.7	5.2	5.2	51.1	12.5	0.657	0.509	0.805
1999	160.5	11.3	7.9	34.8	10.3	0.746	0.618	0.875
1999	148.5	9.2	8.5	36.1	10.3	0.721	0.606	0.836
1999	133.4	9.3	9.4	39.1	10.5	0.705	0.580	0.830
1999	133.1	11.3	9.7	39.9	11.5	0.632	0.484	0.780
1999	177.0	8.6	7.4	38.4	12.7	0.744	0.574	0.915
1999	211.2	5.3	5.8	41.7	13.1	0.837	0.663	1.011
2000	153.1	7.3	8.4	43.7	10.7	0.715	0.591	0.839
2000	140.8	8.7	9.2	38.5	11.3	0.595	0.432	0.758
2000	124.1	9.0	10.4	45.0	11.7	0.549	0.418	0.680
2000	124.2	12.4	10.7	45.2	13.2	0.559	0.308	0.810
2000	123.6	12.0	10.1	40.2	14.3	0.534	0.260	0.809
2001	75.9	20.7	16.2	0.0	12.4	0.159	0.134	0.183
2001	88.9	17.7	14.2	0.6	12.5	0.177	0.153	0.200
2001	93.4	13.9	13.1	1.2	13.4	0.187	0.127	0.246
2001	85.8	15.3	14.2	1.3	13.7	0.143	0.086	0.200
2001	71.0	23.6	17.5	0.2	15.4	0.079	0.025	0.134
2002	107.8	11.1	12.1	36.2	10.3	0.461	0.380	0.542
2002	100.6	13.2	13.2	36.7	11.2	0.466	0.295	0.637
2002	129.7	12.1	10.5	35.4	11.6	0.390	0.212	0.568
2002	139.7	8.1	9.2	33.2	12.1	0.516	0.390	0.642
2002	173.6	8.6	7.6	35.0	12.4	0.724	0.421	1.028
2003	110.7	9.6	11.5	41.2	9.9	0.740	0.545	0.936
2003	117.6	10.1	11.0	39.9	11.3	0.591	0.425	0.758
2003	143.9	8.1	9.1	37.1	12.0	0.619	0.470	0.768
2003	202.4	5.7	6.1	37.8	12.7	0.633	0.540	0.727
2004	95.1	16.1	14.9	38.4	11.9	0.616	0.353	0.878
2004	109.2	11.9	12.2	37.6	12.6	0.427	0.322	0.533
2004	106.7	9.3	12.1	34.4	12.9	0.439	0.353	0.524
2004	112.4	12.0	11.7	27.7	12.7	0.353	0.234	0.472
2004	135.8	10.7	9.6	25.7	13.1	0.307	0.203	0.411
2004	151.4	7.9	8.2	27.2	13.2	0.357	0.220	0.494
2005	92.6	17.1	15.4	26.0	11.5	0.469	0.382	0.556
2005	110.5	12.6	12.8	23.4	12.1	0.604	0.535	0.673
2005	125.7	8.9	10.3	26.8	12.1	0.618	0.562	0.674
2005	145.2	8.6	8.8	30.0	12.2	0.664	0.619	0.709
2005	155.0	6.6	8.0	31.9	12.4	0.541	0.471	0.611
2005	118.4	7.7	10.5	25.6	13.8	0.267	0.193	0.342
2006	175.8	7.9	7.1	31.9	10.1	0.776	0.704	0.848
2006	184.7	7.0	6.8	33.1	11.1	0.766	0.702	0.830
2006	159.6	6.6	7.7	32.5	11.7	0.670	0.607	0.732
2006	175.6	6.8	7.3	36.5	12.9	0.606	0.533	0.680
2006	228.4	4.7	5.3	44.5	13.3	0.668	0.597	0.739
2006	191.6	4.6	6.5	39.2	12.8	0.511	0.439	0.583
2007	116.1	12.7	12.9	38.0	10.9	0.689	0.572	0.805
2007	127.4	10.3	10.5	37.6	11.6	0.733	0.574	0.893
2007	130.5	7.6	10.3	35.6	12.2	0.765	0.647	0.883
2007	135.2	7.7	9.5	35.6	12.8	0.602	0.486	0.718
2007	122.3	7.2	10.8	37.0	13.5	0.587	0.486	0.687
2007	101.7	10.0	14.0	43.7	14.3	0.526	0.301	0.751
2008	91.4	10.1	14.3	47.7	9.3	0.758	0.631	0.886
2008	139.6	29.6	9.8	41.6	10.5	0.741	0.568	0.915
2008	132.1	7.4	9.7	35.2	11.0	0.712	0.613	0.811
2008	164.9	6.9	8.1	40.7	11.5	0.681	0.552	0.811
2008	221.3	4.1	5.6	48.5	11.7	0.709	0.565	0.852
2008	200.4	4.8	6.4	43.6	11.3	0.689	0.600	0.778

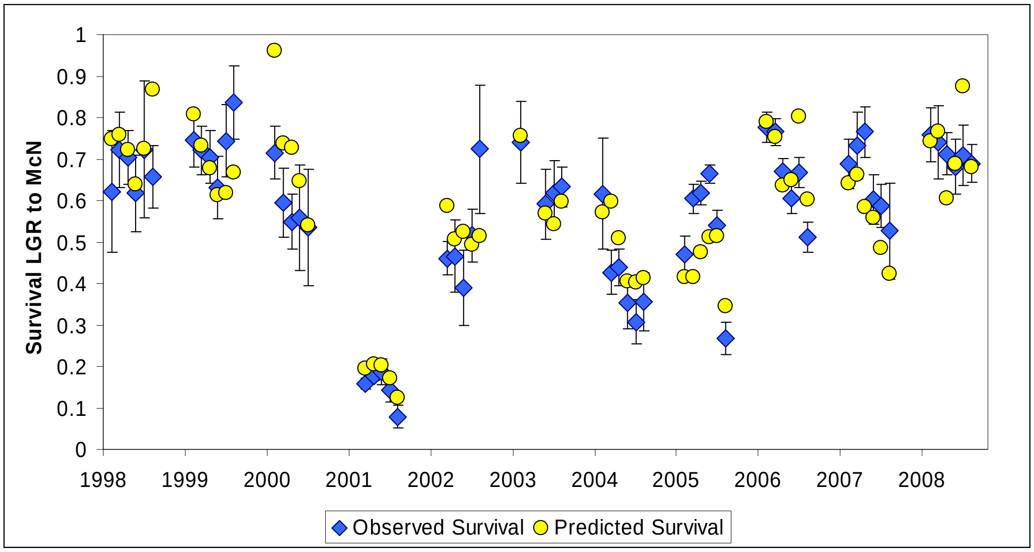

Figure 6. Observed **Steelhead** survival estimates and standard errors, in the reach **LGR to McN** 1998 to 2008 compared to predicted survivals for same reach using weighted average coefficients from multi-model regression analysis (Correlation coefficient 0.84 based on bootstrap).

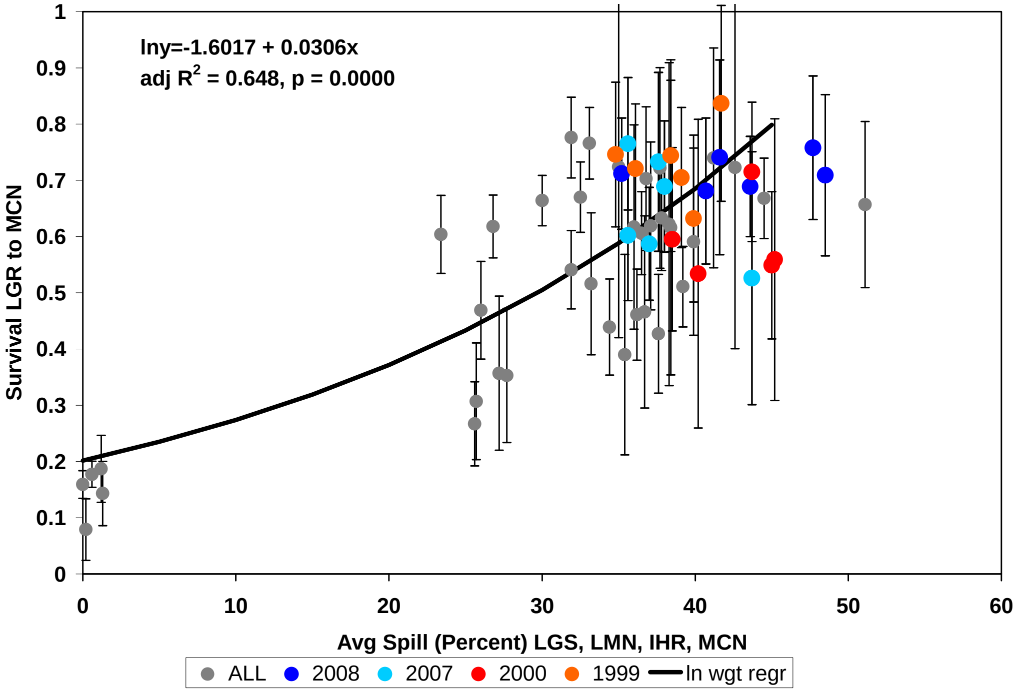

Figure 7. Weighted regression of average percent spill and juvenile reach survival (LGR-MCN) of PIT-tagged Snake River steelhead.

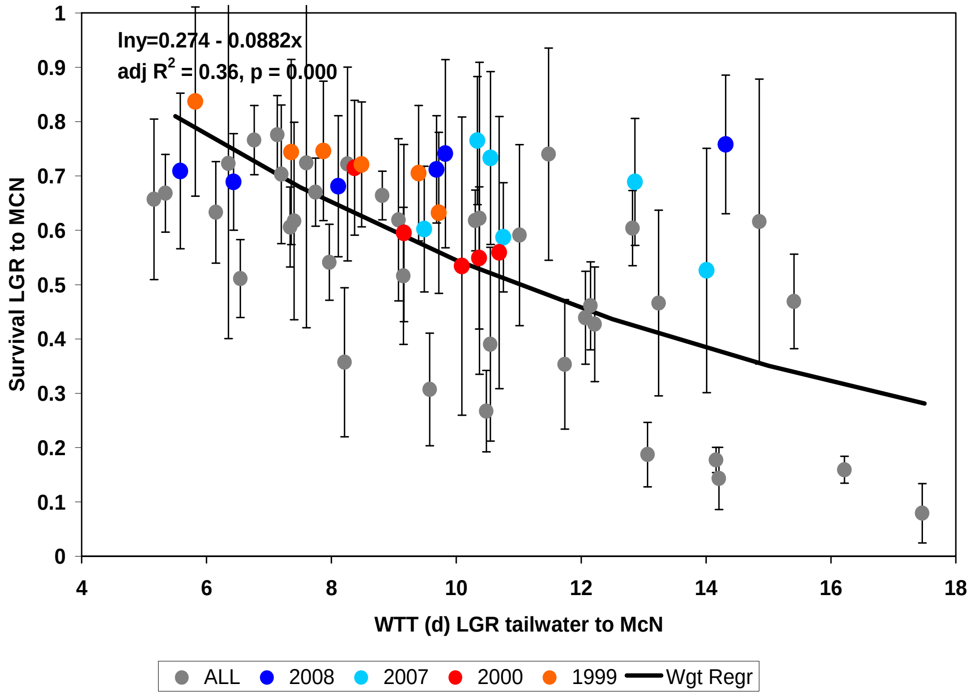

Figure 8. Weighted regression of water transit time (WTT) and juvenile reach survival (LGR-MCN) of PIT-tagged Snake River steelhead.

Based on the multi-year analysis, water transit time and spill proportion were equally important variables in explaining the variability in reach survivals (Table 7). With relative variable weights of 1.00 for WTT and Av_Spil_Prop these variables were present in all models that had any weight in the multi-model analysis. The ranking of models based on AICc scores shows that one model was most likely with a weight of 0.73 and that model included water transit time (WTT), Average Spill proportion (Av_Spil_Prop) and release group (Rel_Grp) variables.

Table 7. Rank of Models based on AICc for **Steelhead** in the LGR to McN reach.

Model	Variables	AICc	delta AICc	Weight
AV_SPIL_PROP,WTT,REL_GRP	3	74.8	0.0	0.730
WTT,REL_GRP,AV_TEMPC,AV_SPIL_PROP	4	76.8	2.0	0.268
AV_SPIL_PROP,WTT,AV_TEMPC	3	86.2	11.4	0.002
AV_TEMPC,AV_SPIL_PROP	2	97.6	22.7	0.000
AV_SPIL_PROP,REL_GRP	2	98.1	23.2	0.000
REL_GRP,AV_TEMPC,AV_SPIL_PROP	3	98.4	23.6	0.000
AV_SPIL_PROP,WTT	2	102.2	27.3	0.000
AV_SPIL_PROP	1	106.5	31.7	0.000
WTT,REL_GRP,AV_TEMPC	3	121.2	46.4	0.000
WTT,AV_TEMPC	2	121.4	46.6	0.000
WTT,REL_GRP	2	124.6	49.8	0.000
WTT	1	143.1	68.3	0.000
REL_GRP,AV_TEMPC	2	156.0	81.2	0.000
AV_TEMPC	1	157.8	82.9	0.000
REL_GRP	1	170.0	95.2	0.000

Hatchery Releases:

Releases of Snake River hatchery steelhead (above Lower Granite Dam, LGR) have also remained consistent over the years analyzed (Table 8). Over the years we analyzed, the average release total for steelhead smolts above LGR was 9,212,092 juveniles. The release totals for migration years 2007 and 2008 were slightly below this average total. Over the years we analyzed, the prevalence of unclipped hatchery steelhead released above LGR has increased. In migration years 2007 and 2008, approximately 15.1% and 16.0% of hatchery steelhead released above LGR were unclipped, respectively. Although these are the highest estimates of percent unclipped hatchery steelhead among the years we analyzed, they are relatively similar to past years.

Table 8. Hatchery releases (by migration year) of steelhead smolts above Lower Granite Dam.

Migration Year	**Total Smolts Released**	**Percent Unclipped**
1998	8,956,107	0.1
1999	9,574,462	0.1
2000	9,568,488	8.7
2001	9,561,078	10.3
2002	9,253,032	13.2
2003	9,468,756	12.8
2004	9,038,700	13.6
2005	8,661,491	14.6
2006	9,029,463	13.9
2007	9,194,782	15.1
2008	9,026,656	16.0

Smolt Transportation:

The overall seasonal estimate of smolts arriving Lower Granite Dam forebay that were destined for transportation in the years 2000 to 2008 are shown in Table 9. The seasonal estimates were similar for hatchery and wild steelhead, which have been calculated separately over the past three years. For both hatchery and wild steelhead, less than 50% were destined for transport in the years 2007 and 2008. This was a significant reduction in transport proportion compared to other years. This reduction in transportation was likely due to continuous spring spill due to Court Order and to the delayed start to transportation.

Table 9. Estimated proportion of Snake River the steelhead population at Lower Granite Dam “destined” for transport.

Migration Year	**Proportion Transported**[a]	
	Hatchery/ Combined	**Wild**
1999	0.83(C)	
2000	0.81(C)	
2001	0.97(C)	
2002	0.68(C)	
2003	0.67(C)	
2004	0.96(C)	
2005	0.94(C)	
2006	0.76 (H)	0. 79(W)
2007	0.47 (H)	0. 44(W)

2008	0.41 (H)	0. 45(W)

[a] Rearing types were estimated separately beginning in 2006.
Rearing type codes are (H) for hatchery, (W) for wild,
and (C) for combined hatchery and wild.

Therefore, it is likely that the increased adult returns of Snake River steelhead in 2009 the result of a combination of good in-river conditions (e.g., low water transit time in 2008 and high spill percent in 2007 and 2008), increased juvenile reach survivals in 2007 and 2008, and lower transportation proportions in 2007 and 2008 (see following analysis). The last year when steelhead adult returns were higher at BON was in 2001 and those adults would have out-migrated in 1999 and 2000. Of all the years analyzed, 1999 and 2000 had some of the shortest water transit times, highest average percent spill, and highest reach survivals similar to 2007 and 2008. In fact, in the four years that contributed to the high return years of 2001 and now 2009, juvenile steelhead out-migrants in the Snake River experienced above average spill proportions (relative to the average spill proportion for all years in the analysis), suggesting that spill impacts, not just reach survival, but also adult returns, as seen in these years.

Summary of Steelhead Survival in the McNary to Bonneville Dam Reach:
Estimating survival for steelhead through the McNary to Bonneville Dam reach is difficult because of low detection probabilities and low numbers of mark groups. This results in large confidence intervals for steelhead survival estimates through this reach. Conditions in 2007 for the two survival cohorts were near the average that the cohorts from previous years experienced in their out-migrations (Table 10). Flows in 2007 averaged at 253 kcfs for the two cohorts, while spill averaged about 34%. The average flows for the survival cohorts in 1999 to 2006 were 246 kcfs and spill proportion averaged 33.6%. Survival for steelhead in the McNary to Bonneville Dam reach for 2007 was near average and similar to previous years (1999-2006). The average cohort survival in 2007 was 0.504 while the average cohort survival for prior years (1999-2006) was 0.531 (Table 10). Removal of screens at the Bonneville second powerhouse precluded the estimation of survival in this reach in 2008.

Project operations in the Columbia River precluded estimation of juvenile survival in 2008.

Table 10. Juvenile steelhead survival (MCN-BON) and in-river conditions experienced by PIT-tagged fish detected at McNary Dam from 1999 to 2007.

Migr. Year	Release Date Range	Avg Flow (Kcfs)	Water Transit Time (days)	Average Spill Percent	Average Temp (C)	Juvenile Survival (MCN-BON)	95% Confidence Interval	
							Lower Limit	Upper Limit
1999	4/27-5/17	280.2	5.9	36.4	11.2	0.727	0.583	0.872
1999	5/18-6/07	343.1	4.9	37.8	14.0	0.561	0.389	0.734
2000	4/27-5/17	269.5	6.2	34.2	12.3	0.656	0.473	0.839
2000	5/18-6/07	227.1	7.3	37.8	15.1	0.329	0.116	0.543
2001	4/27-5/17	133.6	12.8	11.9	13.9	0.255	0.138	0.372
2001	5/18-6/07	140.0	12.0	24.6	16.3	0.232	0.146	0.318
2002	4/27-5/17	222.9	7.5	38.8	11.4	0.809	0.411	1.207
2002	5/18-6/07	307.4	5.4	39.7	14.1	0.474	0.251	0.697
2003	4/27-5/17	226.9	7.4	37.9	11.9	0.528	0.271	0.786
2003	5/18-6/07	288.3	5.8	33.2	14.5	0.733	0.598	0.867

2004	5/18-6/07	253.7	6.7	34.3	14.8	0.397	0.031	0.762
2005	4/27-5/17	231.2	7.3	31.0	13.3	0.476	-0.217	1.170
2005	5/18-6/07	217.6	7.6	36.0	15.0	0.445	-0.198	1.088
2006	4/27-5/17	315.3	5.3	36.6	12.4	0.816	0.458	1.175
2007	4/27-5/17	266.3	6.3	33.6	12.4	0.571	0.422	0.720
2007	5/18-6/07	240.0	6.9	34.9	15.2	0.439	0.252	0.626

Fish Travel Time Analyses

Rock Island to McNary Dam Reach

For all cohorts described in the survival analyses above, FPC staff calculated median fish travel time (FTT) and performed regression analyses to determine the relationship between FTT and WTT. Median travel time from Rock Island to McNary Dam for steelhead ranged between 4.6 and 7.6 days in 2007 and 2008, respectively. In 2008 the last group had the shortest travel time for any of the groups measured from 1998 to 2008. The average travel time for all groups in 2008, combing the three reach median travel times was 6.1 days, while for 2007 it was 6.25 (Figure 9). The average fish travel time for the years 1998 to 2006 was 8.6 days (Figure 9). The years 2007 and 2008 had the shortest combined average water travel times of all years analyzed (1998 to 2008).

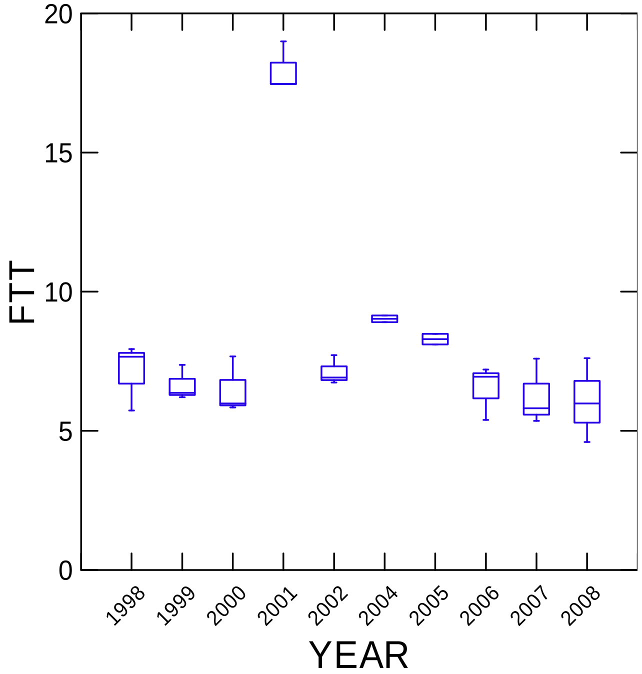

Figure 9. Fish Travel Time Rock Island Dam to McNary Dam for steelhead survival groups. The upper and lower edges of the boxes show central 50% of observations (the inter-quartile range (IRQ), while the whiskers show extent of data points within 1.5*IRQ. Values outside 1.5*IRQ are shown as symbols.

Regression analyses revealed that fish travel time (FTT) for steelhead cohorts in the Rock Island to McNary Dam reach is significantly related to water transit time (WTT), with the regression relation showing an adjusted R-squared of 0.96 and a p value of < 0.0001 (Figure 10).

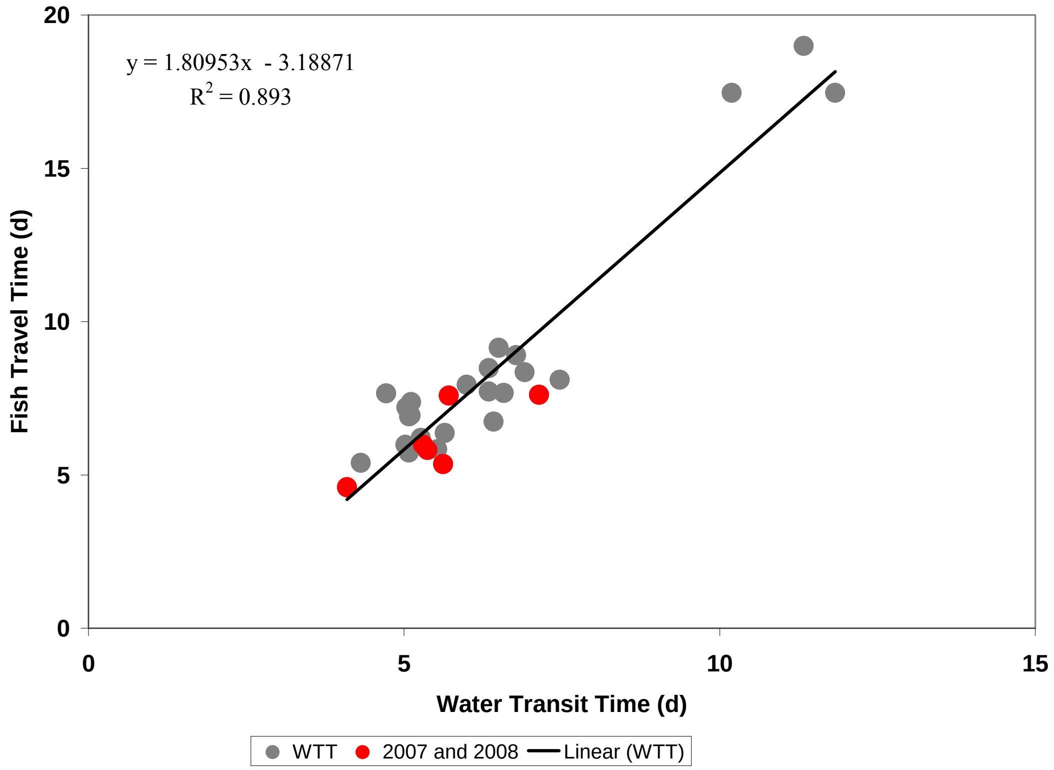

Figure 10. Median **Steelhead** Travel Time estimates in the reach **RIS to McN** 1998 to 2008 and regression equation. Data points for the years 2007 and 2008 are red for comparison to other years.

Lower Granite Dam to McNary Dam Reach

FPC staff also calculated median fish travel time (FTT) for all of the cohorts described for the Lower Granite to McNary Dam reach and performed regression analyses to determine the relationship between FTT and WTT. Median travel time from Lower Granite Dam to McNary Dam for steelhead ranged between 7.2 and 12.7 days (average 9.25) in 2007 while in 2008 FTT was more rapid ranging from 4.1 to 10.1 days with the average 7.1. These two years had relatively different flows, which likely resulted in the different fish travel times. Water transit times in 2008 averaged 9.0 days compared to the average for the years 1998 to 2006 of 9.85. The flows and spill in 2008 were relatively high, likely resulting in shorter water transit times (7.1 days in 2008 compared to an average of 10.2 days from 1998-2006) and shorter fish travel times. In 2007 flows were relatively low but spill was provided. Those fish travel times were relatively short given the low flows.

Multivariate analyses showed that fish travel time in the Lower Granite Dam to McNary Dam reach is a function of both water transit time and spill proportion (Table 11). The top ranking model included only two variables; WTT and Av_Spil_Prop. The top four models received nearly all the weight and those models all included WTT and Av_Spil_Prop. A regression model fitted to the FTT as a function of WTT revealed that the estimates of FTT seen in 2007 and 2008 were all lower than what was predicted (Figure 11). It is likely that this is a result of relatively high spill proportions seen in these years, resulting in decreased fish delay in the forebays at each of the projects and thereby improved fish travel time through the reach. It may also be that the inclusion of surface spill routes at an increasing number of projects is also helping to decrease delay and is synergistically related to spill proportion in that increased spill provides attraction flow resulting in more fish passing via the spillway and therefore more steelhead pass via the RSW's or TSW's at the dams in this reach.

Table 11. Rank of Models based on AICc for **Steelhead** Travel Time in the LGR to McN reach.

Model	**Variables**	**AICc**	**delta AICc**	**Weight**
CONSTANT+WTT+AV_SPIL_PROP	2	**237.8**	0.0	**0.359**
CONSTANT+REL_GRP+WTT+AV_SPIL_PROP	3	**238.3**	0.4	**0.290**
CONSTANT+REL_GRP+WTT+AV_SPIL_PROP+AV_TEMPC	4	**238.6**	0.8	**0.240**
CONSTANT+AV_TEMPC+WTT+AV_SPIL_PROP	3	**240.2**	2.4	**0.110**
CONSTANT+AV_TEMPC+WTT+REL_GRP	3	**252.3**	14.4	**0.000**
CONSTANT+WTT	1	**253.1**	15.3	**0.000**
CONSTANT+AV_TEMPC+WTT	2	**253.5**	15.6	**0.000**
CONSTANT+REL_GRP+WTT	2	**255.4**	17.5	**0.000**
CONSTANT+REL_GRP+AV_SPIL_PROP+AV_TEMPC	3	**286.3**	48.4	**0.000**
CONSTANT+REL_GRP+AV_SPIL_PROP	2	**290.5**	52.7	**0.000**
CONSTANT+AV_SPIL_PROP	1	**300.8**	63.0	**0.000**
CONSTANT+AV_TEMPC+AV_SPIL_PROP	2	**302.2**	64.3	**0.000**
CONSTANT+AV_TEMPC+REL_GRP	2	**315.9**	78.1	**0.000**
CONSTANT+REL_GRP	1	**334.9**	97.0	**0.000**
CONSTANT+AV_TEMPC	1	**338.7**	100.8	**0.000**

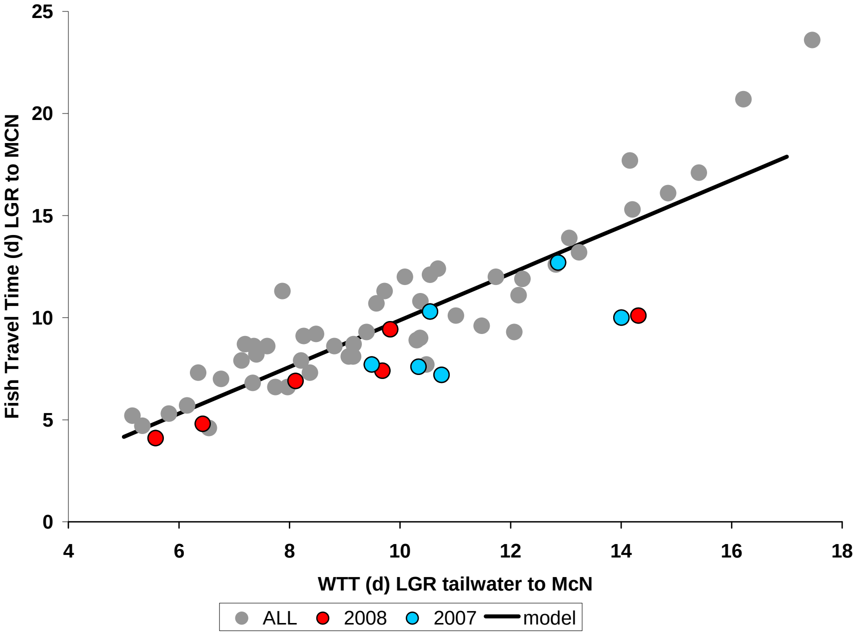

Figure 11. Steelhead Travel Time in the Reach LGR to McN plotted against WTT in that same reach. Predicted model was FTT = -1.5565+1.144WTT (R = 0.757, p=0.0000).

Transportation Proportion and Improved In-river Survival of Steelhead:

Over the past ten years the sites of bird colonies in McNary reservoir have been sampled for PIT tags after the nesting season. Data have shown that a considerable number of PIT tags were recovered and that percentage of tags recovered on the colonies are higher for steelhead than for Chinook. The number of tags recovered is variable from year to year. But in most years the estimate of juvenile steelhead mortality due to bird predation was about 4 to 5%, but could be as high as 21% observed in 2001 (Faulkner et al. 2007, Faulkner et al. 2008). NOAA concludes that the overall in-river survival for steelhead is low due to the bird predation that occurs in the McNary reservoir.

However, subsequent to the initiation of the Court Ordered spill program the estimated in-river survival of juvenile steelhead was higher in 2006 and 2007. NOAA Fisheries (2007, 2008) hypothesized that the increase in survival for in-river migrants was the result of a smaller overall proportion of smolts taken by avian predators. More fish are left in-river to migrate as a result of spill, but bird predators can only remove a set amount leading to the lower overall proportion mortality and, consequently, higher in-river survival (Muir et al 2008).

From the data collected during the 2006 and 2007 juvenile migration, NOAA concludes that in-river survival increases with increasing spill through the indirect effect of reducing individual vulnerability to predation. NOAA cautions that the direct or indirect effects of increased spill may not improve smolt-to-adult survival for the population (Muir et al. 2008).

Thus far for 2009 the number of returning adult steelhead is very similar to the record high number observed to-date during 2001. Complete analyses will not be conducted until after the 2009 steelhead return is completed. The data can then be used to analyze the NOAA caution regarding the direct and indirect benefits of increased spill.

Analysis of Primary Factors Affecting Steelhead Survival and Adult Return

Pacific salmon and steelhead experience considerable mortality within both the freshwater and marine environments (Bradford 1995, Scheuerell and Williams 2005, Schaller et al. 2007). Across several studies, a suite of environmental factors has been identified as being associated with mortality rates over the anadromous life cycle of Pacific salmon and steelhead. Within the freshwater environment of the Columbia River Basin hydropower system, freshwater mortality rates have been associated with water transit time and the percentage of water spilled at dams, along with seasonal effects indexed by Julian day (Schaller et al. 2007). Within the marine environment, survival rates or survival rate indices have been associated with sea surface temperature (SST), the Pacific Decadal Oscillation (PDO, a large-scale index of ocean temperature), and coastal upwelling (Mueter et al. 2005; Scheuerell and Williams 2005; Schaller and Petrosky 2007). Although marine environmental conditions undoubtedly affect mortality in the marine environment, several lines of evidence suggest that conditions experienced in the freshwater environment are partially manifest after exiting the hydrosystem (Budy et al. 2002, ICTRT and Zabel 2007 *draft*) and therefore may also affect mortality in the marine environment. While the relative importance of the freshwater versus marine conditions is a subject of debate, overall life-cycle survival is governed by the combination of conditions in both the freshwater and marine environments (Bisbal and McConnaha 1998). To assess associations between freshwater and marine environmental factors on the mortality rates of Snake River steelhead, we conducted a series of analyses on life-stage-specific and overall life-cycle mortality rate estimates using information theoretic methods described in Burnham and Anderson (2002).

Methods

In-river survival rate (LGR-BON) and smolt-to-adult survival rate estimates (LGR-LGR *SARs*) were produced for PIT-tagged steelhead that migrated during the years 1998 to 2006 (Appendix 1). We used a cohort-based approach, dividing the spring migration season into four, two-week release cohorts based on the date of detection at Lower Granite Dam. To increase sample sizes, we augmented the fish detected at Lower Granite Dam with fish that were first detected at Little Goose Dam, using the median travel time from Lower Granite to Little Goose to assign tagged fish to the Lower Granite release cohorts. The Little Goose detections were expanded to Lower Granite equivalents based on the estimated LGR-LGS survival rates. Single-release mark-recapture survival estimates were generated using Cormack-Jolly-Seber methodology as described by Burnham et al. (1987) using program Mark. SARs were calculated as the number of adult returns to Lower Granite Dam divided by the estimated number of smolts at Lower Granite Dam for each release cohort.

We define the estimates of LGR-BON survival as survival during the freshwater life stage (*S.r*) and the *SAR* estimates as overall life-cycle survival. Survival during the ocean-adult life-stage (*S.oa,* Appendix 1) is calculated as:

$$S.oa = \frac{SAR}{S.r} ,$$

and is an estimate of the survival from Bonneville Dam as a smolt to adult detection at Lower Granite Dam, encompassing survival in the estuary, ocean and during adult upstream migration through the hydropower system.

We used the method described by Bradford (1995) for calculating the total instantaneous mortality rates (*M.r*, *M.oa*, and *M.sar,* Appendix 1) for the estimates of life-stage-specific (*S.r* and *S.oa*) and overall life-cycle (*SAR*) survival, which is simply the negative natural logarithm of a survival rate:

$$M.r = -\log(S.r),$$

$$M.oa = -\log(S.oa),$$

$$M.sar = -\log(SAR).$$

Using a log-transformation for survival rates (i.e., working with instantaneous mortality rates) has a strong theoretical basis (Hilborn and Walters 1992, p. 264-265), is consistent with empirical observations (Peterman 1981) and provides desirable statistical properties (e.g., errors tend to be normally distributed based on the central limit theorem).

We used a combination of regression and information-theoretic methods to assess the associations between environmental variables and freshwater and overall life-cycle mortality rates. Based on the results of Schaller et al. (2007), we considered water travel time, the average percentage spilled at the dams, and Julian day as potential variables for characterizing variation in freshwater mortality rates. For characterizing variation in overall life-cycle mortality rates, we considered the three freshwater variables along with May PDO, June SST, and October upwelling based on the associations identified in Mueter et al. (2005), Scheuerell and Williams (2005), and Schaller and Petrosky (2007).

The full model for examining freshwater mortality rates was:

$$M.r = \beta_0 + \beta_1 Julian + \beta_2 WTT + \beta_3 Spill + \varepsilon .$$

The full model for examining overall life-cycle mortality rates was:

$$M.sar = \beta_0 + \beta_1 Julian + \beta_2 WTT + \beta_3 Spill + \beta_4 PDO + \beta_5 SST + \beta_6 Upwell + \varepsilon .$$

We applied several of the information-theoretic and multimodel inference methods described in Burnham and Anderson (2002). First, we conducted all-subsets regressions using the variables identified above, resulting in a total of seven models for the freshwater mortality rate regressions and 63 models for the life-cycle mortality rate regressions. Each regression was fit using weighted regression, weighting by the inverse variance of the mortality rate estimates. We calculated the AICc and AICc weights for each model and ranked their fit according to the AICc values. Using the AICc weights, we calculated model-averaged mortality rate predictions. We also calculated the relative variable importance for each of the variables considered and model-averaged coefficients. Detailed descriptions of these methods are provided in Burnham and Anderson (2002).

Budy et al. (2002) provided several lines of evidence suggesting that freshwater migration experiences may affect post-hydrosystem mortality, with indices of increased cumulative stress during the freshwater migration associated with higher post-hydrosystem mortality. Under the Budy et al. (2002) hypothesis, we would expect a positive correlation between freshwater and ocean-adult mortality rates. To further evaluate this hypothesis, we calculated the Pearson's product-moment correlation coefficient (r) between the estimates of M.r and M.oa, and conducted a one-tailed test (H_0: $r = 0$ versus H_A: $r > 0$).

Results

The relative variable importance is a quantitative measure ranging from zero to one of how important each individual variable is for characterizing variation in the dependent variable relative to the other variables analyzed. High values for the relative variable importance (e.g., values near one) indicate that a variable is relatively important for characterizing variation, while values near zero indicate that a variable is relatively unimportant for characterizing variation. For characterizing variation in freshwater mortality rates, all three variables (spill, WTT, and Julian day) were important, each with relative variable importance values of 0.98 or greater (Table 12). For characterizing variation in life-cycle mortality rates, spill, Julian day and October upwelling all had high importance values followed by June SST, May PDO and WTT, respectively.

Table 12. Relative variable importance values for regressions of freshwater mortality (M.r) and life-cycle mortality rate estimates for Snake River steelhead.

Dependent variable	Spill	WTT	Julian	SST	PDO	Upwelling
M.r	1.00	0.98	0.98	NA	NA	NA
M.sar	0.98	0.32	1.00	0.76	0.46	0.88

Model-averaged predictions for freshwater and life-cycle survival (obtained by back-transforming the mortality rate estimates) showed a high degree of association with observed freshwater and life-cycle survival estimates (Figures 12 and 13).

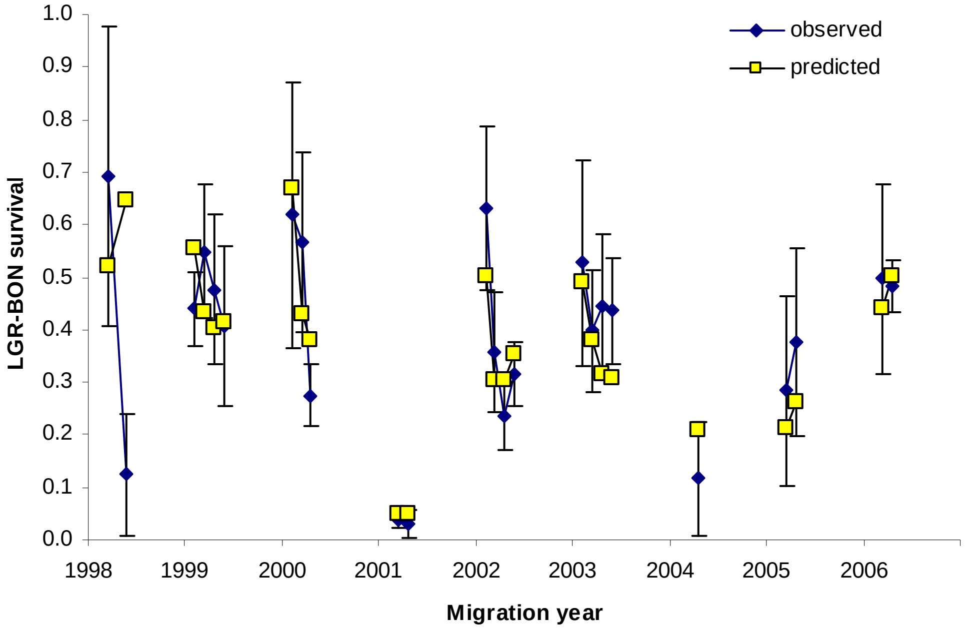

Figure 12. Observed and model-averaged predictions of LGR-BON survival for Snake River steelhead, 1998-2006.

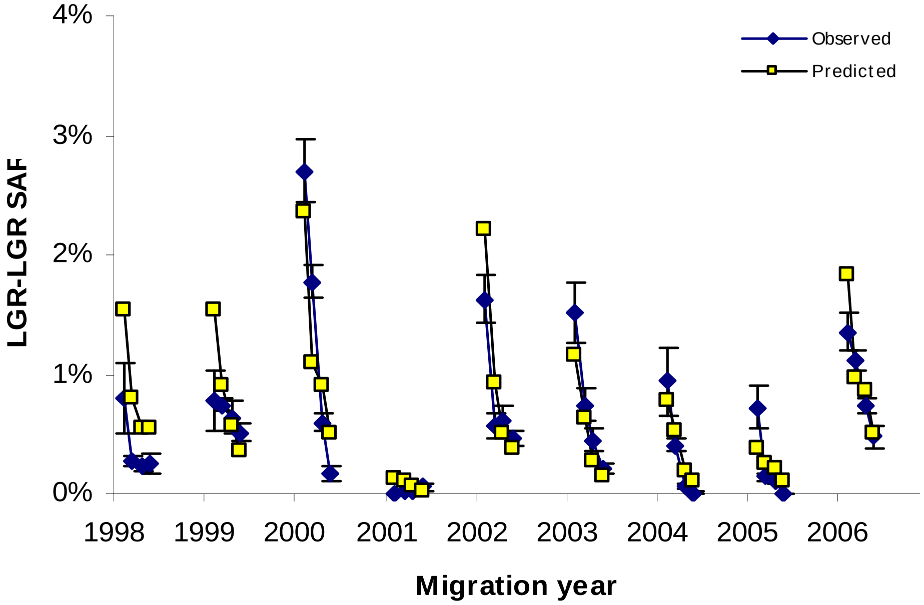

Figure 13. Observed and model-averaged predictions of LGR-LGR SAR for Snake River steelhead, 1998-2006.

Across all observations, the model-averaged predictions accounted for 44% of the variation in freshwater survival rates. However, the freshwater survival estimate for the fourth cohort of 1998 had the lowest value for relative precision (CV = 94%) and the inclusion of this observation dramatically affected measures of the proportion of variation explained. Excluding this observation, the model-averaged predictions accounted for 77% of the variation in freshwater survival rates. Across all observations for life-cycle survival, the model-averaged predictions accounted for 75% of the variation in life-cycle survival rates. It is important to note that only one of the 36 SAR estimates met the 2% minimum SAR objective adopted by the Northwest Power and Conservation Council (NPCC) in the 2009 Fish and Wildlife Program. Similarly, none of the observations during 1998-2006 even remotely approach the objective of a 4% average SAR, also adopted by the NPCC in the 2009 Fish and Wildlife Program.

The model-averaged coefficients provide information on the directionality and magnitude of environmental factors on freshwater and life-cycle mortality rates (Table 13). Freshwater mortality increases with increasing WTT and Julian day, and decreases with the average percent spilled. Mortality is minimized when spill is high and WTT is low early in the migration season. Life-cycle mortality increases with WTT, Julian day, June SST and May PDO, and decreases with the average percent spilled and October upwelling. Life-cycle mortality is minimized when spill is high, WTT is low, SST and PDO are cool and downwelling occurs in October. The directionality of the marine variables is consistent with the observations of Scheuerell and Williams (2005) and Schaller and Petrosky (2007) for spring/summer Chinook salmon.

Table 13. Model-averaged coefficients for freshwater (*M.r*) and life-cycle (*M.sar*) mortality rates.

Dependent variable	Intercept	spill	WTT	Julian	SST	PDO	Upwelling
M.r	-0.1918	-0.0480	0.0685	0.0151			
M.sar	-1.1067	-0.0791	0.0135	0.0402	0.2663	0.1038	-0.0136

The model-averaged coefficients also provide information on the magnitude of change that is expected with changes in environmental conditions (Figures 14-16). At all water travel times, for each 5% increase in average percent spill (e.g., from 20% to 25% or from 35% to 40%), in-river survival is expected to show a 27% relative increase (Figure 14). At all spill levels, for each decrease of 2 days of WTT, in-river survival is expected to show a 15% relative increase (Figure 15). At all ocean conditions, for each 5% increase in average percent spill, LGR-LGR SARs are expected to show a 49% relative increase (Figure 16).

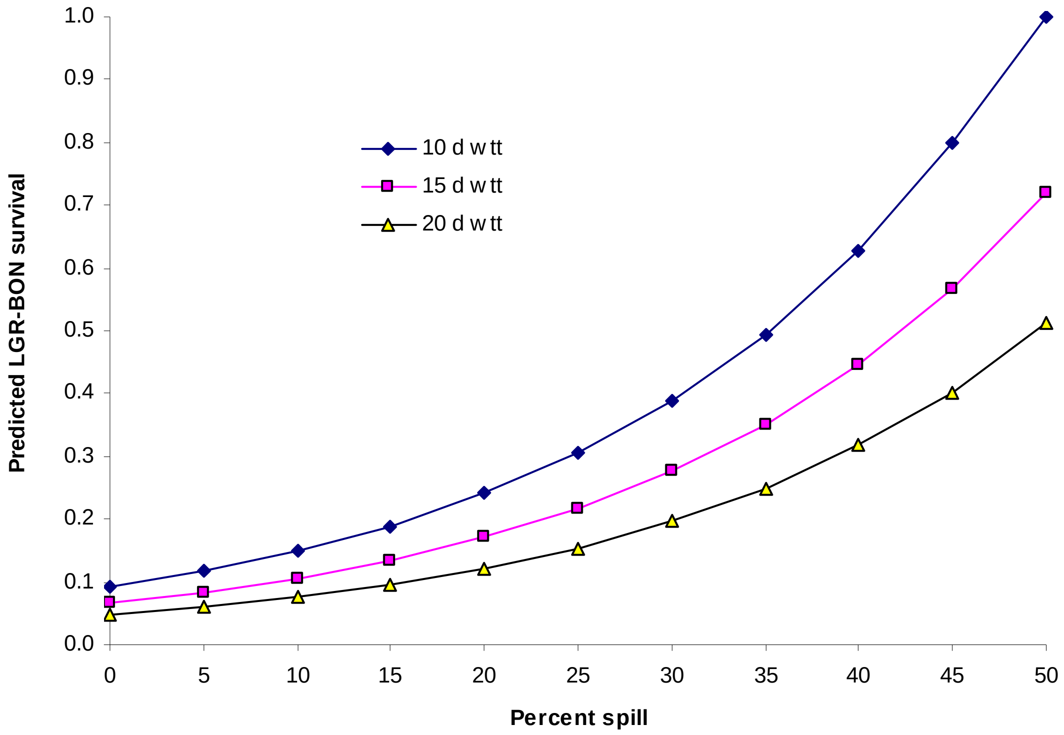

Figure 14. Predicted changes in LGR-BON survival versus the average percent spilled at three levels for WTT.

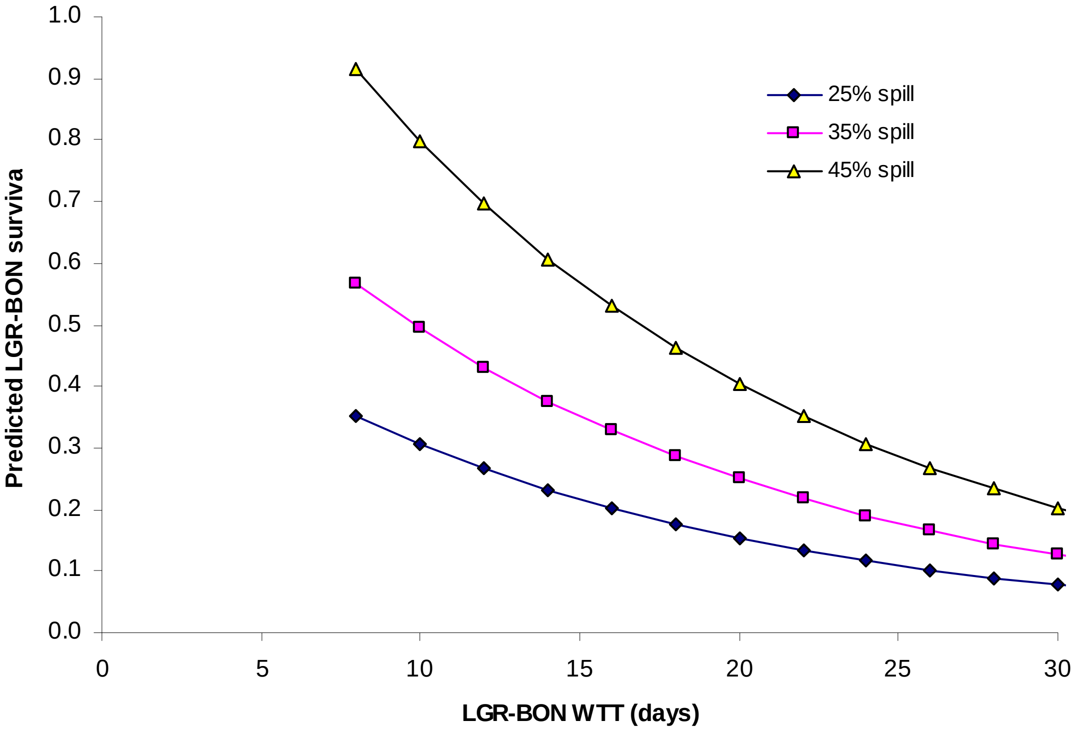

Figure 15. Predicted changes in LGR-BON survival versus water travel time (WTT) at three average spill levels.

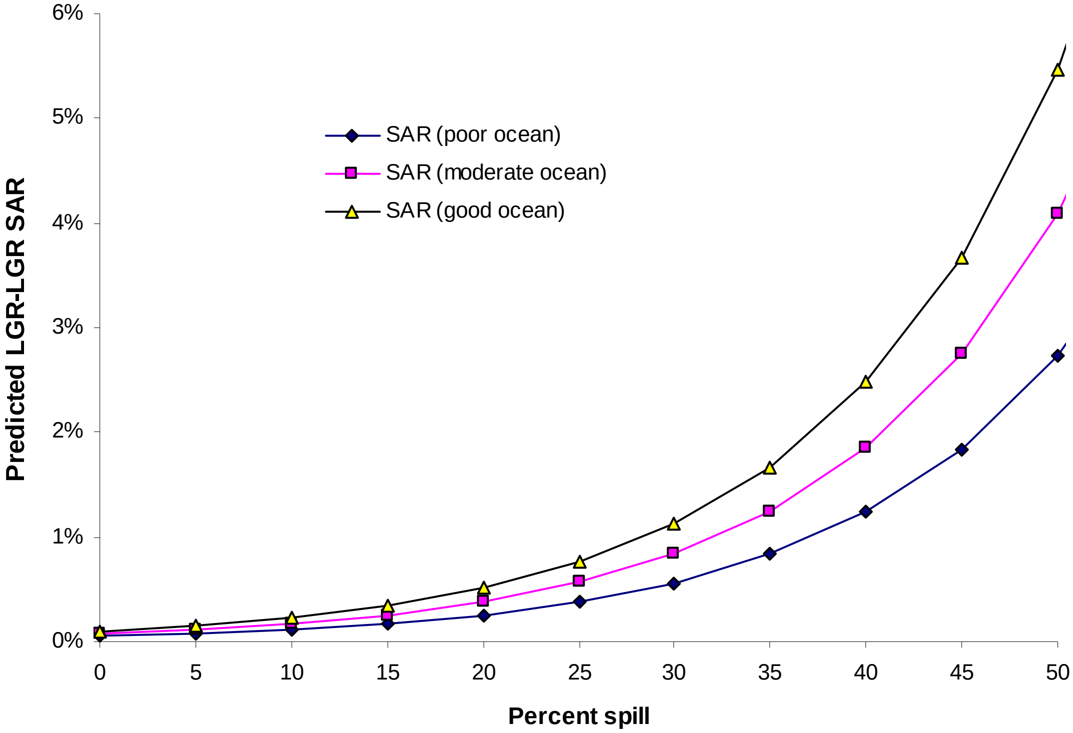

Figure 16. Predicted changes in LGR-LGR SAR versus percent spill during good, moderate and poor ocean conditions.

We evaluated the Budy et al. (2002) hypothesis by calculating the Pearson's product-moment correlation coefficient (*r*) between freshwater (*M.r*) and ocean-adult (*M.oa*) mortality rate estimates. We found evidence for a statistically significant positive correlation between *M.r* and *M.oa* for Snake River steelhead ($\hat{r} = 0.37$, P –value = 0.038). Thus, this analysis supports the hypothesis of Budy et al. (2002); freshwater mortality rates are positively correlated with ocean-adult mortality rates. Therefore factors that tend to increase freshwater survival will tend to increase ocean-adult survival, and factors that tend to decrease freshwater survival will tend to decrease ocean-adult survival.

There is considerable debate as to the relative importance of freshwater versus marine sources of variability in determining overall life-cycle variation. To address this issue, we calculated the mean and variance of *M.r* and *M.oa* across cohorts to assess patterns of variation in life-stage-specific mortality for Snake River steelhead. We found that while the average magnitude of mortality was greater in the ocean-adult life-stage ($\overline{M}.oa = 4.36$ versus $\overline{M}.r = 1.16$), the variation in mortality was greater during the freshwater life-stage than during the ocean-adult life-stage ($\hat{\mathrm{var}}(M.r) = 0.679$ versus $\hat{\mathrm{var}}(M.oa) = 0.578$). The relative variation in mortality rates, as measured by the coefficient of variation (CV), was much greater in the freshwater life-stage (CV = 71%) than the ocean-adult life stage (CV = 17%). Thus, the evidence for steelhead indicates that the freshwater life-stage is the dominant driver of variation in life-cycle survival rates, with levels of variation in freshwater mortality rates exceeding the levels of variation in ocean-adult mortality rates on both an absolute (based on the variance estimates) and a relative scale (based on the CV). These results, in conjunction with the positive correlation between freshwater and ocean-adult mortality rates indicates that improvements in freshwater survival are likely to translate into improvements in ocean-adult and overall life-cycle survival.

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Appendix 1

Estimates of freshwater (S.r), ocean-adult (S.oa) and life-cycle (SAR) survival along with estimates of freshwater (M.r), ocean-adult (M.oa) and life-cycle (M.sar) total instantaneous mortality for Snake River steelhead release cohorts over smolt migration years 1998-2006.

Year	Cohort	Release dates	Julian	S.r	M.r	S.oa	M.oa	SAR	M.sar
1998	1	4/8 to 4/21	104	NA	NA	NA	NA	0.787%	4.84
1998	2	4/22 to 5/5	118	0.692	0.37	0.004	5.52	0.276%	5.89
1998	3	5/6 to 5/19	132	NA	NA	NA	NA	0.239%	6.04
1998	4	5/20 to 6/02	146	0.124	2.09	0.021	3.88	0.255%	5.97
1999	1	4/8 to 4/21	104	0.439	0.82	0.018	4.04	0.772%	4.86
1999	2	4/22 to 5/5	118	0.549	0.60	0.014	4.30	0.748%	4.90
1999	3	5/6 to 5/19	132	0.478	0.74	0.013	4.32	0.638%	5.05
1999	4	5/20 to 6/02	146	0.408	0.90	0.013	4.38	0.511%	5.28
2000	1	4/8 to 4/21	104	0.616	0.48	0.044	3.13	2.702%	3.61
2000	2	4/22 to 5/5	118	0.564	0.57	0.032	3.45	1.786%	4.03
2000	3	5/6 to 5/19	132	0.275	1.29	0.022	3.83	0.600%	5.12
2000	4	5/20 to 6/02	146	NA	NA	NA	NA	0.169%	6.38
2001	1	4/8 to 4/21	104	NA	NA	NA	NA	0.001%	11.51
2001	2	4/22 to 5/5	118	0.037	3.30	0.003	5.68	0.013%	8.95
2001	3	5/6 to 5/19	132	0.030	3.51	0.008	4.81	0.025%	8.29
2001	4	5/20 to 6/02	146	NA	NA	NA	NA	0.060%	7.42
2002	1	4/8 to 4/21	104	0.629	0.46	0.026	3.66	1.617%	4.12
2002	2	4/22 to 5/5	118	0.356	1.03	0.016	4.12	0.576%	5.16
2002	3	5/6 to 5/19	132	0.235	1.45	0.026	3.64	0.617%	5.09
2002	4	5/20 to 6/02	146	0.318	1.15	0.014	4.24	0.460%	5.38
2003	1	4/8 to 4/21	104	0.526	0.64	0.029	3.54	1.519%	4.19
2003	2	4/22 to 5/5	118	0.400	0.92	0.019	3.99	0.741%	4.90
2003	3	5/6 to 5/19	132	0.443	0.81	0.010	4.59	0.450%	5.40
2003	4	5/20 to 6/02	146	0.438	0.83	0.005	5.37	0.203%	6.20
2004	1	4/8 to 4/21	104	NA	NA	NA	NA	0.941%	4.67
2004	2	4/22 to 5/5	118	NA	NA	NA	NA	0.407%	5.50
2004	3	5/6 to 5/19	132	0.117	2.15	0.006	5.09	0.072%	7.24
2004	4	5/20 to 6/02	146	NA	NA	NA	NA	0.007%	9.57
2005	1	4/8 to 4/21	104	NA	NA	NA	NA	0.722%	4.93
2005	2	4/22 to 5/5	118	0.284	1.26	0.005	5.29	0.143%	6.55
2005	3	5/6 to 5/19	132	0.377	0.98	0.003	5.89	0.105%	6.86
2005	4	5/20 to 6/02	146	NA	NA	NA	NA	0.001%	11.51
2006	1	4/8 to 4/21	104	NA	NA	NA	NA	1.362%	4.30
2006	2	4/22 to 5/5	118	0.499	0.70	0.022	3.80	1.117%	4.49
2006	3	5/6 to 5/19	132	0.481	0.73	0.015	4.18	0.738%	4.91
2006	4	5/20 to 6/02	146	NA	NA	NA	NA	0.478%	5.34