Latent Mortality Associated with Passage through Snake River Dams: Tagging Activities in 2011 and Final Report for the 2008 Juvenile Migration Year

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EXECUTIVE SUMMARY

During spring 2011, the National Marine Fisheries Service PIT-tagged yearling hatchery Chinook salmon *Oncorhynchus tshawytscha* for the seventh and final year of a study to evaluate latent mortality associated with passage through Snake River dams. We also monitored adult returns from study fish PIT-tagged in 2008, 2009, and 2010. Returns of age-3-ocean adults in 2011 completed adult returns from 2008 tagging.

In 2011, we used a study design similar to that first used in 2007, wherein smolt-to-adult returns were calculated based on estimated numbers of fish arriving at McNary Dam tailrace rather than actual numbers detected. This design allowed us to reduce the number of fish required for tagging from 301,000 to 111,222. The study design in 2011 differed from that in 2007 in that our earlier design included three groups of fish: one trucked and released below Ice Harbor Dam (reference group); one transported by truck and returned to Lower Granite Dam for release into the tailrace (dam-passage group); and one tagged and released into the tailrace of Lower Granite Dam without having been trucked (truck-effects group).

Tagging three groups required 2 d of tagging for each of the 10 releases, which were planned to be dispersed over the migration period for juvenile hatchery spring/summer Chinook salmon. However, adult returns of study fish to date had shown no effect on smolt-to-adult return rates (SARs) from trucking the dam-passage group. Given this finding, we decided to lessen our impact on the fish passing Lower Granite Dam by omitting the truck-effects group in 2011. This change reduced the time needed for tagging each release to only one day; however, to ensure that our releases were dispersed over as much of the migration period as possible, we limited releases to a maximum of three per week.

We began tagging on 22 April and finished on 13 May, releasing a total of 74,794 hatchery spring/summer Chinook salmon. Of these fish, 29,052 were transported by truck and released below Ice Harbor Dam (reference group); these fish passed no Snake River dam below Lower Granite. Another 45,742 were transported by truck and returned to Lower Granite Dam for release into the tailrace (dam-passage group). These fish passed Little Goose, Lower Monumental, and Ice Harbor Dams. For each replicate, both study groups were released simultaneously.

In 2011, overall estimated survival to McNary Dam for juvenile study fish was 85.8% for the reference group and 73.6% for the dam-passage group. Based on these survival estimates, we estimated numbers of fish from each group arriving at McNary

Dam tailrace at 24,933 from the reference group and 33,353 from the dam-passage group. Estimated detection rates at McNary Dam were 38.4 and 25.9% for the reference and dam-passage groups.

Bonneville Dam is the principle adult recovery site for this study. At Bonneville Dam during 2011, we detected 102 age-3-ocean adults from 2008, 515 age-2-ocean adults from 2009, and 176 jacks from 2010 releases. From releases of tagged juveniles in 2011, adults will return from 2012 (jacks) through 2014 (age-3-ocean fish). Adult returns from these releases will be reported after all fish return in 2014.

Returns of age-3-ocean adults in 2011 completed returns from fish marked as juveniles in 2008. Unlike 2007, the delayed start to the general transport program did not delay the start of tagging in 2008, so all ten planned releases were made.

Based on the estimated numbers of juveniles surviving to McNary Dam tailrace in 2008, SARs were 1.78 (95% CI 161-1.95) for the reference group, 1.60 (1.46-1.74) for the dam-passage group, and 1.52 (1.40-1.65) for the truck-effects group. This produced a weighted geomean SAR ratio of 0.93 (0.80-1.08) for dam-passage to reference groups. We examined the SARs ratio between dam-passage and truck-effects groups to determine whether a trucking effect existed. This comparison resulted in a weighted geomean SARs ratio of 1.16 (1.00-1.34).

The primary goal of this report is to provide preliminary information on fish tagged in 2008 and those returning in 2011. Since 2011 was the last year of tagging for this study, complete adult data from all releases will be available in 2014. Analyses from all years of adult return data will be synthesized and reported when these data are available.

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INTRODUCTION

Populations of Snake River spring/summer Chinook salmon *Oncorhynchus tshawytscha* have declined extensively since completion of the Federal Columbia River Power System (Raymond 1979; Schaller et al. 1999). Declines began in the early 1970s as Lower Granite, Little Goose, Lower Monumental, and John Day Dams were added to the existing hydropower system. Initial decreases in abundance were mainly due to direct mortality suffered by smolts during downstream migration through the completed hydrosystem (Raymond 1988). Since the early 1980s, direct mortality of smolts passing dams has been reduced considerably (Williams et al. 2001), coincident with structural and operational changes designed to enhance downstream passage survival (Williams and Matthews 1995). Despite these efforts, and substantial improvements in smolt passage survival, salmon populations in the Columbia River basin have not recovered.

Thus, an important question facing regional managers is whether or not migration through the hydropower system, as currently configured, causes latent mortality to anadromous salmonids. We define latent mortality as mortality resulting from passage through the hydropower system that is not expressed until after these fish have passed through the system (Budy et al. 2002). The concept of latent mortality related to the hydropower system was developed during the multi-agency process known as the Plan for Analyzing and Testing Hypotheses, or PATH (Marmorek et al. 1998). Latent mortality was hypothesized as a possible explanation for the greater loss in productivity postulated for upper Snake River populations of spring/summer yearling Chinook salmon relative to populations downstream from McNary Dam (Schaller et al. 1996, 2007).

Based on estimated spawner and recruit data, Schaller et al. (1999, 2007) and Deriso et al. (2001) concluded that productivity had declined more for upriver stocks, and that these declines were mostly caused by hydropower development. These researchers also believed that the declines had occurred primarily after completion of the three dams most recently constructed on the Snake River (Lower Granite, Little Goose, and Lower Monumental Dams). Furthermore, they postulated that the decline differential for upriver populations was greater than could be explained by differences in direct mortality resulting from these three Snake River dams. Schaller et al. (1999) argued there was little evidence that factors unrelated to the hydropower system could account for the differences in productivity and survival between upriver and lower river stocks.

This conclusion has been questioned by other researchers, who suggest several other factors that could be at least partially responsible for differences in productivity between salmon populations from the two areas (Zabel and Williams 2000; Hinrichsen

2001; ISAB 2007). However, the scientific debate surrounding this issue will continue unresolved in the absence of experimental data.

The goal of this study is to determine whether migration as smolts through Snake River dams and reservoirs causes latent mortality for upper Snake River yearling Chinook salmon. Specifically, we will compare smolt-to-adult return (SAR) ratios among two treatment groups of yearling Chinook salmon passing McNary Dam. The first treatment group is a *reference* group, consisting of fish transported and released to the tailrace of Ice Harbor Dam; this group will avoid passage of three Snake River Dams. The second treatment group is a *dam-passage* group, consisting of fish transported and released to the tailrace of Lower Granite Dam to migrate in the river past Little Goose, Lower Monumental, and Ice Harbor Dam. The SARs of the dam-passage group will be compared with those of the reference group to evaluate any effect on SARs of passage through three Snake River dams and reservoirs.

Here we present information on tagging of juveniles in 2011 and final results from study fish released in 2008. A synthesis of all adult return data will be reported after 2014, when complete adult return data are available.

METHODS

Juvenile Collection and Tagging, 2011

In 2011, we collected and PIT-tagged Snake River hatchery spring/summer Chinook salmon at Lower Granite Dam from 22 April to 13 May. This tagging period coincided with passage timing at the dam for the largest proportions of hatchery spring Chinook. Timing of the tagging period was based on observations from previous studies, which have shown these fish generally begin passing Lower Granite Dam around 20-25 April and end by mid-May.

Collection and handling techniques followed the methods of Marsh et al. (1996, 2001), including use of a recirculating anesthetic water system. In 2011, as in 2010, we used a new tagging system developed by Biomark, Inc.. Prior to the tagging season, all PIT tags were pre-loaded into disposable single-use hypodermic needles (Biomark HPT12).[1] Each needle had an internal push-rod and a plastic safety cap with a hub that was keyed to the bevel of the needle. For each fish, a needle containing a PIT tag was loaded into a gun-style injector (Biomark MK-25 Rapid Implant). The needle was then inserted into the abdominal cavity of the fish posterior to the pectoral fin and anterior to the pelvic girdle. The trigger of the injector was then pulled, implanting the tag into the fish. Because each needle had an internal push-rod, a single injector could be used for thousands of fish without needing to be disinfected.

Prior to 2011, we had tagged three groups of fish for each of the 10 releases: a *reference* group, which was trucked and released below Ice Harbor Dam, a *dam-passage* group trucked and released below Lower Granite Dam, and a *truck-effects* group that was released below Lower Granite Dam but not trucked. Two days were required to complete tagging of the three groups, with the truck-effects group tagged the first day and the dam-passage and reference groups tagged on the second day. However, based on results from the first 4 years of this study, which showed no truck effect, we omitted the truck-effects group in 2011. This reduced the total time needed to tag all of our release groups from 20 to 10 d.

Despite the shorter number of tagging days, we felt it was still important to release fish throughout as much of the hatchery spring/summer Chinook salmon juvenile migration period as possible. Therefore, we released study fish over the same protracted schedule as in previous years, with no more than three releases per week. On Mondays, Wednesdays, and Fridays, we tagged and released both reference and dam-passage release groups. All tagging was concluded by 1600 PDT each day to comply with the limited number of driving hours allowed per day for truck drivers (for safety reasons).

This allowed the driver releasing fish at Lower Granite Dam to return to his base of operations within the allotted time.

All fish were released at approximately the same time of day. Upon arrival at Ice Harbor Dam (approximately 1900 PST), reference fish were released into the juvenile fish facility bypass pipe. A circuitous route was devised so that the truck carrying dam-passage fish would return to Lower Granite Dam at the same time the truck carrying reference fish was arriving at Ice Harbor Dam. Upon return to Lower Granite Dam, dam-passage fish were released through a pipe that runs along the top of the juvenile fish facility bypass pipe.

Evaluation will be based on annual ratios of SARs, that is, $SAR_{dam\ passage}/SAR_{reference}$ or (dam-passage/reference SAR ratio). Note that as a ratio of SARs from groups "released" at McNary Dam, dam passage/reference is a measure of differential survival below McNary Dam. As such, it is analogous to the differential mortality parameter, *D*, which has been used in comparisons of transported to inriver-migrant fish below Bonneville Dam.

Sample sizes for each year of this study were designed to provide an 80% probability of detection if the true dam-passage/reference ratio was less than or equal to 0.80 (i.e., $\beta = 0.20$ or survival was at least 20% lower for dam-passage fish). Differences were evaluated using a one-sided hypothesis test with $\alpha = 0.05$ (i.e., we tested the null hypothesis, that there was no difference between treatments, or the true SARs ratio was 1.00). We also assumed a SAR for reference fish of at least 1.5% (see below).

Required sample sizes were derived by determining the required precision around the estimated ratio of dam-passage to reference SARs. This level of precision required that the one-sided confidence interval on the true ratio would not contain the value 1.0, or the confidence interval of the true natural-log-transformed ratio, ln(dam passage/reference), did not contain zero. If the confidence interval did not contain 1.0, then we could reject the null hypothesis, that there is no difference in rates of survival to adulthood between dam-passage and reference fish. Therefore, for a desired $\alpha = 0.05$ and $\beta = 0.20$, the number of fish needed was

$$\ln\left(\frac{\text{dam passage}}{\text{reference}}\right) - \left(t_\alpha + t_\beta\right) \times \text{SE}\left[\ln\frac{\text{dam passage}}{\text{reference}}\right] \approx 0$$

and

$$SE\left[\ln\left(\frac{\text{dam passage}}{\text{reference}}\right)\right] \approx \sqrt{\left(\frac{1}{n_{\text{reference}}} + \frac{1}{n_{\text{dam passage}}}\right)} \quad = \sqrt{\frac{2}{n}}$$

where n is the number of adult returns per treatment, and $n_{reference} = n_{dam\ passage}$ (we set the n-value for reference and dam-passage groups to be equal for simplicity). The previous two statements imply that the required number of adults is:

$$n \approx \frac{2\left(t_{\alpha} + t_{\beta}\right)^2}{\left(\ln\left(\frac{\text{dam passage}}{\text{reference}}\right)\right)^2}$$

As stated above, we assumed a SAR for reference fish of at least 1.5%, and we wanted sufficient statistical power to observe a real difference between treatments of at least 20% (i.e., dam passage/reference ≤ 0.80). Therefore, where N denotes the number of juveniles needed per treatment, the sample sizes needed were n = 333 and $N_{reference}$ = 22,200. Thus, if $N_{dam\ passage} = N_{reference}$/(dam passage/reference) = 27,750, then N_{total} = 49,950.

These calculations provided the sample sizes needed for each "release group," or number of study fish estimated to be passing McNary Dam. However, "release groups" were formed from estimates of survival to McNary Dam of fish from each treatment group. Thus, to determine the total number of fish needed for tagging, we used an assumed probability of survival to McNary Dam for the reference and dam-passage release groups. These assumed probabilities of survival were based on survival estimates from our 2006 study year, and accounted for fish removed for transport at Snake River dams below Lower Granite. For 2011, we used an estimated survival rate to McNary Dam tailrace of 0.830 for fish released to Ice Harbor Dam tailrace and of 0.657 for fish released to Lower Granite Dam tailrace.

Thus, to obtain the necessary number of study-fish detections at McNary Dam required sample sizes for release of approximately 26,747 reference fish (22,200/0.83) to the tailrace at Ice Harbor Dam and 42,237 dam-passage fish (27,750/0.657) to the tailrace of Lower Granite Dam. Therefore, the total tagging requirement was 68,984 fish. Because of low SARs experienced in some years, we increased this release number to 75,000. These release numbers were then divided into 10 groups released through time in order to replicate the study over temporal differences such as variation in fish migration behavior, where fish from different hatcheries pass at different times. This design also allowed us to examine differences based on fish condition (level of smoltification), river conditions (flow, turbidity, operation at dams), and environmental fluctuations (temperature, etc.) through the migration season.

Juvenile Collection and Tagging, 2008

Juvenile collection and tagging methods used in 2008 utilized the methodology developed for this study and reported in detail in 2007 (Marsh et al. 2007, 2009). Tagging for each of 10 replicates was conducted in 2-d blocks distributed over the season with a total of 20 d of tagging. On the first day of each 2-d block, truck-effects fish were tagged and sent to a holding tank for 24-h. On the second day of each block, we tagged two treatment groups: one for release at Ice Harbor Dam (reference), and one for release at Lower Granite Dam (dam passage). The single-use injector system was not available in 2008, so tagging was achieved using multiple-use injectors with disinfection, cleaning, and re-loading of tags between fish. As needles became dull, the old needles were removed and replaced with new ones.

Adult Recovery and Data Analyses

Bonneville Dam serves as the principal adult recovery site for this study. Using this site for adult recovery provides for maximum study SARs by avoiding potential losses from upstream passage mortality and mainstem fisheries above the dam. Adult returns for the 2011 study releases will be complete in 2014, and we will analyze these results when they become available. Ratios of SARs for dam-passage vs. reference release groups will be evaluated based on estimates of juvenile fish passing McNary Dam in 2011. Confidence intervals for dam-passage/reference ratios will be calculated using the ratios of these estimates and their associated variances (Burnham et al. 1987).

For returns to date, we have assumed that the true distribution of dam-passage to reference ratios was approximately log normal. We therefore calculated confidence intervals on a natural-log scale and then back-transformed the endpoints to the original scale. We calculated the mean of ratios of paired study groups released over time as a geometric mean. However, we used a weighted geometric mean, where the weights were the estimated inverse of the relative variances (coefficient of variation squared) of ratios between paired groups released over time (Smith et al. 2006). Estimates of variance in SARs ratios for these temporal release groups had to be adjusted to account for variation in the estimation process (since the SARs ratios were themselves estimates). This *a posteriori* adjustment method was used to estimate the number of juveniles that survived and were detected in the tailrace of McNary Dam and is detailed in Appendix B.

RESULTS

Juvenile Collection and Tagging, 2011

The 2011 marking year was the seventh and final study year of juvenile tagging, and tagging goals were met for sufficient sample sizes of both the dam-passage and reference study groups. We began tagging on 22 April based on our prediction that hatchery spring/summer Chinook salmon would begin to reach Lower Granite Dam in large numbers between 20 and 25 April. Unfortunately, we fell short of our tagging goals on 22 and 25 April because too few fish were available as of those dates. Similar to study years 2008 and 2009, hatchery Chinook salmon did not begin arriving in large numbers until the last few days of April. Therefore, after the first two releases, we were over 9,000 fish below quota, based on the sample sizes planned for each release.

Fish actually began arriving in large numbers on 26 April, and in order to comply with our study design, we needed to tag fish in excess of the sample sizes planned during the following six releases. By the eighth release, we had corrected for the shortfall and even surpassed the number of tagged fish needed at that point in the schedule to obtain the correct sample size based on our study design. Therefore, we reduced tagging numbers during the final two releases to stay near our overall tagging goal of 75,000, and ended tagging on 13 May as scheduled.

From 22 April to 13 May, we tagged 74,948 hatchery yearling spring/summer Chinook salmon, releasing a total of 74,794 (Table 1). Fish were divided into two groups, with 29,052 released below Ice Harbor Dam (reference) and 45,742 released into Lower Granite Dam tailrace after being transported by truck for an equal amount of time (dam-passage).

While we did collect mortalities and lost tags prior to each truck being emptied, we were unable to calculate post-tagging mortality because the amount of time between the last fish being tagged and the fish being released was too short for any meaningful estimate.

Table 1. Dates of collection, PIT-tagging, and release of hatchery yearling spring/summer Chinook salmon for the latent mortality study at Lower Granite Dam in 2011. Numbers of fish released are also shown.

Hatchery yearling Chinook tagged in 2011			
Collection date	Tag date	Release date	Number of fish released
21 April	22 April	22 April	6,164
24 April	25 April	26 April	3,197
26 April	27 April	28 April	9,553
28 April	29 April	30 April	7,217
1 May	2 May	3 May	9,072
3 May	4 May	5 May	9,882
5 May	6 May	7 May	10,625
8 May	9 May	10 May	8,914
10 May	11 May	12 May	7,130
12 May	13 May	14 May	6,542

Estimated juvenile survival to McNary Dam in 2011 was 85.8% for the reference group and 73.6% for the dam-passage group (Table 2). Based on these survival estimates, we estimated numbers of tagged fish reaching McNary Dam tailrace at 24,933 for the reference group and 33,353 for the dam-passage group. When adult returns are complete in 2014, these juvenile numbers will be used to determine SARs for comparisons between the two groups.

Table 2. Number of PIT-tagged hatchery yearling spring/summer Chinook salmon released by treatment group for evaluation of latent mortality, 2011. Estimated survival from release to McNary Dam and estimated numbers of fish arriving in the tailrace of McNary Dam by treatment are also shown.

Release group	Number released	Survival to McNary Dam (%)	Estimated number at McNary Dam tailrace
Dam-passage (Lower Granite trucked)	45,742	85.8	24,933
Reference (Ice Harbor trucked)	29,052	73.6	33,353

The survival rate for the 2011 reference group was in the middle of the range of survival rates from 2005-2011 for this group. In contrast, the survival rate for the dam-passage group was the third lowest for this group among the seven study years.

Juvenile Collection and Tagging, 2008

Details of juvenile collection and tagging in 2008 were reported by Marsh et al. (2009), and numbers of fish released in 2008 from the three treatments combined are shown in Table 3. Total tagging and release numbers by treatment are shown in Appendix Table A1. In 2008, our second planned replicate (24 April) had to be postponed because of an error by COE in collecting fish. This error resulted in less than 1,500 total fish being collected for that day, a number far too small to merit an investment of the resources required for tagging. Based on the species composition of fish being collected at that time, a collection of approximately 18,000 fish would have been needed to produce tagged replicates of the appropriate size for our study design. Because hatchery spring/summer Chinook salmon were still available in large numbers, we were able to make up for this lost replicate by tagging on two additional days beyond the planned end of the tagging schedule.

Juvenile fish were monitored as they migrated downstream after release (Table 4 and Appendix Table A2), allowing us to estimate the number of fish arriving in the McNary Dam tailrace for each group. The purpose of the non-transported group released at Lower Granite Dam was to provide a reference for potential effects of transport (truck effects). Based on juvenile detections of the 2008 releases, trucking did not appear to affect the juvenile stage, as the truck-effects and dam-passage groups released at Lower Granite were estimated to have arrived at McNary Dam in nearly the same proportions (Table 4).

Table 3. Dates of collection, PIT-tagging, and release of hatchery yearling spring/summer Chinook salmon for the latent mortality study at Lower Granite Dam in 2008. Numbers of fish released are also shown.

Collection date	Tag date	Release date	Number of fish released	Release number per 2-d block
22 April	23 April	24 April	1,497	
23 April	24 April	24 April	3,017	4,514
24 April				*
27 April	28 April	29 April	2,773	
28 April	29 April	29 April	909	3,682
29 April	30 April	1 May	6,258	
30 April	1 May	1 May	5,285	11,543
1 May	1 May	3 May	6,553	
2 May	3 May	3 May	8,735	15,288
4 May	5 May	6 May	7,880	
5 May	6 May	6 May	9,865	17,745
6 May	7 May	8 May	6,306	
7 May	8 May	8 May	6,288	12,594
8 May	9 May	10 May	5,910	
9 May	10May	10 May	7,304	13,214
11 May	12 May	13 May	4,943	
12 May	13 May	13 May	10,302	15,245
13 May	14 May	15 May	4,810	
14 May	15 May	15 May	9,476	14,286
15 May	16 May	17 May	3,765	
16 May	17 May	17 May	10,058	13,823

* Replicate was postponed to 15-16 May because not enough fish were collected

Table 4. The number of PIT-tagged hatchery yearling spring/summer Chinook salmon released at Lower Granite Dam after trucking (dam passage), released at Lower Granite Dam without trucking (truck effects), and released at Ice Harbor Dam (reference) for evaluation of latent mortality in 2008. Survival estimates to McNary Dam are shown for each treatment group, along with numbers transported from a downstream collector dam and total estimated numbers arriving in the tailrace of McNary Dam.

Study group released	Number released	Estimated survival to McNary Dam (%)	Diverted for transport below Lower Granite	Estimated survival to McNary Dam (n)
Dam passage	42,423	73.5	143	31,059
Truck effects	50,695	74.3	262	37,398
Reference	28,816	83.1	0	23,952

Adult Recovery and Data Analysis, 2008

We began recovering jacks in 2009 from study fish released at Lower Granite Dam in 2008. In August 2011, we completed recoveries from the 2008 release year with the collection of age-3-ocean adults. A total of 1,497 adults returned from all 2008 treatment group releases combined.

In accordance with the modified study design, release groups in 2008 had been formed from estimated numbers of juvenile study fish from each treatment arriving in the tailrace of McNary Dam. In 2008, these numbers ranged from 23,952 to 37,398 (Table 4 and Appendix Table A3). Based on these juvenile "release groups," SARs were 1.78 for reference fish, 1.60 for dam-passage fish, and 1.52 for truck-effects fish (Table 5). These SARs were based on the 427, 498, and 570 adults (including jacks) returning from each respective treatment.

Based on these SARs, the weighted geomean of SARs ratios between dam-passage and reference groups was 0.93 (95% CI, 0.80-1.08), indicating no significant extra mortality caused by migration through the three lower Snake River dams. Unlike the 2006 study year, which showed a trend of increasing SARs ratios between dam-passage and reference groups, the temporal pattern in 2008 showed a generally flat pattern of SARs ratios over time (Figure 1). When we compared SARs ratios between the dam-passage and truck-effects groups, the weighted geomean was 1.16 (95% CI, 1.00-1.34), indicating no significant truck effect.

Table 5. Number of juveniles released, number of returning adults, SARs, and weighted geomean SAR ratios for PIT-tagged hatchery yearling spring/summer Chinook salmon estimated to have arrived in McNary Dam tailrace. Treatment groups were released in 2008 at Lower Granite Dam after trucking (dam passage), released at Lower Granite Dam without trucking (truck effects), or released at Ice Harbor Dam (reference) for a study to evaluate latent mortality.

Juvenile numbers	Returns by age-class			SAR (95% CI)	Weighted geomean SAR ratio (95% CI)
	Jack	2-ocean	3-ocean		
Reference (trucked to Ice Harbor)					
23,952	112	291	24	1.78 (1.61-1.95)	
Dam passage (Lower Granite trucked)					
31,059	119	339	40	1.60 (1.46-1.74)	dam passage/reference 0.93 (0.80-1.08)
Truck effects (no transport)					
37,398	151	383	36	1.52 (1.40-1.65)	dam passage/truck effects 1.16 (1.00-1.34)

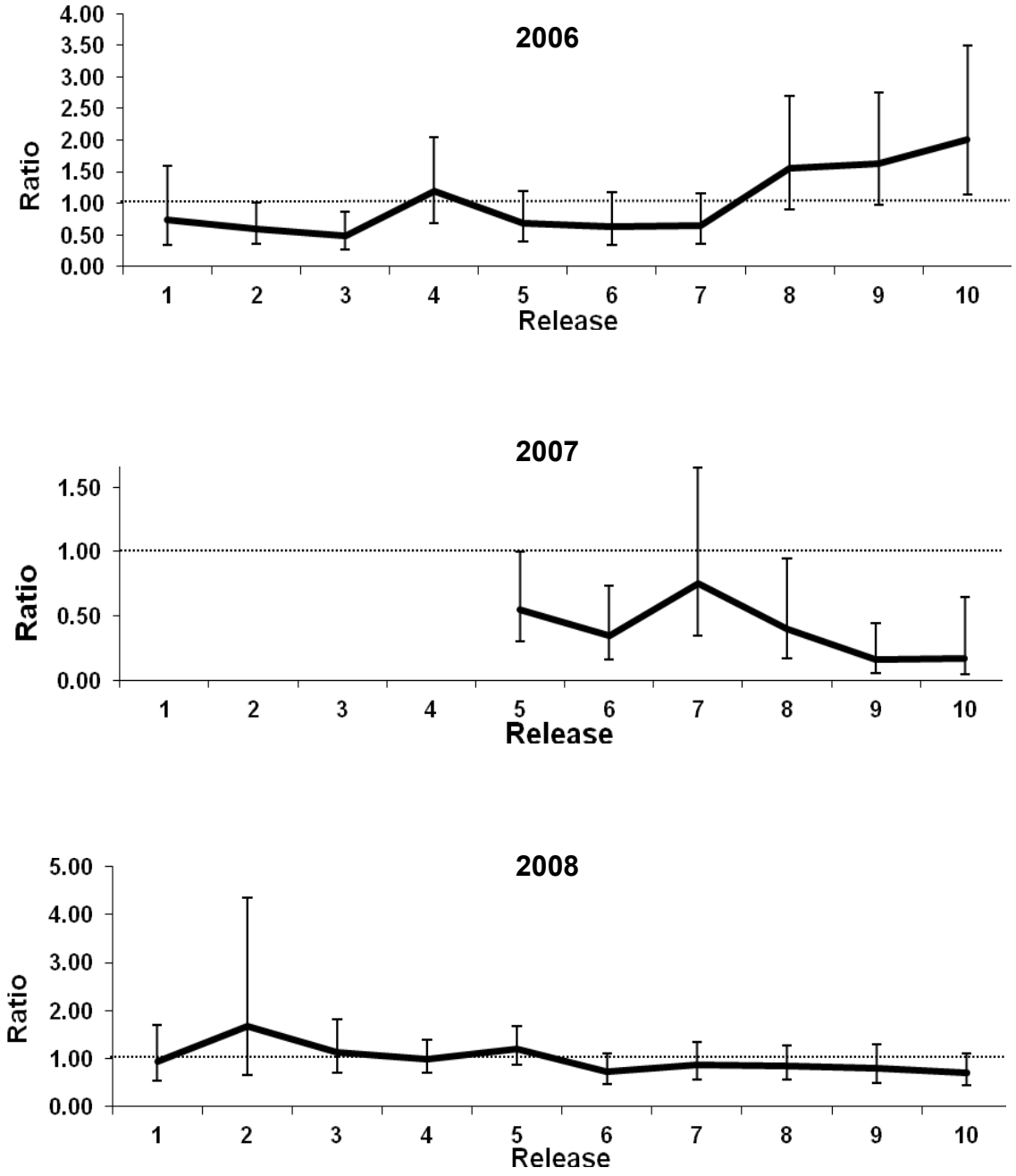

Figure 1. Temporal pattern in the ratio of dam-passage to reference SARs shown against study groups released over the juvenile migration seasons in 2006, 2007, and 2008. Upper panel shows increasing trend for 2006 releases; middle panel shows ratio decreasing over time for 2007 releases; bottom panel shows a generally flat pattern over time for 2008 releases. Dotted line indicates 1 (dam-passage SAR = reference SAR). Values less than one indicate higher SARs for reference fish; values greater than one indicate higher SARs for dam-passage fish. Note that four releases planned for 2007 were not made due to a delayed start in transport operations.

DISCUSSION

In 2008 we began juvenile tagging at Lower Granite Dam on 23 April and finished on 17 May. We were forced to forfeit our second planned release (24-25 April) because a sampling error by dam operators resulted in too few fish being collected for the tagging operation planned on 24 April. However, hatchery spring/summer Chinook salmon were still present in large enough numbers that we were able to make up for the missed release during subsequent tagging on 16-17 May.

For juvenile salmon migrating in 2008, estimated survival from release at Lower Granite Dam to the McNary Dam tailrace was similar to survival estimated for this reach in previous years (Faulkner et al. 2009). River flow and spill in May 2008 were above the 10-year average (1998-2007), and were the second highest of the study years through 2010. Ocean conditions were very favorable for juvenile salmonids entering the ocean in spring 2008 (Peterson et al. 2010).

Results from 2008 were based on the modified study design, which used estimated numbers of fish from each study group arriving in the McNary Dam tailrace rather than actual detections at McNary Dam. Comparison of SARs based on this design showed no significant latent mortality during the 2008 outmigration. In other words, fish that were transported and released below Ice Harbor Dam survived as adults at rates similar to those of fish that were released at Lower Granite Dam and migrated in the river, passing Little Goose, Lower Monumental, and Ice Harbor Dams before reaching McNary Dam. Also, it did not appear that trucking significantly affected smolt-to-adult-return rates.

Juvenile tagging for this project was completed in 2011, and a complete multi-year analysis of SARs will be possible in 2014, when adult returns are complete for all release years. This analysis will allow us to separate timing effects from other potential causes of latent mortality and will thus address the issue of variability introduced by earlier arrival at McNary Dam for Ice Harbor releases than for Lower Granite releases (with the early arriving fish being expected to return at a greater rate; Scheuerell et al. 2009).

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APPENDIX A

Tagging and Release Data for Hatchery Spring/Summer Chinook Salmon in 2008

Appendix Table A1. Totals by treatment of hatchery spring/summer Chinook salmon tagged at Lower Granite Dam in spring 2008. After tagging, truck-effects fish were held 24-h prior to release in the Lower Granite Dam tailrace, dam-passage fish were transported half-way to Ice Harbor Dam and back prior to release in the Lower Granite Dam tailrace, and reference fish were transported and released to Ice Harbor Dam tailrace.

	Reference		Dam passage		Truck effects	
Release Date	Tagged	Released	Tagged	Released	Tagged	Released
24 April	1,315	1,315	1,704	1,702	1,502	1,497
29 April	412	412	498	497	2,775	2,773
1 May	2,488	2,481	2,812	2,804	6,315	3,258
3 May	3,940	3,928	4,806	4,807	6,669	6,553
6 May	4,788	4,758	5,114	5,107	8,159	7,880
8 May	2,410	2,410	3,900	3,878	6,357	6,305
10 May	2,867	2,863	4,453	4,441	5,974	5,910
13 May	4,241	4,218	6,096	6,084	5,022	4,943
15 May	3,445	3,448	6,043	6,028	4,912	4,810
17 May	2,999	2,983	7,107	7,075	3,831	3,765

Appendix Table A2. Total hatchery spring/summer Chinook salmon released at Lower Granite Dam and detected at McNary Dam in spring 2008. After tagging, truck-effects fish were held 24-h prior to release in the Lower Granite Dam tailrace, dam-passage fish were transported half-way to Ice Harbor Dam and back prior to release in the Lower Granite Dam tailrace, and reference fish were transported and released to Ice Harbor Dam tailrace.

	Reference		Dam passage		Truck effects	
Release Date	Released	Detected	Released	Detected	Released	Detected
24 April	1,315	279	1,702	423	1,497	370
29 April	412	108	497	140	2,773	769
1 May	2,481	629	2,804	771	3,258	1,563
3 May	3,928	1,204	4,807	1,209	6,553	1,678
6 May	4,758	1,540	5,107	1,197	7,880	1,676
8 May	2,410	723	3,878	745	6,305	1,253
10 May	2,863	808	4,441	365	5,910	591
13 May	4,218	910	6,084	411	4,943	283
15 May	3,448	660	6,028	443	4,810	335
17 May	2,983	297	7,075	603	3,765	331

Appendix Table A3. Estimated numbers of hatchery spring/summer Chinook salmon arriving in McNary Dam tailrace in spring 2008 after release at Lower Granite and Ice Harbor Dam. After tagging, truck-effects fish were held 24-h prior to release in the Lower Granite Dam tailrace, dam-passage fish were transported half-way to Ice Harbor Dam and back prior to release in the Lower Granite Dam tailrace, and reference fish were transported and released to Ice Harbor Dam tailrace.

	Reference		Lower Granite trucked		Ice Harbor trucked	
Release Date	Released	Arrived in tailrace	Released	Arrived in tailrace	Released	Arrived in tailrace
24 April	1,315	946	1,702	1,370	1,497	1,079
29 April	412	294	497	348	2,773	2,059
1 May	2,481	2,055	2,804	1,989	3,258	4,931
3 May	3,928	3,314	4,807	3,801	6,553	5,500
6 May	4,758	3,925	5,107	3,965	7,880	6,029
8 May	2,410	2,281	3,878	2,695	6,305	4,887
10 May	2,863	2,618	4,441	3,304	5,910	3,884
13 May	4,218	3,640	6,084	4,308	4,943	2,793
15 May	3,448	3,048	6,028	5,359	4,810	3,770
17 May	2,983	2,499	7,075	5,150	3,765	2,908

APPENDIX B

Estimated Variance of Smolt-to-Adult Return Ratios

In this study, ratios of the proportion of smolts that returned as adults (SARs) were estimated between paired treatment groups. The estimated variance of SARs ratios has been calculated for NMFS transport studies over many years using Equation 2. This method is widely used to estimate variance in ratios, for example, in relative survival estimates. In most studies, release numbers of smolts are known, and thus assumed to be "fixed," with no variation. However, in this study, release numbers were estimated. Therefore, variance of the estimation process must be incorporated into the variance of the proportions (SARs) and ratios, to reflect the added uncertainty resulting from "non-fixed" release numbers. The derivation shown below in Equations 1 and 2 can be applied to any general pair of treatment groups.

From Mood, Graybill, and Boes (1974, p. 181), using the Delta Method for independent x and y,

$$V\left(\frac{x}{y}\right) \approx \left(\frac{\mu_x}{\mu_y}\right)^2 \left(\frac{V(x)}{\mu_x^{\,2}} + \frac{V(y)}{\mu_y^{\,2}}\right) \tag{1}$$

For $R = SAR_1/SAR_2$, assuming the SARs are binomially-distributed, and using estimated values, this becomes:

$$\hat{V}(\hat{R}) \approx \hat{R}^2 \left(\frac{1}{n_1} - \frac{1}{N_1} + \frac{1}{n_2} - \frac{1}{N_2}\right) \tag{2}$$

since,

$$\frac{\hat{V}(S\hat{A}R_1)}{S\hat{A}R_1^{\,2}} = \frac{S\hat{A}R_1(1 - S\hat{A}R_1)}{N_1 S\hat{A}R_1^{\,2}} = \frac{1 - S\hat{A}R_1}{N_1 S\hat{A}R_1} = \frac{1}{n_1} - \frac{1}{N_1} \tag{3}$$

and similarly for SAR_2.

If, however, N_1 and N_2 are calculated from R_1S_1 and R_2S_2, where the R is the release number and S is survival from release to some location, then from (1):

$$\hat{V}(\hat{R}) \approx \hat{R}^2\left(\frac{\hat{V}(S\hat{A}R_1)}{S\hat{A}R_1^{\,2}} + \frac{\hat{V}(S\hat{A}R_2)}{S\hat{A}R_2^{\,2}}\right) \tag{4}$$

Now,

$$\hat{V}(S\hat{A}R_1) = \hat{V}\left(\frac{n_1}{N_1}\right) = \hat{V}\left(\frac{n_1}{R_1\hat{S}_1}\right) = \left(\frac{1}{R^2}\right)\hat{V}\left(\frac{n_1}{\hat{S}_1}\right)$$

$$= \left(\frac{1}{R^2}\right)\left(\frac{n_1}{\hat{S}_1}\right)^2\left(\frac{\hat{V}(n_1)}{n_1^{\,2}} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}}\right) \tag{5}$$

by (1) and,

$$S\hat{A}R_1^{\,2} = \left(\frac{n_1}{N_1}\right)^2 = \left(\frac{1}{R^2}\right)\left(\frac{n_1}{\hat{S}_1}\right)^2 \tag{6}$$

So from (5) and (6), and assuming the SARs are binomially distributed,

$$\frac{\hat{V}(S\hat{A}R_1)}{S\hat{A}R_1^{\,2}} = \frac{\hat{V}(n_1)}{n_1^{\,2}} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}} = \frac{N_1S\hat{A}R_1\left(1 - S\hat{A}R_1\right)}{n_1^{\,2}} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}}$$

$$= \frac{n_1\left(\frac{N_1 - n_1}{N_1}\right)}{n_1^{\,2}} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}} = \frac{N_1 - n_1}{n_1N_1} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}} = \frac{1}{n_1} - \frac{1}{N_1} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}} \tag{7}$$

Then from (4) and (7) and substituting the estimators for N_1 and N_2,

$$\hat{V}(\hat{R}) \approx \hat{R}^2\left(\frac{1}{n_1} - \frac{1}{R_1\hat{S}_1} + \frac{1}{n_2} - \frac{1}{R_2\hat{S}_2} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}} + \frac{\hat{V}(\hat{S}_2)}{\hat{S}_2^{\,2}}\right) \tag{8}$$

For this study, R is the ratio of Treatment 1 SAR to Treatment 2 SAR from McNary Dam (MCN) as juveniles to Bonneville Dam as adults, R_1 and R_2 are the release numbers for the two treatments, N_1 and N_2 are the numbers of the two treatments estimated alive in the MCN tailrace, n_1 and n_2 are the adult return numbers, and S is the survival from release to MCN. The hat notation means that the quantities/parameters are estimated using Cormack/Jolly Seber (CJS) methods.

Data that were ratios of binomial proportions were assumed to be log-normally distributed. Therefore, confidence intervals for this study were calculated as ±2 SEs (for $\alpha = 0.05$, the multiplier is approximately 2) around the natural log-transformed ratio. These endpoints were back-transformed to the original scale. The standard error of the ratio on the log-scale is:

$$\hat{V}(\ln(\hat{R})) \approx \hat{R}^2\hat{V}(\hat{R}) \approx \left(\frac{1}{n_1} - \frac{1}{R_1\hat{S}_1} + \frac{1}{n_2} - \frac{1}{R_2\hat{S}_2} + \frac{\hat{V}(\hat{S}_1)}{\hat{S}_1^{\,2}} + \frac{\hat{V}(\hat{S}_2)}{\hat{S}_2^{\,2}}\right) \tag{9}$$